JOURNAL OF THE A·I·E·E·

JANUARY — 1926

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Midwinter Convention, New York, N. Y., February 8-11

Annual Business Meeting, New York, N. Y., May 21

Annual Convention, White Sulphur Springs, W. Va., June 21-25

Pacific Coast Convention, Salt Lake City, Utah, (Dates to be announced in subsequent issue)

Regional Meetings

Middle Eastern District, Cleveland, Ohio, March 18-19

Great Lakes District, Madison, Wis., (early in May)

Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

New York Electrical Society, Engineering Societies Bldg., New York, N. Y., January 6

Convention of Institute of Radio Engineers, Engineering Societies Bldg., New York, N. Y., January 18-19

Annual Meeting of American Society of Civil Engineers, Engineering Societies Bldg., New York, N. Y., January 20-22

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Lighting and Continuity of Service

In spite of the great development within the last few years of devices for the protection of electrical apparatus against lightning and the vast improvement in the insulation of transmission lines, this source of disturbance still remains one of the most serious threats against continuity of service in our large overhead systems. In perfecting remedies, or preventatives, it is highly desirable to know the cause and nature of the attack of lightning on the line, for it is on the transmission line rather than in the station, that interruptions to service usually occur.

Lightning *may* as a theoretical matter affect a transmission line either by electrostatic induction; that is, by the release of a bound charge that has been gradually drawn onto the line, or by direct stroke from the atmosphere which may be a heavy and conspicuous stroke or a minor, almost unnoticed flash. As a practical matter, especially when considering the installation of one or more ground wires over a transmission line, it is important to know which sort of action is dominating. Mr. Peek has pointed out that under certain conditions of cloud discharge we may expect a voltage to appear on a transmission line from the release of a bound charge sufficiently high to flash over even a 220-kv. insulator string. Of this there can be little doubt. On the other hand, some considerations may be raised tending to indicate that the line will in all probability actually be subject to direct strokes, *usually of a minor magnitude.* This may be reasoned as follows:

It can hardly be doubted that on all occasions when a person notes a flash and thunderclap substantially simultaneously, (and this happens to the average individual several times a season), this means a lightning flash within one or two hundred feet, since sound travels about 1000 ft. per second. Yet it may be years before any notable lightning damage occurs in any one village or town. This clearly means that most discharges are of very limited energy or severity and find some path to ground without leaving any trace, presumably, usually down tree trunks. There is further ample direct evidence that strokes of minor severity do actually occur. It would seem to follow, then, that there is every reason to suppose that transmission lines, extending for many miles and being twenty to fifty feet in the air and usually free of the protection of trees, will be actually struck occasionally by these low-power strokes, which, while of low power so far as the ability to do conspicuous damage is concerned, are of sufficiently high voltage to flash over insulators.

This view is strongly supported by the evidence of the record of lightning disturbances on the Taylors Falls line* where many insulators were shattered without power on the line, and some poles were splintered, a condition which could hardly be caused by any charges induced on line conductors.

Considering the use of overhead ground wires as a means of protection, we have the following considerations to indicate some material practicable limitations. in the effectiveness of overhead ground wires. Consider a transmission line with ground wire protection just the moment before the discharge of the cloud by a lightning stroke. A considerable bound charge has been drawn to the surface of all the conductors and of the ground wires but the potentials are normal. The instant the cloud is discharged, these bound charges raise the potential of all the wires, conductors and ground wires alike to appropriate voltages which may be very high. So far, the presence of the ground wire is no relief to the voltage on the conductor. But the charge on the ground wire is free to run to earth through the tower, which it does; and *when the potential of the ground wire has fallen toward earth potential* sufficiently, it establishes a static capacity to the line conductors, and this tends to reduce the potential produced by the original bound charge. This might be of very material benefit, except that in all probability, (at least with long span construction), the time required to empty the charge on the ground wire through the tower into the ground through whatever ground resistance may exist, is enough to give the charges on the conductors time to flash over, if they are at sufficiently high voltage to do so.

Of course, the presence of the ground wire tends to reduce the original bound charge on the conductors, since the flux from the ground wire must traverse much of the same path as the flux from the conductors, but the numerical relations are such that at least with six conductors and one ground wire, the effect of the seventh wire must be almost negligible.

However, broadly speaking, from the point of view of absolute continuity of service, since it must be admitted that occasional failures due to one cause or

*Reference. Three papers. A. I. E. E. TRANSACTIONS, Vol. XXVII, Part 1, 1908, By J. F. Vaughan, pp. 397, N. J. Neall, pp. 421, P. H. Thomas, pp. 755. A review of these three papers treating this remarkable set of records will be well worth while to a person interested in the attack of lightning on transmission lines.

another must occur on any line, the use of independent lines, double circuit or single circuit as may be most suitable, running by separate routes would seem to be the only way of getting continuous service.

PERCY H. THOMAS

Some Leaders of the A. I. E. E.

Lewis Buckley Stillwell, the twenty-second president of the American Institute of Electrical Engineers, was born in Scranton, Penn., March 12, 1863. He prepared for college at the Scranton High School; matriculated at Wesleyan University in the class of 1886; transferred to Lehigh University at the end of his sophomore year and completed the course in Electrical Engineering at that institution in 1885, following this by special work in mechanical engineering during the next academic year.

In October, 1886, he entered the employ of the Westinghouse Electric Company at Pittsburgh, and before the end of that year became Assistant Electrician of the company, which position he retained for about five years. During this period, he was actively associated with George Westinghouse, O. B. Shallenberger, William Stanley, Albert Schmid, Nikola Tesla, Charles F. Scott and others, in the rapid development of the alternating current system.

In 1889 and 1890, he was sent to Europe as technical adviser to the British Westinghouse Company and traveled extensively in Great Britain and on the continent, investigating the development of alternating current and other electric systems.

In 1890, while in London, he first met Mr. Edward D. Adams, President of the Cataract Construction Co., and Dr. Coleman Sellers, its Chief Engineer, who were investigating the problem of power development and distribution at Niagara Falls, and from that time until the adoption of the polyphase system and award of the initial Niagara contract to his company, his attention was closely concentrated upon the development of electrical machinery for power transmission.

As Electrical Engineer of the Westinghouse Company, he installed the first three 5000-horse power units at Niagara.

Resigning from the Westinghouse Company and occepting appointment as Electrical Director of the Niagara Falls Power Co., he removed his residence to NiagaraFalls, *and* devoted three years to the extension and completion of power plant No. 1, with local distribution and transmission to Buffalo. During this period, he assumed responsibility for the operation of the plant as well as for the electrical engineering incident to its increase from the original three 5000-horse power units to eleven units.

While at Niagara, he invented and patented the first time-limit circuit-breaker and the diagrammatic switchboard control, these inventions together with the induction regulator, patented in 1888, being among the most important inventions upon which the successful transmission and distribution of alternating-current power has since depended.

In 1899, while still at Niagara, he was appointed by the Manhattan Railway Company Consulting Electrical Engineer, and in that capacity had charge of the electrification of the elevated railways in Manhattan and the Bronx. For something over a year, he divided his time between Niagara Falls and New York City, and, in September, 1900, the first power house unit at Niagara having been completed, and the commercial success of transmission to Buffalo having been demonstrated, tendered his resignation as Electrical Director of the Niagara Companies and established his office as Consulting Engineer in New York.

In 1900, he was appointed Electrical Director of the Rapid Transit Subway Construction Co., and during the next eight years directed the electrification of the New York subways.

In addition to the electrification of the elevated and subway lines in New York, some of his more important professional engagements included consulting engineer for the following:

Consulting Engineer, Hudson Companies, in charge of electrical, mechanical and rolling stock equipment, 1905-1913. Member, Erie Railroad Electric Commission, 1906; United Railways & Electric Co., Baltimore; Interborough Rapid Transit Company; N. Y., New Haven & Hartford R. R. Co., (Hoosac Tunnel Electrification); N. Y., Westchester & Boston Railway Co.; Lehigh Navigation Electric Co., N.Y.; Municipal Railway Corporation; N. Y. State Bridge & Tunnel Commission; and N. J. Interstate Bridge & Tunnel Commission. He was also a Member of the Board of Economics & Engineering, National Association of Owners of Railroad Securities, 1921-1922.

As Consulting Engineer to the Lehigh Navigation Electric Company, in cooperation with his associates, M. G. Starrett, John Van Vleck and the late H. S Putnam, he designed and supervised the construction of the initial 45,000-kw. power plant at Hauto, Penn., with its distribution system—the first large power plant erected in America at the "mouth of the mine."

During the war, he served as a member of the National Research Council.

Mr. Stillwell is a Fellow of the American Institute of Electrical Engineers, Past-President of the American Institute of Consulting Engineers (two terms), member of the National Academy of Sciences, the American Society of Civil Engineers and of the British Institution of Electrical Engineers.

He is a Life Trustee of Princeton University, and for three years served as a member of the Board of Directors of the United States Chamber of Commerce—the only man elected to that body to represent the engineering profession.

Theory of the Autovalve Arrester

BY JOSEPH SLEPIAN[1]

Member, A. I. E. E.

***Synopsis.**—The advantage of valve type arresters for high-voltage, power-system protection is briefly discussed. The theory of the autovalve arrester is given.*

I. Induction and Regulation of Surges

In the last few years, considerable light has been shed on the manner of induction of high voltage on power systems by lightning,[2] and some estimates of the magnitudes involved have been made. Charges on clouds produce electrostatic fields extending down to the ground, which induce charges on power lines. The vertical gradient at the earth's surface due to these fields has been estimated[3] to be of the order of 100 kv. per ft. When the inducing charges on the clouds disappear suddenly by a lightning discharge, the induced charges on the power lines produce voltages to ground equal to the height of the lines multiplied by the inducing gradient, and, therefore, of the order of hundreds of kilovolts. The induced charges may be a few miles in extent.[4]

The power line becomes then a source of voltage, so high as to be dangerous to connected machines, and the very important question arises when considering the possibility of relief by lightning arresters as to what is the regulation of this source of voltage. It is now well recognized[5] that voltage due to a free charge of this type on a power line regulates like a generator having an internal resistance of a few hundred ohms. Hence the voltage can be quickly materially reduced if, and only if, sufficient current is drawn from the line. An arrester will be effective, if, and only if, it draws nearly two amperes per kilovolt of induced surge[6]. An arrester then must be able to discharge hundreds of amperes with only a moderate rise of voltage.

II. Energetics of Surge Dissipation

The large current which must pass through an arrester if it is to be really effective introduces great difficulties in the design of arresters of the arc-resistance type for higher voltage circuits. This is not due to the energy of the surge itself, which is only moderate in amount because of its short duration, but to the energy supplied by the normal working voltage, which lasts throughout the whole arcing period, and may be from one-half cycle to several seconds. For example, a surge 1.86 mi. long, will discharge for only 1/100,000 sec. If an arrester connected to a line, the normal voltage of which to ground is 10,000 volts, discharges 900 amperes from this surge and reduces the voltage thereby to 30,000 volts, the energy involved will be only 30,000 by 900 by 1/100,000, or 280 watt-seconds. On the other hand, if the normal line voltage discharges 300 amperes for one half cycle, or 0.0083 second, the energy will be 10,000 by 300 by 0.0083 or 24,900 watt-seconds, or more than 90 times the energy due to the surge alone.

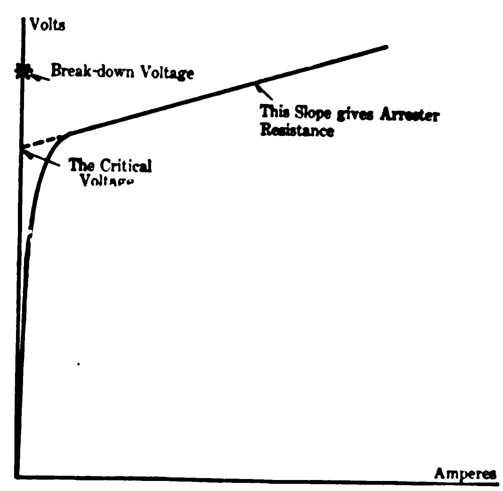

Fig. 1—The Valve Characteristic

Valve type arresters, being built up of elements having the characteristic shown in Fig. 1, are not subject to the disadvantage of disposing of this large draft of energy from the normal voltage. With the passing of the surge, and the restoring of normal voltage, the discharge ceases. It is, therefore, entirely practical to construct valve type arresters with adequate discharge capacity for even the highest voltages.

Some illuminating calculations made for an arrester set at the center of a freed charge as shown in Fig. 2 are given in the curves of Fig. 3. The initial surge voltage is taken as 250 kv. The normal voltage to

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1. Research Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

2. A. L. Atherton, Trans. A. I. E. E., Vol. XLII, p. 179 (1923); E. E. F. Creighton, Trans. A. I. E. E., Vol. XLI, p. 52 (1922); D. W. Roper, Trans. A. I. E. E. Vol XXXIX, p. 1895 (1920); C. P. Steinmetz, Trans. A. I. E. E., Vol. XXXIX, p. 1941 (1920).

3. F. W. Peek, Trans. A. I. E. E., Vol. XLIII, (1924); H. Norinder, *Electrical World*, Feb. 2, 1924; E. E. F. Creighton, Trans. A. I. E. E., Vol. XLIII, (1924).

4. H. Norinder, loc. cit.; F. W. Peek, loc. cit.

5. H. Rudenberg, "Elektrische Schaltvorgange," Berlin 1924, p. 330.

6. E. E. F. Creighton, Trans. A. I. E. E., Vol. XLII, p. 179 (1923).

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

ground is taken to be 8660 volts, and the line surge impedance, 400 ohms. The heavy line curves show the reduction in voltage for varying resistance in an arrester of the arc type and one of the valve type with critical voltage, 10,000 volts. Evidently suitable protection is not obtained until the arrester resistance is less than 50 ohms.

The light lines show the energy dissipated in the arrester. In order to get the curve for the valve type well into the picture, it is necessary to consider a surge 400 mi. long; the more reasonable surge length, 4 mi. would be barely visible on the scale chosen.

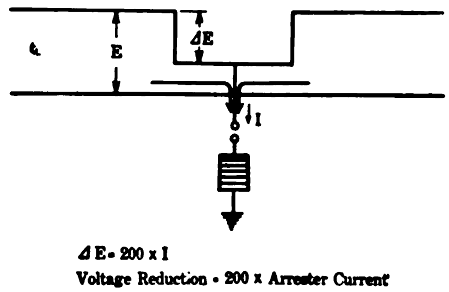

Fig. 2—Basis of Calculation of Fig. 3

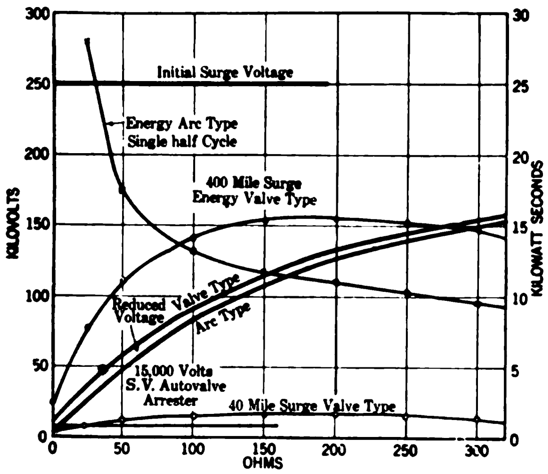

Fig. 3—Energetics of Surge Dissipation

The energy relations illustrated in Fig. 3 have proven determining factors. The only practical arresters with adequate discharge capacity for high-voltage lines are the valve type arresters.

III. Modern Valve Types

The so-called valve characteristic, shown in Fig. 1, has been frequently discussed, and the terminology indicated in the figure is generally used. Conducting systems having this characteristic are numerous in nature. However, in most of these systems the critical voltage is too low (as in contacts or electrolytic polarization cells) or the current which may be carried is too small, (as in thermionic or low-pressure gas tubes), to be useful for lightning arresters for power lines. So far the only systems which have been found to possess the valve characteristic to a necessary degree have been certain films which are made conducting by application of sufficient voltage, but which are subject to constant repair action, requiring the continued application of the high voltage for the maintenance of the conductivity and in which the original resistivity is restored when the voltage is reduced. Three practically used arresters have been developed utilizing films of this type.

The Electrolytic Arrester. The film in this arrester consists of a layer of gas-laden, aluminum oxide, which forms on an aluminum anode in a suitable electrolyte. Application of a few hundred volts breaks this film down, but the flow of current brings about a repairing electrolytic action.

The Oxide Film Arrester. In this arrester, the film is initially a layer of varnish, which, in use, is gradually replaced by litharge, PbO. The repairing action lies in the thermal effect of the current upon lead peroxide, which reduces it to litharge at the points of breakdown of the film.

The Autovalve Arrester. Here the film is a thin layer

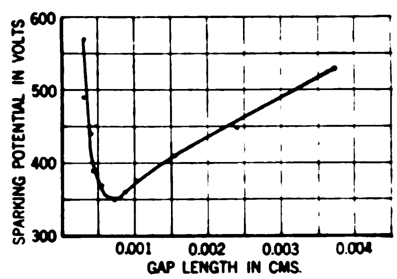

Fig. 4—Sparking Potential for Short Air-Gaps

of air next to a cold cathode which is the seat of the cathode drop in a glow discharge. With the application of sufficient voltage, this air film becomes highly ionized, but the discharge of these ions into the electrodes and recombination quickly restore the normal resistivity when the voltage is reduced.

IV. The Breakdown of Air Between Parallel Plane Electrodes

Since the active element in the autovalve arrester is air, any explanation of the arrester's design and functioning must include a discussion of the properties of air with respect to electrical breakdown and resulting conductivity. Fig. 4 shows the relation between breakdown voltage and distance between parallel plane electrodes. A striking feature of this curve is the minimum at electrode separation of 0.001 cm., so that shorter separation than this requires increased voltage for breakdown. This remarkable fact is readily explained by the current theory of ionization by collision[7].

7. J. J. Thomson, "Conduction of Electricity in Gases," p. 381 J. S. Townsend, "Electricity in Gases," Chap. VIII and IX.

The existence of a minimum breakdown potential of about 350 volts for short gaps may seem contradictory to experience. For example, a widely used type of telephone protector consisting of two small carbon blocks separated by 0.002 in. will usually break down at 200 volts, or sometimes even less. In this case, however, the breakdown is due to the lining up of carbon dust particles in the intense electric field so that a conducting bridge which starts an arc is formed. If precautions are taken to prevent contacts taking place in this or any other manner, the existence of a minimum breakdown voltage may be shown experimentally.

In the autovalve arrester, as will be explained later, it is necessary to use gaps between resistance material electrodes with a breakdown voltage of little more than 350 volts. The curve of Fig. 4 indicates that an electrode separation of 0.0003 in. is necessary for this. At first sight, so minute an electrode separation would appear impracticable in a commercial arrester.

This difficulty was overcome in the early experimental autovalve arresters by merely placing the resistance electrode disks in contact. Due to the resistivity of the electrode material, the gap would not be short-circuited at the contacts. At the same time,

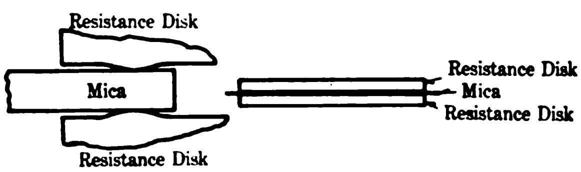

Fig. 5—The Autovalve Gap

in the neighborhood of each contact, there would be points at which the electrode separation was 0.0003 in., and there, breakdown at 350 volts would occur.

A better solution now used was found later and consists in using a mica spacer, 0.003 to 0.005 in. thick, placed directly between the disks. Fig. 5 shows the standard autovalve element (right) and section at the mica spacer, highly magnified (left). The mica, having a dielectric constant of six to seven, distorts the electrostatic field, very much as if it were conducting. Thus there is a concentration of electrostatic stress at the corners of the mica. Due to inherent variations in the nature of the surface of the resistance disk and its contact with the mica spacer, the total voltage applied is not expended symmetrically between the two disks and the edges of the mica, but at some points nearby, all the voltage appears between one resistance disk and the adjacent mica edge, and at other points between the other resistance disk and adjacent edge. Hence, when a little more than 350 volts is applied, these highly stressed points break down and precipitate the discharge of the whole gap. Numerous tests have shown that in commercial autovalve arresters, the breakdown of the column of disks is less than 400 volts per gap.

This expedient of using the electrostatic influence of the mica spacer to precipitate the discharge at low voltage is not practically useful if metal electrodes are used. The discharge must start at the mica, and if it is permitted to concentrate at its point of origin, as with metal electrodes, the mica is quickly destroyed. In the autovalve arrester relatively high resistivity electrodes are used, which limit the intensity of the discharge next to the mica. Hence, thousands of discharges may be sent through it with no deterioration of the mica.

V. Electric Discharges in Air

Arc Discharge. The breakdown of a gap is due to the ionization produced by the high electrostatic gradient.

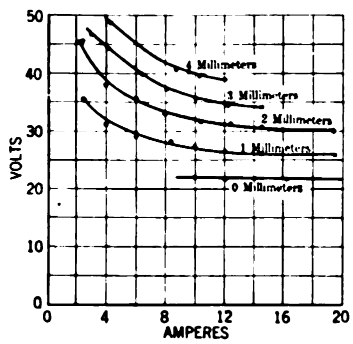

Fig. 6—Arc Characteristics for Copper

If the gap is to remain conducting for the duration of a discharge, this ionization must somehow be maintained. If the cathode remains cold the ionization is effected by the field becoming so distorted that with carbon electrodes approximately 350 volts are impressed across a layer of air 0.001 cm. thick next to the cathode. The discharge then takes the form of a glow. If, however, the cathode becomes sufficiently hot for thermionic emission, much less voltage need be expended at the cathode and the discharge takes the form of an arc.

In the arc discharge the voltage expended at the

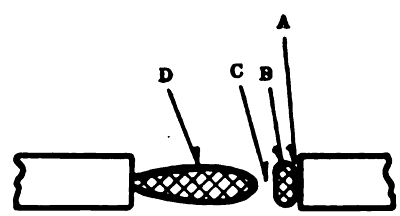

Fig. 7—The Glow Discharge (magnified)

cathode must be sufficiently great to maintain the cathode at a temperature sufficiently high for thermionic emission, and also must be sufficiently great, and concentrated on a sufficiently small space next to the cathode, so that the electrons liberated thermionically will ionize by collision. Twenty volts is sufficient for both these purposes for most electrode materials.

In addition to the voltage expended at the cathode some must be expended in carrying current in the remainder of the discharge. This additional voltage is found to vary inversely as the current strength, so that characteristics such as shown in Fig. 6 are obtained.

It is now clear why an arc discharge is not suitable for giving the valve characteristic to a gap. Aside from the melting or burning of the cathode due to its necessary high temperature the voltage of the arc discharge is too low, (about 20 volts for short gaps) in comparison with the lowest reliable gap breakdown of about 350 volts.

Glow Discharge. When the cathode is too cold for thermionic emission the glow form of discharge takes place in which the ionization is primarily produced by ionization through collision due to high gradient in a film of air about 0.001 cm. thick next to the cathode. The voltage expended in this film is about 350 volts for carbon electrodes. Fig. 7 shows on a magnified scale the appearance of such a glow between copper electrodes. This was obtained by reducing the current to a few milliamperes by means of a high series resistance. When the current is so small, the heating of the cathode is insufficient for an arc, and so the glow discharge may be maintained indefinitely. *A*, the cathode dark space, is the 0.0003-in. film which is kept broken down by the high gradient due to the 300 volts (cathode drop for copper) across it; *B*, the cathode glow is a highly ionized blue region, about 0.005 in. thick. *C*, the Faraday dark space, is also highly conducting, and is about 0.010 in. thick. *D*, the pink positive column, extends to the anode.

So long as the cathode is not completely covered by the discharge, the cathode drop and the cathode current density are approximately independent of current, the cathode glow simply increasing or decreasing in area as the current is varied. The cathode drop and current density do vary with the nature of the cathode; for carbon, the cathode drop and current density are respectively about 350 volts, and 10 amperes per cm^2.

When the cathode is completely covered by glow, further increase of current must of course increase the current density. An increase of current density causes a moderate increase in the cathode drop. Extrapolation of a theoretical formula shows that an increase in current density of 25 amperes per sq. cm. increases the cathode drop by 37½ volts.

The conductivity of the blue glow and the Faraday dark space is so great that little voltage is consumed in these parts. In the pink column, however, the resistivity is greater, and for small currents, the gradient in it may amount to over 5000 volts per cm. However, this gradient decreases, as the current increases.

Volt-ampere characteristics of a glow between copper electrodes are shown in Fig. 8. The longer gap lengths show a falling characteristic due to the properties of the pink positive column. For the 0.1 mm. gap, the positive column is completely eliminated and so, a flat characteristic is obtained.

Transition from Glow to Arc Following Sparkover. At the moment a spark-gap is broken down by high voltage, the electrodes and, in particular, the cathode are, of course, cold. It follows, then, that the discharge must begin as a glow. After a short but finite time, the energy input at the cathode, due to the glow, heats some spot to such a degree that thermionic emission begins there. The cathode drop then falls to about 20 volts and the current concentrates at the point to sufficient degree to maintain the point hot. For a definite time, then, immediately following a sparkover, the discharge is in the form of a glow.

Heating of Autovalve Disk. It would seem, then, that if the time taken between the sparkover of a gap and the transition from the resulting glow into an arc is long compared to the duration of a surge, it should be very easy to make a lightning arrester which would only discharge in glow form. It is easy to get an estimate of the time involved. The formula given on page 98 of "Mathematical Theory of Heat Conduction,"

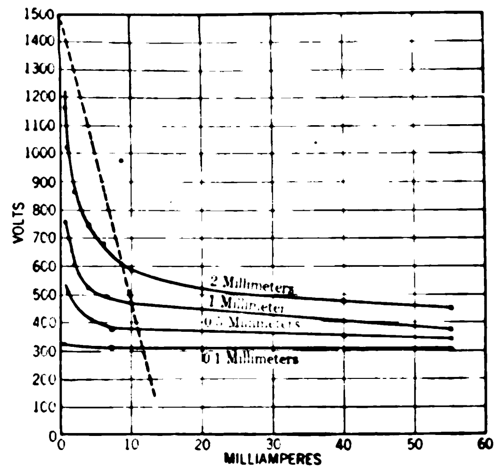

Fig. 8—Glow Characteristics for Copper

Ingersoll and Zobel, Ginn & Co., may be readily transformed into

$$T = \frac{W}{4.18 \sqrt{k\,c\,\delta}}$$

where k, c and δ are heat conductivity, heat capacity and density, respectively of the material making up an infinite solid; W is the power input per unit area on an infinite plane surface in that solid, and T is temperature rise at that surface. Units are deg. cent., small calories, grams, centimeters and watts.

For the resistance material electrodes used in the autovalve arrester, $c = 0.185$ cal. per gr., $k = 0.016$ cal. per cm^2. per deg. cent. per cm^3. $\delta = 2.0$ gr. per cm^3. For a glow discharge at normal current density we have approximately 10 amperes per cm^2. at 350 volts, giving $W = 3500$. Using these numerical values, we get the curves shown in Fig. 9. Remembering that each one-thousandth of a second corresponds to 186 miles of surge, it is evident that the heating of the electrode surface is so slow that in any surge of practical length the temperature rise will be only a few degrees; hence the discharge will still be in the glow form when the surge has ended, and if the normal line voltage per

disk is less than glow voltage, the discharge will stop when the surge voltage disappears.

Current Concentration at Inhomogeneities. So far, it would appear from the formula for the surface temperature rise under a glow that the most desirable materials for electrodes would be those having the highest thermal conductivity and capacity. Metals, then would seem to be particularly suitable, and one would expect to find them superior to the resistance material used in autovalve arresters. However, when put to test contrary results are obtained. With metal electrodes, a heavy discharge only ten microseconds long, will usually end as an arc, whereas, with autovalve arrester disks, it will still be a glow for a discharge 100 times as long. Some as yet unconsidered factor is playing a part here. This factor is the great current concentration in the glow which takes place at any points of the metal surface which happen to have a lower cathode drop than the rest of the metal surface.

It has been mentioned before that the cathode drop

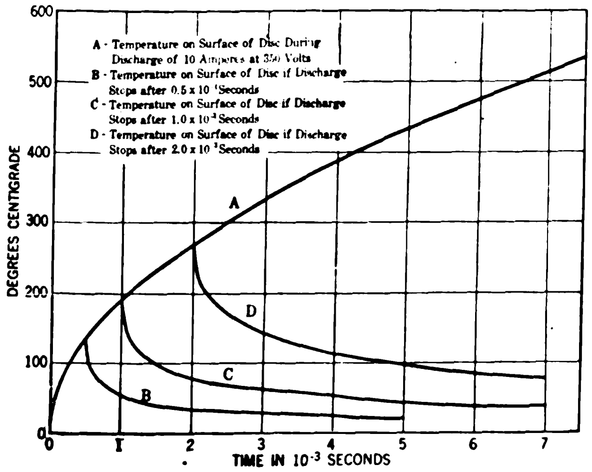

Fig. 9—Temperature Rise of Resistance Material Cathode

in a glow discharge is a function of the material making up the cathode, being 350 volts for carbon, 300 volts for copper, 250 volts for iron, etc. However, like other properties of surfaces, these cathode drops are not absolute constants of the material, but vary somewhat depending upon the state of the surface. Films of absorbed gas or moisture change the cathode drop by a small amount. Dust particles or adhering impurities of any kind may lower the cathode drop enormously. The alkali metals and their oxides are particularly effective in this respect, and may lower the cathode drop to less than 150 volts.

Now imagine on a cathode carrying a glow discharge a point at which the cathode drop is a few volts less than that of the rest of the surface. It is evident that instead of a uniform current distribution over the cathode surface at the moderate density of ten amperes per cm²., there will be concentration of current at the point of low cathode drop. This point will heat up very much faster than is indicated by Fig. 9, and the transition from glow to arc will take place in a much shorter time.

Another effect which is even more important for very short gaps in hastening the transition from glow to arc, is the lining up of minute conducting dust particles, under the intense electrostatic field. In the cathode dark space, the electric gradient is of the order of 350,000 volts per cm. The mechanical force on conducting particles in such fields is relatively enormous, and there is a tendency for these particles to form into chains almost instantly. In very short gaps, five mils or less, these chains bridge the electrodes and start arcs by the current concentration in them with resulting rise in temperature.

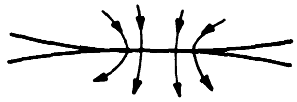

Fig. 10—Current Flow at a Contact

Temperature of a Contact. The effects of surface inhomogeneities and conducting bridges in causing premature heating of some cathode surface point and striking of an arc is combated in the autovalve arrester by giving the electrode material sufficient resistivity. We may say that if at any point less voltage is consumed in the discharge or gap space than at other points, then this difference of voltage will be expended on the resistance of the path offered to current immediately behind this point in the electrode material. Conditions are then very similar to those which take place at a

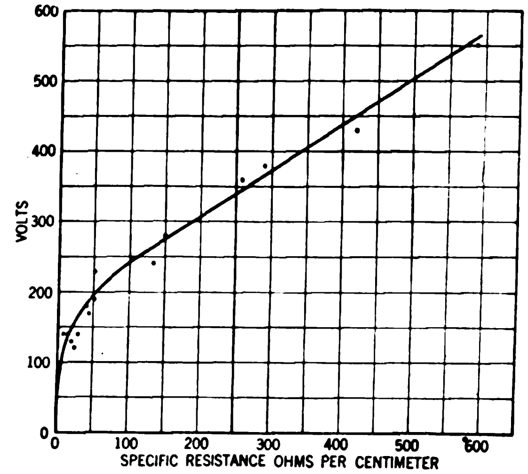

Fig. 11—Voltage to Draw on Arc by Contact

point of contact between electrodes as illustrated diagrammatically in Fig. 10, the arrows indicating the lines of flow of current. It is not difficult to calculate the approximate temperature rise at such a contact, if the contact area is assumed circular. It is

$$T = \frac{E^2}{33\,k\,\rho}$$

where, E is the voltage on the contact, and

k and ρ are the thermal conductivity and electrical resistivity, respectively, of the electrode material. Because of the very small thermal capacity of the

contact, this temperature rise is almost instantaneous. If copper electrodes were used with $k = 1.0$ and $\zeta = 10^{-6}$, a surface inhomogeneity or conducting bridge which would throw 10 volts onto the electrode material at a point would give a temperature rise of

$$T = \frac{100}{33 \times 1 \times 10^{-6}} = 3 \times 10^{6} \text{ deg. cent.,}$$

so that an arc would form instantly. Autovalve electrodes on the other hand with $k = 0.016$ and $\rho = 20$ give

$$T = \frac{100}{33 \times 0.016 \times 20} = 9.4 \text{ deg. cent.,}$$

or a practically negligible increase in the tendency to strike an arc.

Experiments on Arc Drawing at a Contact. The considerations given above show that the voltage necessary to start an arc by contact, increases with the resistivity of the electrode material. The results of experiments confirming this are shown in Fig. 11.

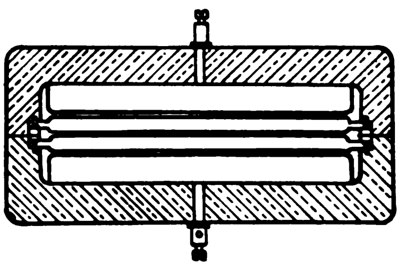

Fig. 12—The Thomas Arrester

The parabolic relation found between voltage and resistivity is predicted by the formula,

$$T = \frac{E^2}{33\, k\, \rho}$$

Design of Autovalve Arrester. The three essential parameters in the autovalve arrester element which determine its electrical performance, are gap length, electrode resistivity, and electrode area. A desirable characteristic is a discharge voltage only little less than the breakdown voltage, and this with a minimum of resistivity in the electrode material so that impractically large area will not be necessary for adequate discharge capacity.

From Fig. 8 it would appear that if the current density is sufficiently limited, a discharge voltage nearly equal to the breakdown voltage may be obtained. Thus the valve characteristic may be obtained for any gap length if only electrodes of sufficiently high resistivity are used. It is very interesting that this principle was understood and described seventeen years ago by P. H. Thomas in his U. S. Patent No. 882,218. Fig. 12 shows his proposed arrester. Quoting from his patent, "It is an essential characteristic of my invention that there shall be an opportunity for a large number of independent static discharges between the discharge plates and that each discharge path shall have such resistance that the dynamo current cannot follow the static discharge."

However, it is only by using very short gaps with a few hundred volts breakdown, that resistivity sufficiently low for a practical arrester may be used. To see this, consider again the curves of Fig. 8 for glow discharge between copper electrodes. Suppose that by using mica spacers or otherwise, a 2-mm. gap could be broken down by 1500 volts. Then the current and voltage of the discharge would be determined by the intersection of the 2-mm. glow curve, and the straight line drawn from 1500 volts on the voltage axis, with a slope equal to the resistance of the circuit. The line shown in the figure corresponds to a resistance of 102,500 ohms, and with this resistance, the discharge voltage is only 600 volts. If the discharge voltage is to be raised up to 20 per cent less than 1500 volts, that is 1200 volts, the line must be swung around until it corresponds to a resistance of 440,000 ohms. At its point of intersection with the 2-mm. glow curve the current will now be one milliampere. Taking 10 amperes per cm². as the current density in the glow this gives 0.001 cm². as the area. The resistance in an electrode up to such an area is given by $\frac{0.261}{a}\rho$ where ρ is the resistivity of the material, a is the radius of the area, in this case 0.0056 cm. Thus, $\rho \times 46.6 = 440{,}000$ or $\rho = 9400$ ohms per cm³. This is prohibitively large. If, however, the gap length and breakdown voltage are lessened, the resistance necessary to keep the discharge voltage nearly equal to the breakdown voltage decreases, and when 0.1-mm. gap with 350-volt breakdown is reached, no resistance is necessary for keeping up the discharge voltage.

For a practical arrester, then, it is necessary to use a gap so short that its glow volt ampere curve is substantially flat. This will occur if the glow has no positive column and from the dimensions given in connection with Fig. 18, this means a gap length not over 0.015 inch. In the commercial autovalve arrester, gap length of not over 0.005 inch is used to ensure breakdown at little more than 350 volts.

With gap lengths less than 0.015 inch the resistivity of the electrode material must be made only high enough to take care of surface inhomogeneities and the partial contacts due to bridging particles. These are not calculable, and the permissible low limit resistivity must be determined by test. The low limit for resistivity in commercial autovalve arresters at present is 20 ohms per cm³., giving a total resistance of only a fraction of an ohm per disk.

The gap length and resistivity being thus given, the area of the electrodes will determine the discharge rate of the arrester. In the *S V* type of autovalve arrester the area has been chosen to give a discharge rate equal to that of the electrolytic arrester.

Carrying Capacity of 60-Cycle Busses for Heavy Currents

BY TITUS G. LE CLAIR[1]

Associate, A. I. E. E.

Synopsis.—*Up to the present time it has seldom been necessary to design busses for carrying capacity above 2000 or 3000 amperes. Within the last few years we have passed this mark, and we shall soon be required to design busses for very much larger capacities.*

For simple geometrical designs there are formulas from which we may calculate the capacities of large busses. These simple designs cannot be easily mounted, and for this reason we must resort to styles which are easier to construct. These types cannot be calculated readily by the mathematics available to the ordinary engineer. This paper is presented with the idea of giving a ready reference for determining bus capacities without involved calculations.

Curves are given showing the carrying capacity of a few types which are proposed as standards, and, in addition, a few curves compiled from tests showing the distribution of current in busses to show the necessity of this type of design. By a little careful study of these curves, the average designer may quickly choose the type of bus which will best meet his requirements for carrying capacity and allowable space. All busses are designed on the basis of 30 deg. cent. temperature rise, and their ratings may be proportionately increased if the conditions warrant a 40 deg. temperature rise.

As the usefulness of electric power becomes more and more widespread and its uses more diversified, large blocks of power are frequently required in a small space. This is especially true in factories where there may be a great many machines on a small floor area with individual motor-drive, or for electric furnace work. In consequence, we find it necessary to supply large blocks of power at low voltage, with correspondingly heavy currents.

As the transmission system grows in size the energy of short circuit on the high-tension system is so great that the cost of protective apparatus, as well as the expense of insulating for high voltage, requires that all power be supplied from large, well protected transformer banks in fire-proof vaults. This means that very heavy currents must be brought out from the transformer bank to the distribution switchboard or to the furnace through a single low-tension bus. Due to this rapid development it has become necessary within the last few years to design busses far beyond the old limits of 2000- or 3000-ampere capacity, with the time not far in the future when we shall need to carry 10,000 amperes or more on a single low-tension bus.

Theory

In any d-c. circuit, be the conductor solid, laminated or stranded, the current divides in all parts in proportion to the resistance, which means that with a conductor of homogeneous material, the current is practically the same in all parts. The same condition does not hold true, however, for alternating current. In addition to the resistance drop, an alternating current introduces an alternating flux surrounding any element of the conductor. This alternating flux generates a voltage which tends to oppose the flow of current in the conductor element. When we consider a large conductor, it is obvious that the lines of force caused by an element in the outer part surround the entire conductor, but, for a central element, some of the flux does not cut the outer element. The result is that the effective impedance of an element in the central part of the copper is higher than in the outer edge, thereby forcing most of the current to the outer surface, producing the so-called skin effect. In very large conductors this can be carried so far as to have the current in the center of the bus very nearly in the opposite direction to the current in the outer part of the bus, as well as being smaller in magnitude.

When the phases are placed close together there is, in addition to the skin effect, a voltage induced by the flux from an opposite phase which is not uniform over the entire conductor and forces current toward the near side. This is called the proximity effect. Both the skin effect[2] and proximity effect[3] can be calculated for cylindrical or tubular conductors from formulas developed by H. B. Dwight.

Unfortunately, it does not often pay, due to the difficulty of mounting and of making connections, as a practical problem to use a circular conductor for very large bus work. Former practise has been to build the bus of laminated copper bars for the required capacity. For a bus of this shape, it is impracticable, if not utterly impossible, to calculate the distribution of current in order to obtain the losses and temperature rise on alternating current circuits. To further complicate the problem nearly all high capacity busses are three-phase and not single-phase, which makes it more difficult.

Tests

Due to the demand for large increases in bus capacity and the impossibility of making calculations, we have just completed a series of tests to determine, if possible, an efficient and practicable type of bus construction for very high currents.

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1. Of the Commonwealth Edison Co., Chicago.

To be presented at the Midwinter Convention of the A. I. E. E., to be held in New York, Feb. 8-11, 1926.

2. *Skin effect in Tubular and Flat Conductors*, H. B. Dwight, A. I. E. E. Vol. XXXVII, p. 1379.

3. *Skin effect and Proximity Effect in Tubular Conductors*, H. B. Dwight, JOURNAL A. I. E. E., Vol. XLI, p. 189.

In order to make these tests applicable to heavy currents and three-phase circuits, a three-phase bus, 20 ft. long was set up and connected in the circuit between the transformer and three of the rings of a 3900-kw., 230-volt, rotary converter. (See Fig. 1.) This converter could be operated in parallel with another machine on the d-c. side and permitted a ready control of the current up to quite high values. Practically all tests were run with constant current to determine the ultimate temperature rise of the various types of bus construction.

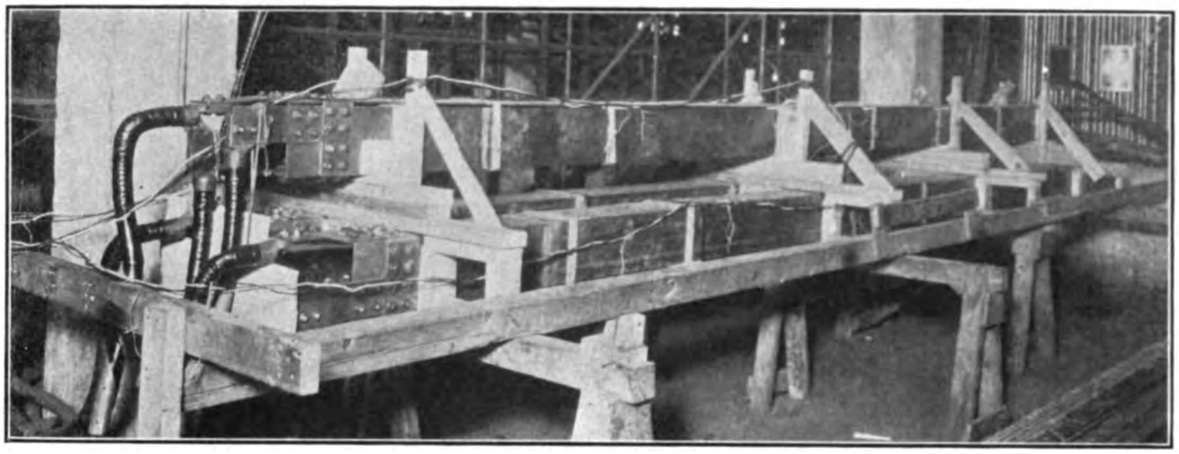

FIG. 1—TEST BUS

Consisting of four 8-in. by ¼-in. copper bars per phase, arranged in rectangular form. Phases on corners of an equilateral triangle, 17-in. sides.

Temperature measurements were made by means of thermocouples connected to the centers of the various bars in this 20-ft. section. A number of checks were made during the progress of the test with temperature measurements at points other than the center of the bus to be sure that no contact resistance or other variables were affecting the results. Impedance voltage drop was measured by means of straight leads perpendicular to the bus, carried far enough away to be out of the influence of the magnetic circuit.

In addition to these measurements, the current in various parts of individual conductors was also determined by a method similar to that described by C. F. Wagner.[4] The leads described running parallel to the bars, were No. 24 enameled wire. In order to be positive that there was no space between the wire and the bus surface and no sag, this wire was cemented to the surface of the copper with asbestos cement. To eliminate end effects, only the central 15 ft. of bus were used. In the lower right-hand corner of Fig. 1 may be seen a four-inch bar with five leads cemented on.

We have found a number of things which enter into the construction of a bus that are not constant for all circuits. For example, the current distribution will be very different on single-phase from that on three-phase circuits. Also, there is an extremely great difference between isolated-phase and group-phase busses due to proximity effect.

The majority of engineers are not particularly interested in the exact distribution of current in various parts of the bus. The primary question which enters the designer's mind is rather how much copper he must use and how he may best use it. A concrete example of the distribution of current will, however, clarify ideas of the results of skin effect and proximity effect and help a great deal in deciding for a particular case what form should be used. In Fig. 2 is shown a three-phase bus,

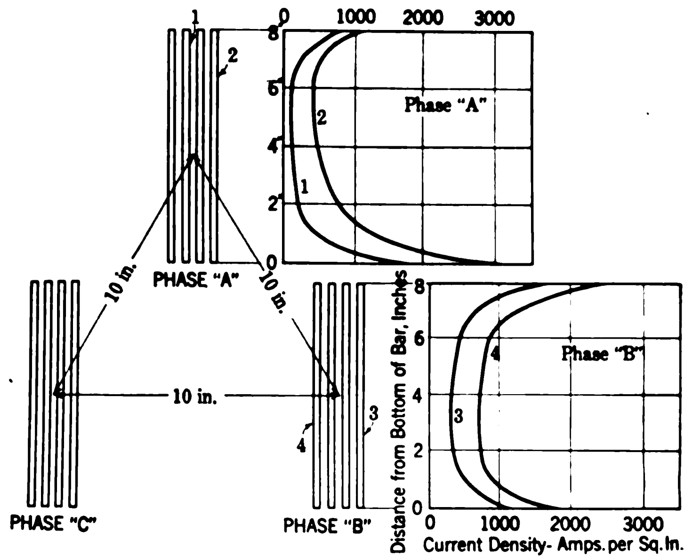

FIG. 2—CURRENT DISTRIBUTION IN A THREE-PHASE BUS

Consisting of four 8-in. by ¼-in. copper bars per phase, at 4000 amperes per phase.

each phase consisting of four 8-in. by ¼-in. bars per phase with phases set in an equilateral triangle on ten-inch centers. It will be noted that the current in A phase bus is practically all in the very bottom edge of the bars, and the usefulness of the upper half of the bar is more in the nature of a radiator than a conductor. For this

4. "Current Distribution in Multi-conductor, Single-Phase Busses," C. F. Wagner, *Electrical World*, March 18, 1922.

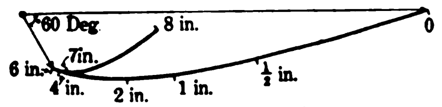

Fig. 3—Polar Diagram of Current Distribution in Outer Surface of 8-In. by ¼-In. Bar

Figures refer to distances from bottom edge of bar The surface considered is the same as Curve 2 in Fig. 2.

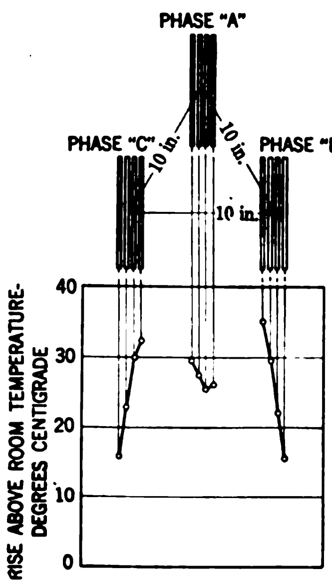

Fig. 4—Temperature Rise on a Three-Phase Bus

Consisting of four 8-in. by ¼-in. bars per phase under a continuous load of 4000 amperes per phase. Bus mounted in still air and not enclosed.

reason a bus of similar construction, except made of four-inch bars in the same layout, that is, four bars wide and two bars high, would not be nearly so effective because the upper set of bars would not carry much

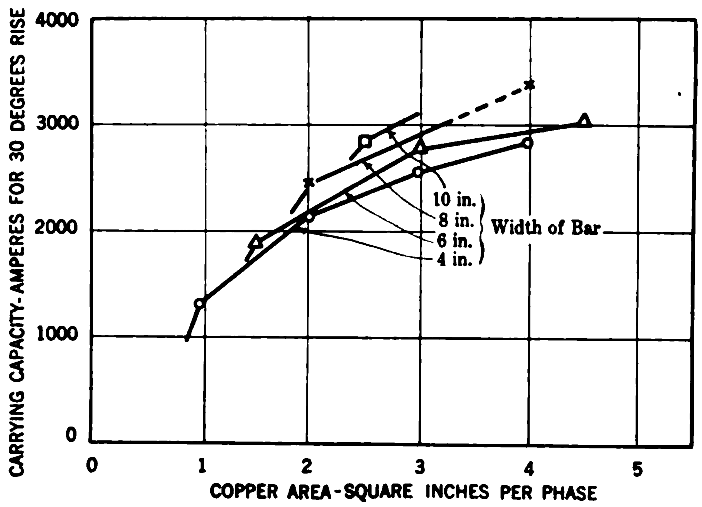

Fig. 5—Electric Power Club Standards

Ratings of laminated busses on grouped phases up to 3000 amperes at 60 cycles. Centers on a straight line with 8 in. between phases; ¼-in. spacing between laminations.

current, and in addition would have poor heat connection to the lower bars. Hence, they would not serve as good radiators.

It may also be interesting to note in Fig. 3 the relation of the phase angle of current in various parts of the bar.

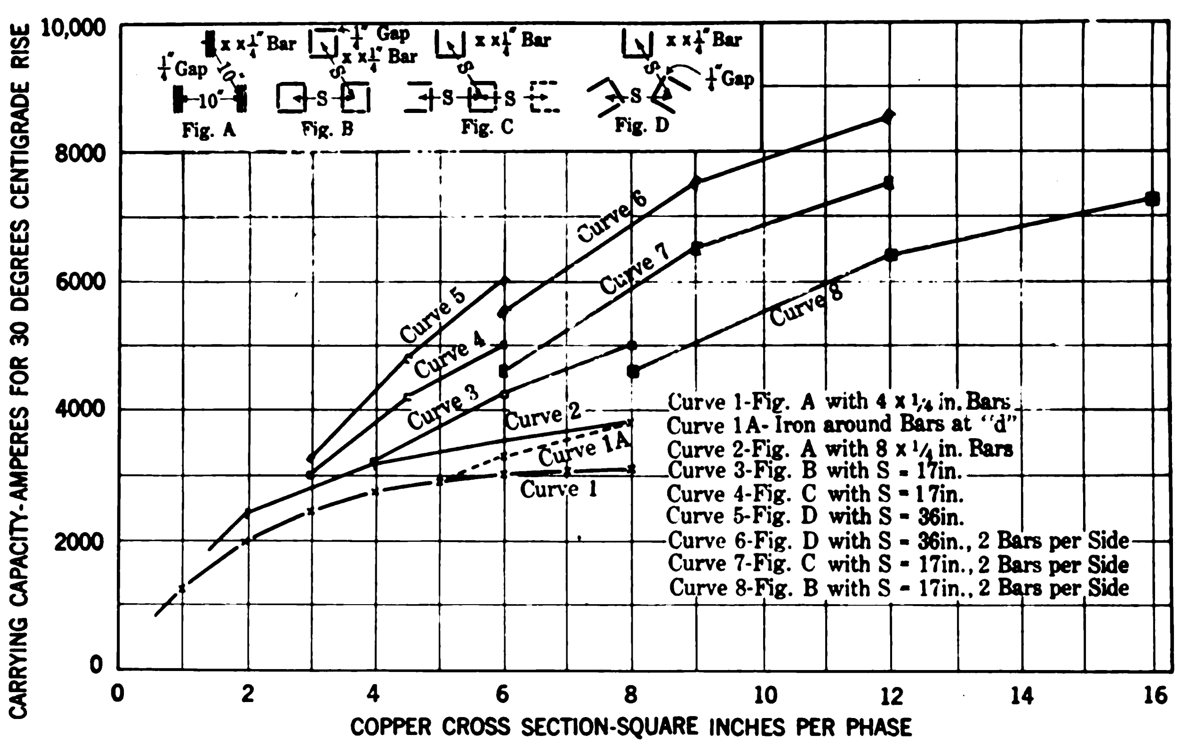

Fig. 6—Ratings of Busses on Grouped Phases Above 3000 Amperes at 60 Cycles

All bars are ¼ in. thick by 4 in., 6 in. or 8 in. wide. For instance, the center point on Curve 6 represents six bars of 6-in. by ¼-in. copper and the upper point on the same curve means six bars of 8-in. by ¼-in. copper.

It will be seen that the current at the minimum point lags 60 deg. behind that in the lower edge and that the point of minimum current is 6 in. instead of 4 in. from the bottom of the bar. As we go nearer to the center of the bus, the current lags further behind that in the outer edge of the outer conductor until we find the current at the center is very nearly 180 deg. out of phase. As a striking example, in a bus consisting of four bars

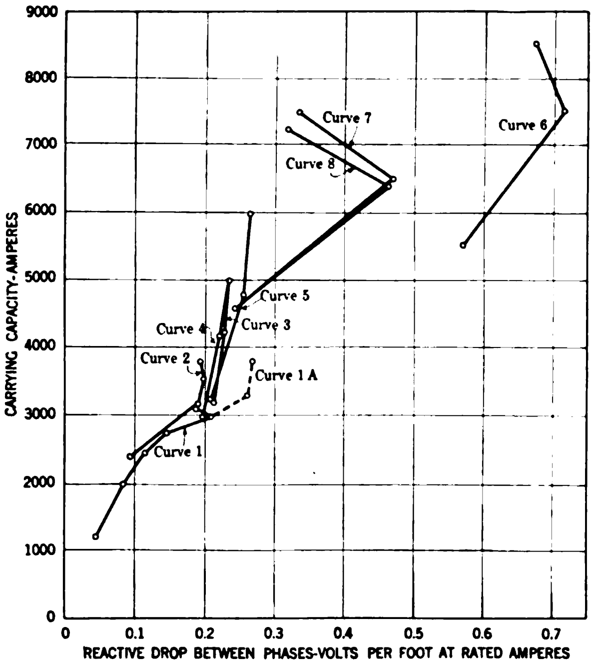

FIG. 7—REACTIVE VOLTAGE DROP ON THREE-PHASE BUSSES

Curve numbers and points refer to corresponding curve numbers and points for busses shown in Fig. 6. With phases arranged with centers on the same straight line, the average drop will be about 25 per cent higher and the drop in the two outer phases will be higher than that in the center phase.

laid on the sides of a rectangle, the addition of a fifth bar in the center actually increased the losses and temperature rise for the same current. In Mr. Wagner's article,[4] for single-phase busses he draws the curve from the outer edge to the center of the bar, and assumes that the same condition holds from the center to the opposite edge of a bar. This is perfectly true in some cases but not at all true in others, and the electrical center, or the point of minimum current in a bar, may not be the physical center.

If we now look at Fig. 4 to get the temperature rises of the various bars and consider that the temperature rise is proportional to the square of the current, we get a somewhat erroneous impression, due to the fact that while the central bars may be carrying some current, this is not a measure of their effectiveness, because as stated before the current in the central bar may be sufficiently out of phase to be of little or no value.

For moderate currents the important item in the design of a bus is the matter of ventilation. When we come to consider very heavy currents, this matter of ventilation is of minor importance, since ventilation is useless if all the current is carried in a small portion of the bus. The prime consideration, then, is to put the copper where it will be most useful.

BUS CAPACITIES

There are very few data available at this time on the carrying capacity of busses for heavy current. For example, some operating companies have for many years used the standard of 1000 amperes per square inch of copper section. This gives ample copper for busses up to 2000 amperes, but beyond this point the rule no longer holds. For isolated phases, the General Electric

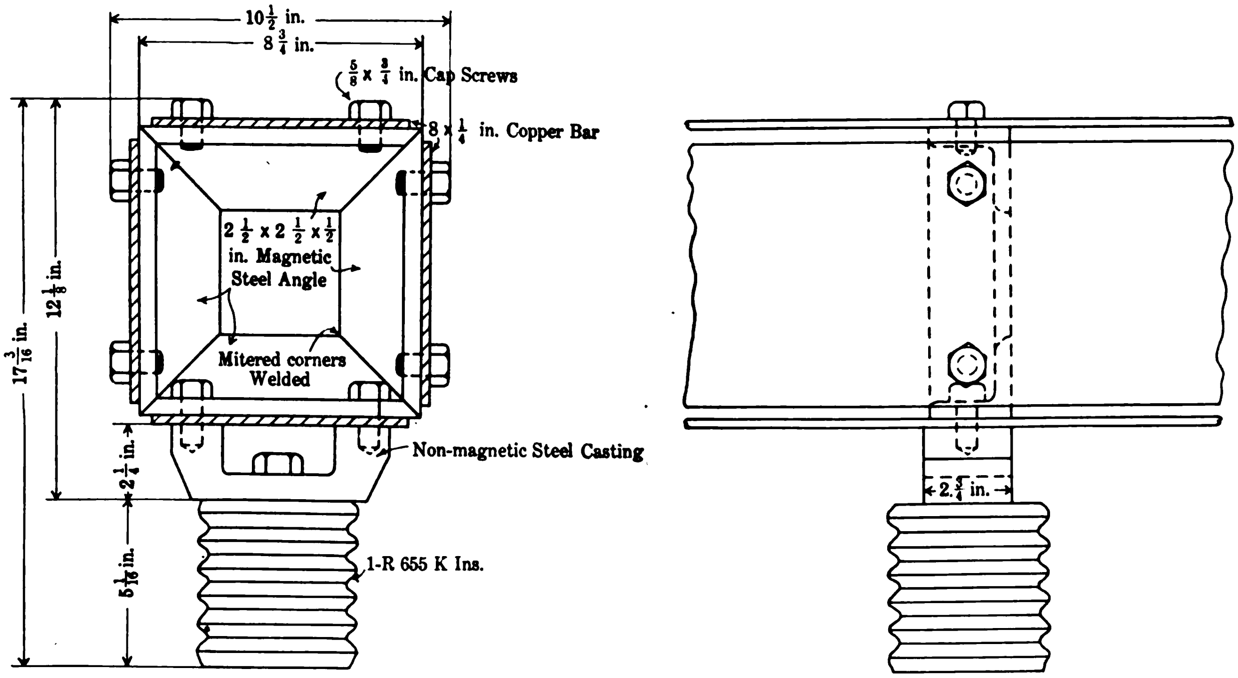

FIG. 8—FORM OF BUS SUPPORT FOR RECTANGULAR BUSSES REQUIRING DRILLING OF COPPER ON JOB. NO CLAMPS REQUIRED

Company has worked out a system of busses[5] which is not at all difficult to mount and is very satisfactory for currents up to 7400 amperes at 60 cycles. Due to the proximity effect as shown in the test data, it is obvious that this type of bus construction would be of little value for group phases on very close centers since the current would all be thrown into one corner of the bus and would cause it to run very hot. The Electric Power Club has given as a standard Fig. 5, which is for group phases up to 3000 amperes. Beyond this point we have compiled from our test data the curves in Fig. 6 for special types of bus construction. The curves do not, of course, give all the data required for any particular installation, but they give the points necessary for determining what should be used.

In Fig. 6, Curve 7 gives the rating of C on 17-in. centers. If the phases are separated further, the ratings of these busses will be raised somewhat but not so high as Curve 6. Curve 6 gives the rating of D on 36-in. centers, and the rating of this bus would be lower on the closer centers but not so low as Curve 7. In Curve 8 the rating may be very materially increased by one or both of two methods, either by a wider opening of the corners of the rectangle, or by further separating the phases. If both these things are done, we may obtain a bus of perhaps higher carrying capacity than that given in Curve 6. When the space limitations or the allowable reactive drop does not demand that phases be on the corners of an equilateral triangle, the dotted arrangement shown in C is practically equivalent in carrying capacity to that of D.

5. *General Electric Bulletin No. 87000-D*, Sept. 1924, p. 26.

Up to about 3000 amperes the reactance of the bus is not of very great importance, but beyond this point and especially for low voltages it becomes quite a serious item. For instance, on a bus carrying 6000 amperes at 230 volts and only 30 ft. long, it may be readily seen from Fig. 7 that the reactive drop may be from 3 per cent to 8 per cent of line voltage. This, in addition to the reactance of feeders, may cause a very poor voltage regulation at low power factors unless care is used in the selection of the bus.

Another important point in the matter of reactance is that it is frequently necessary to parallel transformer banks of different sizes or with different lengths of copper from the banks to the point of paralleling. For large transformers the bus reactance is considerable compared to the transformer reactance and up to the point of paralleling, the bus reactance may be considered a part of the transformer reactance so far as division of load is concerned. This effect is especially noticeable where transformer banks of different capacities are paralleled, because the percentage reactance per foot is very much higher for large than for small busses. Sometimes it even becomes necessary to install a reactance in series with the smaller transformer bank to prevent overheating of one bank when the other is not fully loaded.

In Curve 1-A, Fig. 6, is shown the carrying capacity of a laminated bus, balanced with magnetic steel, as proposed by Mr. Wagner. It is true that the addition of this magnetic steel does increase the carrying capacity. However, the amount of iron to be added must be determined by the cut-and-try method for any in-

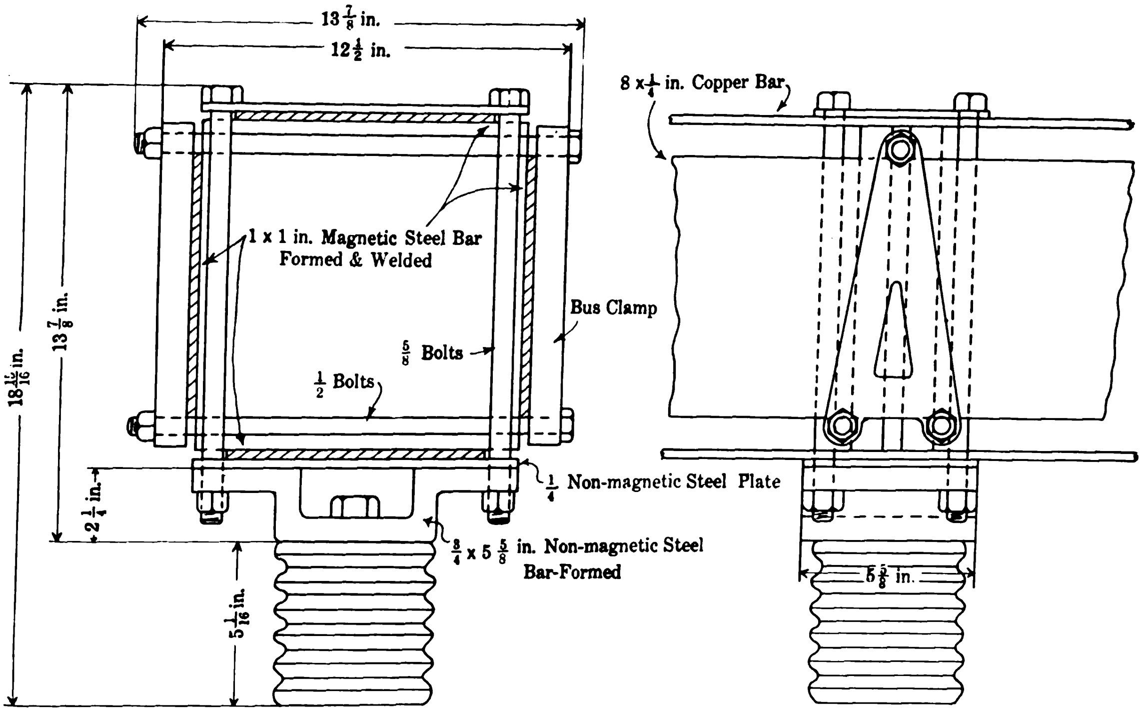

FIG. 9—FORM OF BUS SUPPORT FOR RECTANGULAR BUSSES REQUIRING NO JOB DRILLING OF COPPER

stallation and the cost of adding this balancing becomes prohibitive, especially when the class of labor usually employed knows nothing of what is to be done.

The principal objection to the use of a rectangular form of bus is the same as one of the objections to the tubular form of bus; that is, the difficulty of mounting. However, a little careful consideration will show that the rectangular bus is not particularly difficult to mount since flat clamps may be used which are very similar to those used for an ordinary laminated bus.

The manner of making taps is little more difficult than with the ordinary laminated bus because all the copper surfaces are flat. Especially is this true if the corners of the rectangle are left open, making room to handle bolts inside. The necessary bracing between phases may be attached to the clamps in practically the same way as is done with laminated busses. We have added two preliminary sketches of supports, (Figs. 8 and 9). The type which is cheapest to use depends a good deal upon the type of labor employed. Where skilled and experienced labor is used on the job, Fig. 8 requires less material and would probably be cheapest to install. Where the labor is not particularly skilled or fast, or where labor costs are high, Fig. 9, although it requires more material, takes very little time to mount and would not be as expensive per ampere of current carried as the clamp now used for laminated busses. Neither one of these supports is particularly difficult to handle, nor is it particularly difficult to make taps to this bus since there is room for strap copper or lug connections on the surface of every bar. When these supports are used on the form of bus shown in Fig. 6c, the bar nearest the support may be omitted without changing the method of mounting.

In presenting this paper we have hoped to give a ready reference through which engineers may choose the type of bus best adapted for their needs without any involved calculations which they have neither time nor inclination to make. In conclusion, let us state that although the Electric Power Club Standards call for the maximum of 30 deg. cent. temperature rise and the busses given are designed on this basis, nevertheless, a number of years' experience has shown that a 40-deg. temperature rise gives no trouble due to oxidation when reasonably good connections are made. Especially is this true when the ambient temperature is nearer to 25 deg. than to 40 deg. cent.

Motor Band Losses

BY T. SPOONER[1]

Member, A. I. E. E.

Synopsis.*—It is shown that railway motor band losses are of appreciable magnitude, sometimes sufficiently large to be detrimental to the cooling of the machine. By tests of a small machine checked against those of a large one, the band losses are found to vary according to the 1.7 power of the frequency and from the 1.35 to the 1.8 power of the induction, depending on the width and type of band. These losses are shown to be due chiefly to the change in the radial component of the flux as the band passes by the pole tip. For average bands, about 15 per cent of the losses (hysteresis and eddy) are due to the tangential flux in the bands. A typical set of curves is shown for calculating band losses.*

* * * * *

IN most types of rotating electrical apparatus, the rotor windings are held in position by some sort of slot wedge. However, in the case of d-c. railway motors, it is almost universal practise, (in this country at least), to hold the rotor windings in the slot by means of wire bands. These bands, when over the core material, are placed in shallow slots in the core. They are from ½ in. to ¾ in. wide and are spaced approximately three in. apart. Much wider bands are often used over the end windings but in this paper we shall be concerned only with the bands over the core.

It is often assumed that the band losses are so small as to be negligible; and even if they are not negligible, the heat is readily dissipated, since the bands are on the surface of the rotor. As a matter of fact, band losses are sometimes of quite considerable magnitude and they occur adjacent to the windings, thus preventing loss of heat from the windings and teeth, even though they do not actually transfer heat to these parts. Moreover, the band losses may materially heat the cooling air in the air-gap, thus making it much less effective.

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BAND CONSTRUCTION

There are many kinds of band construction and band materials in use, but here we shall deal with only three or four common types. The steel banding wire for the experiments to be described had a diameter of either 0.0453 in. or 0.0641 in., and a resistivity of about 18.5 microhm-centimeters. The bands were wound on a 0.0125-in. soft iron, tinned strip which, in turn, was insulated from the core by means of a strip of asbestos tape. In order to reduce the band losses, in some cases each band was divided into two sections, each section having its own strip and the two sections insulated from each other. The wires of each band or

section were held together by clips of 0.0125-in. soft iron about ½ in. wide, spaced approximately every three inches. The wires were wound on the armature under considerable tension and the wires, strips and clips were soldered together. The solder was of pure tin, having a resistivity of about 13 microhm-centimeters.

Factors Affecting the Band Losses

The problem of band losses is much more complicated than is evident from a first inspection. So far as the phenomena have been analyzed, the following factors enter into the problem:

a. Width of bands
b. Width of teeth at air-gap
c. Size of band wires
d. Amount of solder used
e. Dimensions of tinned strips and clips
f. Normal resistivity of wire, solder and tinned strips
g. Temperature of bands
h. Frequency
i. Induction
   1. Tooth (radial)
   2. Band (tangential)
j. Field form
k. Air-gap
l. Depth of band groove

If the bands are not insulated from the core, the losses due to the bands may be anywhere from the insulated values to many hundred per cent higher, the values depending on the intimacy of contact between the bands and laminations. The following discussion assumes perfect insulation from the teeth.

There are several types of band loss for a given total armature flux which may be classified as follows:

1. Eddy-current losses in band wires, solder and tinned strip, due to radial flux.
2. Eddy-current losses in band wires, solder and tinned strip due to tangential flux.
3. Normal hysteresis loss in band wires and strip due to tangential flux.
4. Additional hysteresis losses due to displaced hysteresis loops.
5. Additional armature tooth loss (eddy-current) due to the damping out of flux by the bands in the region of the pole tips, thus producing flux across laminations which may result in extra eddy losses.

The eddy-current losses which occur in the bands themselves, due to item 1, (radial flux), are by far the most important, as can be shown by a few simple calculations from data available. The induced voltage in the bands has much the same wave form as given by the familiar case of an exploring coil surrounding a tooth and connected to an oscillograph. It has, in general, two large positive humps, followed by two large negative humps, with many intervening ripples. The large humps are produced when the tooth passes a pole tip and their shape and magnitude are a function of the shape of the pole tips.

The tangential fluxes passing from one pole tip to the next, through the bands, are usually of much higher flux density than the radial fluxes, but due to the small thickness of the bands, the eddy-current losses are small. However, the hysteresis losses correspond to the tangential flux; namely, the maximum induction.

The bands are subjected to an elliptical field and we shall assume that the hysteresis loss is the same as would be produced by the maximum tangential induction acting under alternating flux conditions. This tangential flux is a maximum in the position just before the band passes under the pole tip. It is lower at a position midway between the poles and zero at the center of the pole. This decrease in flux at the mid-point between the poles produces a minor hysteresis loop. Since this loop is greatly displaced from the normal position, there results appreciable increase in the hysteresis losses.

Due to the eddy currents in the bands, caused by the radial flux and the consequent damping out of the flux through the bands, the air-gap flux must tend to pass around the bands, giving decreased relative induction in that portion of the tooth under the bands. These fluxes tend to become uniform again under the bands, thus producing a flux component at right angles to the plane of laminations which may produce appreciable eddy-current losses.

Test Apparatus

The test results to be described were obtained chiefly on a typical small four-pole railway motor direct-coupled to a d-c. shunt motor. Two armatures were provided with the following dimensions:

	Armature A.	Armature B.
Diameter	9 in.	9 in.
Length	7 "	7 "
Number of slots (open)	31	16
Slot width at air-gap	0.370 in.	0.635 in.
Slot pitch at air-gap	0.911 "	1.77 "
Slot depth	1.00 "	1.50 "

The armatures had three band grooves 0.125 in. deep and 0.75 in. wide. The motor was provided with two sets of poles, one normal and the other chamfered 1/16 in. at each tip. The bands consisted of fourteen turns each of 0.0453 in. wire or eight turns each of 0.0641 in. wire. Both single and double bands were used for the larger size of wire. In the case of the double bands, each section had four turns.

Test Methods

Tests were made with three air-gaps; namely, 0.1 in., 0.2 in. and 0.3 in. and three speeds; 600, 1200 and 1800 rev. per min., corresponding to 20, 40 and 60 cycles respectively. Chamfered poles were used with 0.0452 in. and 0.0641 in. bands and 0.1 in. air-gap only.

The d-c. drive motor was supplied by a storage battery. No-load losses were determined with the bare armature for the various air-gaps and for various field excitations. The armature flux-per-pole was determined for various excitations by means of an exploring coil and d-c. voltmeter connected through a synchronous contactor. Corresponding maximum armature tooth inductions were determined ballistically by means of a tooth exploring coil and a ballistic galvanometer. Also the r. m. s. tooth voltages were determined by means of the tooth exploring coil and a Paul dynamometer type voltmeter which had a very small frequency error. From a previous investigation, data were available for the actual tooth-voltage wave forms as obtained by oscillograph.

In order to determine the tangential inductions in the bands the exploring coil was wound on the center band between two teeth. The motor field was reversed and the band inductions obtained ballistically. This was done for various field strengths for the position opposite the center point between the poles and for the position of maximum tangential induction, namely, with the exploring coil a little beyond the tip of the pole. Also a curve was obtained for one field strength and the various air-gaps between tangential band induction and armature position for a rotation of 90 electrical degrees.

Test Results

While the test results are referred to the average tooth-top induction, since this factor probably correlates best with the band losses, it should be remembered that the actual radial band inductions are considerably less and sometimes only about one-half the values corresponding to the average tooth top induction, due to the greater reluctance produced by the band grooves.

Fig. 1 shows some typical curves for tangential band inductions, which inductions are chiefly responsible for the hysteresis losses. The radial flux is, of course, approximately proportional to the tooth-top inductions and has nearly the shape of the field form. Fig. 2 shows some typical band-loss data for armature A, with the armature core, tooth and pole-face losses included for comparison. It will be noted that in one case the tinned strip was omitted from under the band wires.

Fig. 3, plotted on double log paper, shows band-loss calculation curves for a 0.0461-in. insulated band, eight wires wide. This method of plotting makes a very convenient form in which to have the results, since the losses vary approximately exponentially with frequency and induction. From theoretical and somewhat meager test considerations the band losses apparently vary about as the square of the band width. If desired, another curve could be added to Fig. 3, giving a factor to take care of the width.

It was found that the band losses varied only slightly with air-gap for a given armature flux, due probably to the fact that with larger air-gaps, though the radial flux increased, the rate of flux change became less, thus giving a relatively smaller induced band voltage. Also pole chamfering had only a small effect due to the fact that while the maximum individual voltages were less, the maximum tooth inductions were greater for the same total pole flux.

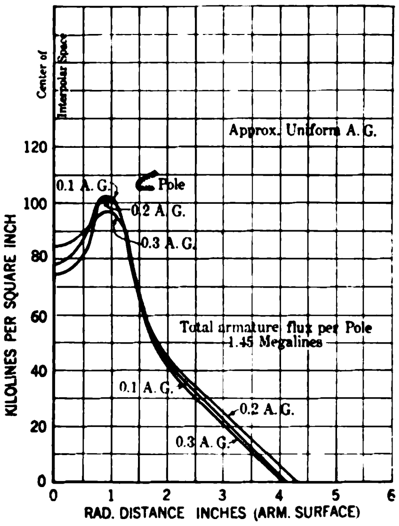

Fig. 1—Tangential Band Inductions—0.0641 Bands

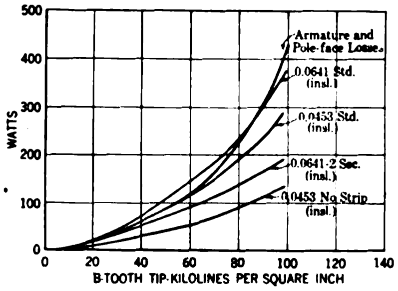

Fig. 2—Band Losses for D-C. Railway-Motor Armature "A" 0.2 Air Gap—1200 Rev. per Min.

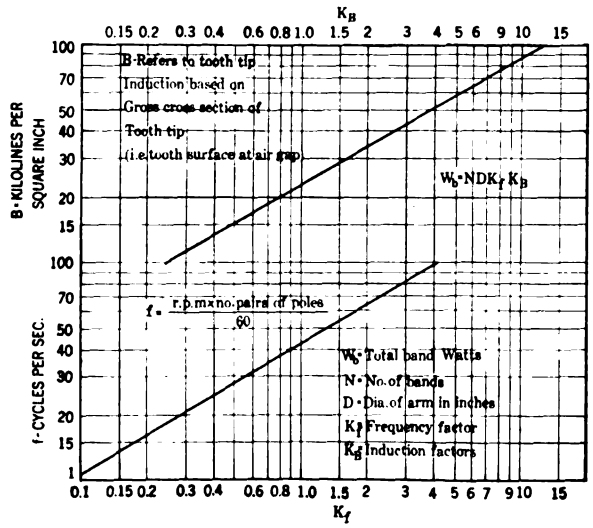

Fig. 3—Band Losses for D-C. Railway-Motor Armature 8-0.0453 in. Diameter Wires— One Sec. Strip

The following table gives the band loss coefficients, tooth-induction and frequency exponents for the *A* armature.

TABLE I
BAND LOSS COEFFICIENTS AND EXPONENTS
Coefficients are for 1200 rev. per min. (40 cycles), 80 kilolines tooth tip induction, and 0.1 in. air-gap.

Band (Diameter of wires-in.)	Coefficient	Exponents Frequency	Tooth Induction	Remarks
0.0453 in.	71	1.71	1.52	No strip
0.0453 in.	230	1.71	1.63	Strip
0.0641 in.	238	1.67	1.73	Strip—one sec.
0.0641 in.	188	1.85	1.87	Strip—ch. poles
0.0641 in.	180	1.68	1.34	Strip—two sec.

The coefficients are the total losses due to the presence of the bands for the specified conditions. There is some variation in exponents and coefficients for various air-gaps and frequencies. The values given are the mean results for the exponents. Tests on a much larger machine gave approximately the same results.

In order to show the relation between the various band losses, the hysteresis losses due to the tangential fluxes were calculated for certain conditions as follows: 0.0641 in. bands (one section), 60 cycles, 80 kilolines/sq. in. tooth-top induction and 0.2 in. air-gap.

Tangential eddy current loss	= 43	watts
Hysteresis loss	= 23	watts
Sum	= 66	watts
Actual test loss	= 470	watts.

This indicates that for these conditions 85 per cent of the loss is due to the radial flux.

It would normally be assumed that wider teeth would produce higher band losses. Tests obtained with the *B* armature, however, having only 16 as against 31 teeth and correspondingly wider tooth tops, gave approximately the same band losses. By means of a ballistic exploration of the tooth-top inductions over the leading and trailing portions of the teeth as they passed by the pole tips, it was found that most of the change in flux as a point on the tooth top passed the pole tip occurred over a distance equal to less than one-half the tangential width of the tooth top for the *B* armature. This means that for these particular poles a tooth top width of from 0.5 to 1 inch or over will give approximately the same band losses. For still narrower teeth there might be considerable difference.

Some tests made on the experimental and other machines show that if the bands are not insulated from the core, very much larger losses than normal will occur. The armature laminations are short circuited on the shaft and the bands touching the laminations at the periphery complete an electrical circuit, which may make a very good path for induced currents. It was found possible to produce losses of several kilowatts in the small 7 x 9 armature by this means. It is possible to apply uninsulated bands without producing these extra losses but only in the case that the slot windings are so thick radially that the bands do not touch the core. In practise, this procedure is not possible and there is a general tendency toward the use of insulating materials even though most of the band tension is carried by the coils.

Discussion of Results and Conclusions

The eddy currents in the bands due to the radial flux which are chiefly responsible for the band losses are undoubtedly of sufficient magnitude to appreciably hinder the change of flux as the band passes under the pole tip. This is analogous to skin effect. It will be noted that at low and moderate inductions, the two-section bands have nearly as much loss as the wide single-section bands, although theoretically the losses for the former should be ¼. This is probably due partly to the fact that the losses for the wide bands are reduced by skin effect at the lower inductions. At the higher inductions, the magnetizing forces become so great that the damping effect of the eddies becomes less important and relatively more radial flux passes through the wide bands, thus giving a higher induction exponent for the wide bands than for the narrow. Again due to these damping currents, flux may pass around the bands under certain conditions, thus altering the eddy-current losses in the teeth by producing flux components at right angles to the tooth laminations. This is purely speculative. These induction exponents are lower than would be expected. It may be that heating of the bands has much to do with it.

The frequency exponents are less than two, due, undoubtedly, partly at least, to the skin effect in the bands.

It has been impracticable so far to derive a theoretical mathematical formula for calculating the band losses caused by the radial component of flux. This is an interesting problem for anyone mathematically inclined. The chief difficulty, even without assuming any damping effects, is to determine the most probable path of the eddy currents in the bands.

Considerable reduction in band losses may be effected by omitting the metal strip under the wires, but this gives less satisfactory construction from a mechanical standpoint. The insulation under the bands can not be dispensed with safely in all cases.

Non-magnetic band wire may be used if desired, but due to its inferior mechanical properties and slight effect on the band losses, its use is probably not justified.

A band wire and a solder of high electrical resistance would be of considerable advantage if they were otherwise suitable.

In large railway motors, the band losses may, under certain conditions, amount to two or three kilowatts and are therefore not negligible. Band temperatures up to 200 deg. cent., or more, may occur. At very high inductions the band temperature may increase so rapidly that the rate of increase of band losses with induction will sometimes decrease very considerably due to the increased resistance of the bands.

A New Edition of A. I. E. E. Standards

BY F. D. NEWBURY[1]

Fellow, A. I. E. E.

Editor's Note. The following article was prepared by Mr. Newbury in July and was first published in the September issue of *The Electric Journal.* It has been revised in some minor respects to bring it up to date and is published here in order to extend the knowledge of the new Institute Standards to a still wider circle of engineers.

THE American Institute of Electrical Engineers is now issuing a new edition of its Standards that involves a complete change in form of publication and many important changes and additions in subject matter. This is an event of importance to the electrical industry and engineers generally should become familiar with these new Standards. The purpose of this brief article is to bring the subject to the attention of engineers and point out some of the major changes that have been made.

Since the first publication of Institute Standards, more than twenty-five years ago, there have been only two other revisions that compare with the present one in scope and importance. In December, 1914, a complete revision was published which had been initiated by the extensive program of papers presented at the first Midwinter Convention in February 1913. This first revision was notable for the new material it introduced: the hot spot principle in determining limiting temperature rises; the classification of insulations according to safe temperature limits; the single 50 deg. rating without overload for rotating machines and the use of the embedded temperature detector method of measuring temperatures in large alternators. This revision definitely extended the scope of the Standards to include other types of apparatus than rotating machines and transformers, with which the earlier editions had been principally concerned.

The second major revision appeared in 1921. The Standards were completely revised in form and arrangement but only minor changes in substance and additions of new sections were made. This change in form consisted of the separation of the Standards into chapters containing general material applying to all types of machines, and apparatus, and chapters containing specific material applying to a particular type of apparatus. There were three of these general chapters; one on General Principles on which the Standards are based, a second on General Rules (applying to all types of apparatus), and a third on General Definitions. These general chapters were followed by thirteen chapters, each dealing with a specific type of apparatus or a specific branch of the electrical art, as, for example, rotating machines, transformers, control apparatus, wires and cables, etc.

It is perhaps worthy of note that two of the three major revisions (the third being the present one) have followed an extensive reorganization of the Standards Committee, itself.

The 1914 revision was carried out by the committee appointed August 1, 1913, which was considerably enlarged in order to permit the formation of subcommittees to care for various parts of the work. Six subcommittees were appointed to deal with such subjects as rating, (with particular reference to machines and transformers), telegraph and telephone standards, railway standards, nomenclature and symbols, wires and cables, and control apparatus. This was the first recognition, in the organization of the Standards Committee, of a major interest in Standards other than machines and transformers. Permanent subcommittees, each responsible for a part of its work, were a feature of the Standards Committee organization from that time to 1922. With the gradual increase in the scope of the Standards Committee's interests, the membership grew until in 1921-22 there were 37 members. The organization of the American Engineering Standards Committee and the increasing interest of other societies in standardization brought up many problems of policy and procedure. The consideration of these questions necessitated frequent meetings and an experienced membership familiar with the increasing complexity of organization relationships and the policies involved.

To meet these new conditions, the Standards Committee was completely reorganized by the Board of Directors of the Institute and the Committee appointed August 1, 1922, centers about a small executive committee which meets monthly or more frequently, if necessary. The formulation of Standards is entrusted to representative working committees. Each working committee is appointed for a specific task, and is discharged when that task is completed. Non-members of the Institute may be appointed on Working Committees.

Since this reorganization in 1922, thirty-nine working committees have been appointed and several hundred engineers have been actively connected with the preparation of Standards. But the regular business of directing the work has been in the hands of the small executive committee of from ten to 15 members. The Standards Committee consists of the Executive Committee, all the chairmen of active working committees and various Institute representatives on other standard-

1. Manager, Power Eng. Dept., Westinghouse E. & M. Co. Member Executive Committee, A. I. E. E. Standards Committee.

izing committees. This is a fluctuating membership and has included as many as fifty members. The principal function of the Standards Committee is to vote on the adoption of Standards completed by working committees. Thus, there are three elements in the complete organization: a small executive committee to direct the work, a flexible organization of working committees to formulate standards, expanding and contracting with the volume of work to be done, and a relatively large Standards Committee of experienced members to pass on a standard before it is approved. This form of organization has met the requirements successfully during the past three years, and, so far as can be seen at the present time, will continue to function successfully under conditions as they may be anticipated to develop in the future.

It was believed when the 1921 edition was approved that the new arrangement of the Standards would facilitate their use and make it possible to readily make changes and additions as they became necessary. Experience, however, soon developed certain defects in this edition that completely overshadowed these expected advantages.

The separation and amplification of the material in the chapter on General Principles gave this theoretical groundwork of the Standards an undue importance. The standard figures for total hottest spot temperature limits and the conventional allowances (the assumed temperature differences between hottest spot temperatures and observable temperatures) were applied too rigorously. The principle, for simplicity's sake, assumed a single value of conventional allowance for a given method of temperature measurement; actually this temperature difference varies with the total temperature, the kind of insulation and the type and dimensions of the construction employed. Many conflicts arose in determining limiting temperature rises; the rigid application led to one figure while practical experience led to a different figure. These experiences developed a strong sentiment in favor of making the application of the principle of hottest spot temperatures less rigid in arriving at practical working standards.

It was also found that the new arrangement of material adopted in the 1921 Edition of the Standards made the Standards actually less convenient in their every-day use. The material relating to any specific type of apparatus—and this was particularly true in the case of rotating machines and transformers was separated and the user of the Standards might have to look in three different chapters for the information he sought. A strong feeling developed that the material for each major class of machinery or apparatus should be collected in one place. Engineers interested in transformers, for example, prefer a single inclusive chapter on transformer standards rather than one chapter for certain general definitions, such as Classes of Insulation, another chapter for other general definitions of interest to transformer engineers, still another chapter for certain temperature limits and other rules of general application, and a fourth chapter for other temperature limits and other specific transformer standards.

The increasing scope of electrical standards and the increasing number of technical and commercial organizations interested in the subject has gradually developed the necessity of dividing the single book of A. I. E. E. Standards into a sufficient number of separate sections or pamphlets, so that the Standards for each major type of machinery or apparatus could be printed as a separate pamphlet that would be, as far as practicable, complete in itself, and could be revised without reference to any other Institute Standard. This separation of the complete body of Institute Standards into a number of separate publications had advantages, not only from the standpoint of time of revision, but also from the standpoint of the different organizations interested in different standards. There are a large number of organizations interested in one or more subjects dealt with in the A. I. E. E. Standards, but no other organization is interested in the whole body of A. I. E. E. Standards.

A final criticism of the 1921 Edition concerns the grouping of standards relating to rating and testing with standards and recommendations relating to safe operation under service conditions. The distinction between a standard test rating and permissible outputs under various conditions met with in service may require explanation and illustration. A standard "test rating" of a machine is based on its capacity under certain standardized test conditions. These are relatively simple and capable of exact definition as is required by their purpose. Two of the most important test conditions are cooling air temperature and altitude. The standard test conditions are intended to be the same as the corresponding conditions usually found in service, but the test conditions are few in number and limited in range while service conditions are infinite in variety and in combination, and vary widely in numerical values. Thus, according to the Institute Standards, tests to determine the test rating shall be made with the cooling air temperature between the limits of 10 deg. and 40 deg. and at an altitude between the limits of sea level and 1000 meters. These are "standard test conditions" and likewise "usual operating conditions." But users of electrical apparatus are interested in the outputs that can be taken safely from apparatus at various air temperatures and altitudes within and beyond the limits of standard test conditions and under other than normal conditions of voltage, frequency, power factor, etc. This has led to the demand for rules or recommendation for "operating recommendations" for conditions of service other than standard test conditions. As a simple example of this distinction between rating under standard test conditions and permissible output under various conditions encountered in service, consider a

motor having a "test rating' of 10 h. p. This is the usual nameplate rating. The same motor may also have the following permissible outputs under the given conditions:

8.5 h. p. at 50 deg. air temperature and 1000 meters altitude
8 h. p. at 4000 deg. meters altitude and 40 deg. air temperature
11.5 h. p. at 25 deg. air temperature and 1000 meters altitude
10 h. p. at 25 deg. air temperature and 2500 meters altitude

These numerical values are illustrative only; no official action has been taken to standardize such values.

There still exists some mixture of rules for rating and testing under standard test conditions and rules or recommendations for operation under service conditions in the new revision of the Institute Standards, but this edition has been greatly improved in this respect. A great deal of confusion has existed, and, to a degree, still exists in the rating situation because of a failure to distinguish clearly between a test rating, established for purposes of comparison between machines or equipment or between equipment and specifications, and the actual loading of machines and apparatus in service. Engineers, interested in the further development of electrical standards are working on this problem, and a Working Committee of the Standards Committee has been appointed to study the problem of formulating rules or recommendations concerning the performance of apparatus under service conditions.

In the new edition of the Standards, there will be, when it is completed, more than forty separate sections or pamphlets, each dealing with one major type of machinery or apparatus. Any combination of these sections can be supplied in a loose-leaf binder to suit the interests of any engineer. The following lists give those sections that are completed and those that are in an advanced stage of preparation:

Available Adopted Sections.

No. 1. (April 1925) General Principles upon Which Temperature Limits are Based in the Rating of Electrical Machinery.
5. (July 1925) Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.
7. (July 1925) Standards for Alternators, Synchronous Motors and Synchronous Machines in General.
8. (March 1925) Standards for Synchronous Converters.
10. (July 1925) Standards for Direct-Current and Alternating-Current Fractional Horse-Power Motors.
11. (July 1925) Standards for Railway Motors.
13. (August 1925) Standards for Transformers, Induction Regulators and Reactors.
14. (March 1925) Standards for Instrument Transformers.
15. (Dec. 1924) Standards for Industrial Control Apparatus.
16. (July 1925) Standards for Railway Control and Mine Locomotive Control Apparatus.
19. (July 1925) Standards for Oil Circuit Breakers.
22. (July 1925) Standards for Disconnecting and Horn-Gap Switches.
30. (August 1925) Standards for Wires and Cables.
34. (June 1922) Standards for Telegraphy and Telephony.
36. (June 1922) Standards for Storage Batteries.
37. (July 1925) Standards for Illumination.
38. (March 1925) Standards for Electric Arc Welding Apparatus.
39. (July 1925). Standards for Electric Resistance Welding Apparatus.
41. (July 1925) Standards for Insulators.
42. (March 1924) Standard Symbols for Electrical Equipment of Buildings.

Sections in Preparation.

No. 2. Standard Definitions and Symbols.
4. Standards for the Measurement of Test Voltages in Dielectric Tests.
9. Standards for Induction Motors and Induction Machines in General.
12. Standards for Prime Mover and Generator Units.
20. Standards for Air-Circuit Breakers.
21. Standards for Lever Switches and Enclosed Lever Switches.
27. Standards for Switchboards.
28. Standards for Lightning Arresters.
29. Standards for Electric Railways.
33. Standards for Electrical Measuring Instruments.
35. Standards for Radio Communication.

(Sec. 1)—General Principles

The importance from a practical standpoint of the "General Principles upon Which the A. I. E. E. Standards Are Based" which appeared as Chapter 1 of the 1922 Edition has been very considerably reduced. The impossibility of rigidly applying the principle to many practical cases has been mentioned before. This basic material is of very considerable value to those interested in the formulation of standards but it has led to confusion when the attempt has been made to use it in working standards. In the new edition this material is included as Section 1 but it does not have the force or standing of rules for rating or testing. To quote the preface of this new section: "The limits of temperature and temperature rise given in this pamphlet are not limits for the rating or testing of electrical machinery. The pamphlet deals with the general considerations upon which rating limits are based."

The only temperature limits given in the revised Standards (with the exception of certain operating temperature limits given for traction motors) are the limiting temperature *rises* corresponding to the standard test rating. Total hottest spot temperatures for the different classes of insulation, conventional allowances, and the corresponding total observable temperatures have been completely eliminated from the sections dealing with machinery or apparatus standards.

In the A. I. E. E. Standards from the 1914 to the 1922 Editions inclusive, the Institute recognized three methods of temperature measurement and only in a few instances was one method definitely specified in a particular application. In the 1922 Edition, for example, Section 1001 states:

"The General Principles stated in Section 1000 permit the use of whichever method (of temperature measurement) is best suited to the class of machine, or part thereof to be tested, by introducing appropriate values for the limiting observable temperature by each method."

Table 200, Section 2230 indicated in many important instances temperature limits for both thermometer and resistance measurements and therefore, according to A. I. E. E. standards, either method could be required in an acceptance test unless the purchaser and manufacturer had agreed on a more definite program in some other way.

In distinction to this indefinite program regarding the application of the several recognized methods of temperature measurement in previous editions, the 1925 standards definitely specify the method (or, in some instances, the two methods) that shall be used in each case.

Some of the more important additions and changes made in the various sections are given in the concluding part of this article. To give all of the important change would be impossible within reasonable space limits and the reader is referred to the standards themselves for more complete information.

(Sec. 5)—Standards for Direct-Current Generators and Motors

(1) Limiting Temperature Rises. No changes have been made in temperature rises as specified in previous editions. The temperature rise for insulated windings is 50 deg. measured by thermometer. The unsettled situation existing in connection with the standard rating of general purpose motors is recognized by the following note appearing with the table of limiting temperature rises:

"The temperature limits on which the rating of general purpose motors is based are under discussion at the present time and no agreement has yet been reached. In order that work being done in this connection may not be influenced or impeded, the Institute refrains from taking any action at the present time towards revising its rules for this class of machinery."

(Sec. 2)—Shutting-Down Machine at End of Temperature Test. In d-c. machines it is very difficult to correct temperatures taken on the rotating part after shut-down for the decrease in temperature that occurs during shut-down. In order to more completely standardize the conditions of test a new rule has been added requiring machines to be shut-down within definite times. Up to and including 50 kw. this is one minute; up to and including 200 kw. it is two minutes and for still larger machines three minutes.

(Sec. 3)—Successful Commutation Defined. A new definition is included that recognizes normal maintenance as the criterion of successful commutation.

(Sec. 4)—Brush Friction. Conventional values of 8 watts per sq. in. of brush contact surface per 1000 ft. per min. peripheral speed for carbon and graphite brushes and 5 watts for metal graphite brushes are established for calculation of brush friction. If these values are not acceptable to either party the brush friction is to be measured as heretofore.

(Sec. 5.) Stray Load Losses. A very important change has been made by including stray load losses in the total losses from which the conventional efficiency is determined. These are calculated as one per cent of the output for all loads; *i. e.*, 1 per cent of the rating at full load and 0.05 per cent of the rating at half load. This new rule does not apply to motors of 200 h. p. at 575 rev. per min. and smaller. This new rule will operate to reduce the full load efficiency, which is as usually specified, one per cent.

(Sec. 7)—Standards for Alternators and Synchronous Motors

(1) Limiting Temperature Rises. Two tables of limiting temperature rises are given, one for steam-turbine driven alternators and a second for other synchronous machines. For both classes of machines, rises by embedded detectors (between coil sides) are 60 deg. for Class A insulation and 80 deg. for Class B insulation. The option of using higher temperature rises for Class B insulation (if such higher figures are the subject of special guarantee by the manufacturer) permitted by the 1914 to 1922 editions (inclusive) has been eliminated in this edition. For steam-turbine generators the limiting temperature rise of the rotor winding is 90 deg. by resistance for Class B insulation; and for lower speed synchronous machines the corresponding figures for field windings are 60 deg. and 80 deg. for Class A and B insulation, respectively. An important change has been made in the method of temperature measurement; all insulated field winding temperatures are now to be measured by resistance.

The detector method of measurement has been specified for turbine generators above 750 kv-a. in rating and for other machines above 1500 kv-a. These limits replace the 20-in. core length used in previous editions.

These limiting temperature rises and methods of measurement were adopted as international standards at the recent Hague meeting of the I. E. C., with the exception that the detector method was specified for use only on much larger machines.

This national and international agreement on Class B insulation temperature rises is a very important step forward and is a matter of congratulation among engineers interested in this class of machinery.

(2) Zero Power-Factor Method of Loading for Temperature Tests. This method of loading has been rapidly growing in favor during the past ten years and is now recognized as an approved method in this edition of the standards.

(3) Short Circuit Requirements. It is definitely specified that all synchronous machines shall be capable of withstanding short circuit when tested under conditions of no-load rated frequency and 110 per cent rated voltage. The higher voltage is intended to

compensate for the difference between no load and rated load flux.

(4) *Variations in Armature Current* present in synchronous motors driving air compressors or other machinery with reciprocating parts is limited to 66 per cent of rated current. This value was first adopted by the Electric Power Club and the American Society of Refrigerating Engineers and was accepted by the A. I. E. E. Committee.

(SEC. 8)—STANDARDS FOR SYNCHRONOUS CONVERTERS

(1) *Limiting Temperature Rises.* The temperature rises are unchanged, except that the 65 deg. rise previously specified for commutators of all commutating machines has been reduced to 60 deg.

(2) *Shutting-Down Converter at End of Temperature Test.* A rule similar to the one previously discussed in connection with d-c. machines is added. A single limit of three minutes for all converters is specified. A single limit is permissible on account of the relatively large size of the converters.

(3). *Successful Commutation Defined.* The same new definition is given for converters as for d-c. machines.

(4) *Power Factor Limitations.* A new requirement is added to the effect that all converters rated at unity power factor shall be capable of operating without dangerous heating at 98 per cent power factor. This is intended to provide only against unintentional departures from unity power factor.

(5) *Brush Friction.* The same conventional method of determining brush friction, as provided in the d-c. machine section, is included in the converter section.

(6) *Stray Load Losses.* Stray load losses are included in the conventional efficiency as one per cent of the output. In previous editions, the stray load losses were omitted. This change will have the result of reducing efficiencies, as previously calculated, 1 per cent at full load.

(SEC. 10)—STANDARDS FOR FRACTIONAL HORSE POWER MOTORS

In previous editions of the Standards fractional h. p. motors have not been distinguished from larger motors of the same types. The standards included in this section are essentially the same as for larger motors, except where the difference in size has led to different practise, as, for example, in the case of small motors, the input-output method of efficiency determination is the preferred method. The present situation, regarding the rating of general purpose motors, is recognized by the insertion of the same note, as quoted in the comments on the Direct-Current Machinery Section.

(SEC. 11)—STANDARDS FOR RAILWAY MOTORS

This section is of more than usual interest, because the Working Committee responsible for it has included in it some operating recommendations, but this has been done in a way that clearly distinguishes them from the rules concerning the standard test rating.

In a section headed "Service Conditions," there is a table of "limiting observable temperatures recommended for service." These temperatures are given as a guide to operating engineers in the every-day application and use of railway motors. These are total temperatures and include the cooling-air temperature. "Peak Values" corresponding to 40 deg. air temperature and "normal values" corresponding to 25 deg. air temperature are both given. This table is quoted below, so that it may be compared with the temperature rises given later for the test rating:

LIMITING OBSERVABLE TEMPERATURES RECOMMENDED FOR SERVICE

Method of Temperature Determination	Peak Values		Normal Values	
	Resistance deg. cent.	Thermometer deg. cent.	Resistance deg. cent.	Thermometer deg. cent.
Class A Insulation......	125	105	110	90
Class B Insulation......	145	120	130	105

In another part of the Railway Motor Standards are sections on Rating and Heating, referring to the test rating. *Temperature rises* are given for various parts of the motor for a one-hour rating and for continuous rating and for Class A and Class B insulations and for ventilated and totally enclosed motors. For the purpose of illustration the following temperature rises for armature and field windings are quoted:

	Type Enclosure	Method Temp. Meas.	Limiting Temperature Rise: One Hour Rating, Class A	One Hour Rating, Class B	Continuous Rating, Class A	Continuous Rating, Class B
Arm. and Fld Windings......	Ventilated	Resist	100	120	85	105
		Thermo	80	95	65	80
	Totally Enclosed	Resist	110	130	95	115
		Thermo	90	105	75	90

It will be noted that the temperature rises given for the continuous test rating on stand test are equivalent to the limiting observable temperatures recommended for service with average air temperature of 25 deg. cent.

An important change has been made in the standard test conditions regarding ventilation. In the 1922 and previous editions the test conditions included "with the motor covers arranged to secure maximum ventilation without external blower." This resulted in tests being made with "covers off." The revised standards provide that "Motors shall be tested with the covers and cooling system, if any, arranged as in service." This is a change in the direction of agreement between test conditions and "usual service conditions."

These American railway motor temperature rises for test rating were adopted at the recent Hague meeting of the International Electrotechnical Commission.

(SEC. 13)—STANDARDS FOR TRANSFORMERS, INDUCTION REGULATORS AND REACTORS

(1) *Altitude Correction.* For air-cooled oil-immersed apparatus the correction for temperature rises observed at high altitudes is 0.4 per cent for each 100 meters above 1000 meters instead of 1 per cent as in the previous editions. This change is based on recent experimental work.

(2) *Short Circuit Current of Transformers.* A new requirement is included that transformers shall be capable of withstanding, without injury, for two seconds a short circuit across the secondary terminals under specified service conditions. Exceptions are made in the case of auto-transformers, certain low reactance transformers, and transformers which are to be directly connected to other apparatus possessing inherent reactance.

(3) *Dielectric Test Voltages.* Important new material appears in the revised Standards concerning transformers with graded insulation and transformers tested by induced voltage. Transformers having windings with graded insulation and directly and permanently grounded shall be tested by induced voltage with connections so made that the ungrounded or line terminals shall receive test voltage to ground not less than 2.73 times the normal voltage developed by the winding plus 1000 volts. If this test does not also produce between terminals two times the rated voltage of the circuit plus 1000 volts, an additional test to produce this result shall be made.

When transformers are tested by inducing the required voltage in the winding, frequencies higher than normal are generally employed in order to avoid over-saturation in the core, and also, in the case of large transformers, to enable the test to be made with testing equipment of reasonable size. Recent experimental work by Montsinger at Pittsfield and Vogel at Pittsburgh has shown that the severity of the dielectric test increases with frequency in such rates that, for equal severity, the time should be reduced in the same ratio as the frequency is increased. For purposes of standardization the following times are used for the respective frequencies:

Frequency	Time in Seconds
120 and below	60
180	40
240	30
360	20
400	10

Considerable new material relating to induction regulators has been added to the Standards. Limiting temperature rises, method of loading for temperature tests, short-circuit current, efficiency and losses are included for the first time.

(SEC. 9)—STANDARDS FOR INDUCTION MOTORS
(*in preparation*)

This section is largely a collection of previously existing A. I. E. E. Standards, relating to induction machines. The definitions have been revised and new definitions have been added for the *squirrel-cage induction motor, wound rotor induction motor, induction frequency converter* and *"slip"*.

Shutting-Down Machines at End of Temperature Run. When the stopping time is limited to specified values, no correction of observed temperatures is required. These values are the same as for d-c. machines:

Up to and including 50 h. p.	1 minute
Above 50 h. p. and including 200 h. p.	2 minutes
Above 200 h. p.	3 minutes

Stray Load Losses. The 1922 Standards specified a method for measuring stray load losses in induction machines, but also stated:

"In windings consisting of relatively small conductors, these eddy-current losses are usually negligible."

The specified method of measuring these losses—with rotor removed—has seldom been used in practise, and stray load losses have usually been neglected. In the 1925 revision, the following provisions have been incorporated:

"Stray Load Losses. In induction machines, no allowance for stray load losses shall be included."

A footnote calls attention to the fact that stray-load losses may be considerable, if the primary winding contains conductors more than 3/8 in. in depth in a 60-cycle machine. Modern designs use conductors considerably smaller than this.

Rating of Elevator Motors. A new paragraph has been added which is the same as the previously existing Electric Power Club Standard.

STANDARDS FOR INDUSTRIAL CONTROL APPARATUS

In the 1922 Standards, Industrial Control Standards were grouped with switching, circuit breakers, and protective apparatus. No distinction was drawn between the different apparatus and general conditions existing in the industrial field and in the field of power supply. The separation of these diverse kinds of equipment into a number of separate sections has led to a considerable increase in material and a general improvement in these standards.

The new material in Industrial Control Standards mainly concerns limiting temperature rises, conditions and methods of making temperature tests and limitations other than heating, such as range of operating voltage for contactors, test for operation at minimum voltage, durability test and tests to determine successful operation.

This section has the distinction of being the first section to be given the status of an American Standard under the procedure of the American Engineering Standards Committee. This American Standard was sponsored jointly by the Electric Power Club and the A. I. E. E.

STANDARDS FOR OIL CIRCUIT BREAKERS

Considerable new material relating to rating of oil circuit breakers has been included. This material, while new to the A. I. E. E. Standards, is well established in the practise of the industry.

STANDARDS FOR INSULATORS

This is an entirely new specification, and is the result of painstaking work on the part of a representative group of engineers during the past three years. It is essentially a test specification and prescribes procedure, in considerable detail, for both pin- and suspension-type insulators.

STANDARDS FOR ELECTRICAL MEASURING INSTRUMENTS (*in preparation*)

This is another wholly new standard and is a good example of the cooperation that exists between the technical committees of the Institute and the Standards Committee. This section first appeared as an Institute paper by H. B. Brooks, prepared under the direction of the Technical Committee on Instruments and Measurements. A Working Committee of the Standards Committee is now putting the section in suitable form for approval—using the Brooks paper as a basis.

These are the more important changes and additions to be found in the new edition of the Institute Standards. It is confidently believed that this edition will prove a worthy successor to the long line of older editions, and that it will serve the industry in even greater measure.

ONE GENUINE METHOD OF SOLVING THE AUTOMOBILE HEADLIGHT PROBLEM

Possession of a little card, signifying that the bearer thereof has expended seventy-five cents to have his automobile headlights tested and adjusted, has not solved the problem of automobile headlight glare. On paper the theory sounds very well, but in practise there are a number of conditions which shake its security. Every road bump, every car track, every vibration constitutes one of these mitigating conditions.

It is not enough to conform to the letter of the law once or twice a month by visiting headlight-testing stations. It helps the motorist who has to look into glaring headlights not one whit, if after leaving the testing stand, a jar or a twist will leave the lights of any given car in position to blind everyone into whose range they come. No amount of legislation nor even of testing and adjusting can prevent glare from strong headlights along rolling road-beds.

Like many another panacea, the remedy has been applied to the effect rather than the cause; the fact remains that roads are not ideal in contour, and even perfect adjustment does not prevent a car coming up over a rise in the road from sending its perfectly focused rays full into the eyes of drivers approaching on the other side.

Yet there is a way to remedy the condition that is not dependent on law enforcement. It consists of illuminating the highways scientifically.

Regardless of road conditions, regardless of the condition of the apparatus of the individual cars that traverse them, scientific highway lighting will be uniform.

The idea carries with it commercial possibilities to the electrical industry, naturally, but more than that it will bring satisfaction that the problem is being solved in the best and most sensible way. The success of street lighting, where illumination has been the chief object sought rather than mere ornament, has brought forth as a by-product this vision of highway illumination potentialities. That the headlights of an automobile are practically unnecessary on well-lighted streets has suggested that highways might be made safe in the same manner.

The electrical industry is not the only one which will profit from highway illumination. Tests made recently on a stretch of highway in the East have demonstrated actually by count that without altering the highway traffic could be increased 100 per cent by having them well lighted. Practically all the trucking load upon highways is carried at night. With well-lighted highways the amount of trucking over highways can be increased 100 per cent, the experiment proved, and the highways still remain safe for traveling motorists.—*Journal of Electricity*, November 1, 1925.

KILOCYCLE-METER CONVERSION TABLE

There is increasing tendency in radio practise to use radiofrequencies in kilocycles rather than wave lengths in meters. "Kilo" means a thousand, and "cycle" means one complete alternation. The number of kilocycles (abbreviated kc.) indicates the number of thousands of times that the rapidly alternating current in the antenna, transmitting set, or receiving set repeats its flow in either direction in one second.

The bureau has just issued in chart form a "Kilocycle-Meter Conversion Table." It is Miscellaneous Publication No. 67 and replaces Letter Circular No. 123 of January 27, 1925. The table is printed on a single sheet of cardboard and can be posted in a convenient place for ready reference. (Copies may be obtained for 5 cents each from the Superintendent of Documents, Government Printing Office, Washington, D. C.)

The table gives accurate values of kilocycles corresponding to any number of meters and vice versa. The table gives values for every 10 kilocycles or meters, and is entirely reversible; that is, for example, 50 kilocycles is 5996 meters and also 50 meters is 5996 kilocycles. The range of the table is from 10 to 10,000 kc. (10,000 to 10 m) and this can be extended in either direction by changing the decimal point.

Transmission Systems with Over-Compounded Voltages

BY H. B. DWIGHT[1]

Member, A. I. E. E.

***Synopsis.**—A usual method of calculating a transmission line with transformers, in which the voltage is held constant at both ends by synchronous condensers, is to use the circle diagram method. It is often advisable to use "over-compounded" voltage instead of constant voltage; that is, to increase the voltage as the load increases. Methods of calculation are given in this paper for two cases, first with over-compounded generator voltage and constant receiver voltage, in which case the diagram is a circle, and second, with over-compounded voltage at both generator and receiver, in which case the diagram is an ellipse. Examples are given and the diagrams are shown in Fig. 2.*

A short discussion is given of the advantages and limitations of using over-compounded voltage.

* * * * *

It is a very usual practise to control the station voltages of transmission systems by automatic voltage regulators, which adjust the field currents of generators and synchronous condensers so that the desired voltages are obtained. In such cases, very great advantages are obtained in many stations by maintaining a higher voltage at a time of heavy load than at a time of light load. This may be called "over-compounded voltage," and can be easily accomplished by means of a simple arrangement with an automatic voltage regulator, which is often called line drop compensation. One of the most common methods of producing line-drop compensation is to put a few turns of winding, carrying current from series transformers, on the magnet of the relay which controls the voltage. These series ampere-turns usually amount to not more than about 25 per cent of the ampere-turns of the shunt winding, which is the main winding. Therefore, the result is that, at no load, the main winding operates the regulator so as to produce a certain voltage. With load conditions and the series winding opposing the shunt, a higher voltage is necessary before the regulator will operate; therefore, a higher voltage than at no load is maintained.

A somewhat similar arrangement to give over-compounded voltage is frequently provided with induction voltage regulators.

Advantages of Over-Compounded High-Tension Voltage

The statement is sometimes made that the voltage supplied to a certain customer or city by a transmission system should have not more than a specified amount of variation, say five per cent. Where such a statement is made, it practically always refers to "under-compounded" voltage; that is, the voltage variation is caused by the load and the voltage is low at times of heavy load. It is evident that, if a voltage of 12,000 volts or higher is under-compounded, then circuits of 2300 or 115 volts will be still more under-compounded due to the drop in the intervening transformers and lines at full load. If the higher voltage is over-compounded, then the drop in transformers and lines tends to decrease the variation in the distribution voltage instead of increase it.

It can be stated that, in general, twice as much over-compounding as under-compounding of a circuit of 12,000 volts or higher can be allowed for the same amount of inconvenience and for the same necessity of using feeder voltage regulators. In reality, the circuits which feel the disadvantage of voltage variation most are 115-volt circuits, where changes in voltage are noticeable at once in the changed brightness of lamps. Voltage variation in 2300-volt circuits is often inconvenient mainly because it causes variation in the connected 115-volt circuits. Slightly over-compounded voltage on a motor circuit is not very disadvantageous, for low voltage is most liable to occur out of working hours, when there is light load on the power system. Such an arrangement is the least troublesome, and further, is economical, for the core loss of transformers and motors is reduced during the night when they are giving what is often practically only stand-by service. Good speed and good starting torque and pull-out torque in induction motors are especially desirable when loads are heavy, and these are all helped by over-compounded voltage.

It may be said that over-compounded voltage on circuits operating at greater than 115 volts is more desirable than constant voltage or under-compounded voltage, in almost every case. This is true for practically any customer, city, or place where there are generators, synchronous condensers or induction regulators to give control of the voltage; but it is particularly true of the generating end of long transmission lines. Where there is an appreciable amount of charging current, at no load the equivalent voltage at the generator terminals must be lower than at the load end with no synchronous condensers connected, due to the reactance of the transformers and of the line. However, it would not be economical to operate the generators always at this low voltage, since this would involve greater resistance loss and a larger rating of synchronous condensers if such are used for voltage regulation. The generators at full

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1. Mass. Inst. of Technology.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., Feb. 8-11, 1926.

load should be operated at full rated voltage. It is also, in many cases, inadvisable to operate the generators at constant full rated voltage, for this produces too high a voltage at the distant end at no load, necessitating delay when starting to put the synchronous condensers on the line for even a small amount of load, or for paralleling with other lines. Unduly high voltage increases strain on the insulation and produces trouble in the generating station in handling the charging current. Accordingly, if automatic voltage regulators are used, as is generally the case with long transmission lines, they should, if possible, be adjusted for a moderate amount of over-compounding of the voltage rather than for constant voltage. It is fortunate that the over-compounding is practically proportionate to the true kilowatt load, and is not appreciably affected by the quadrature charging current.

Where there are several generators in a station often only one or two are used to carry the load in the middle of the night. At such time each generator should have less amount of compounding than it would have when the entire station is operating. However, since the over-compounding or line-drop compensation feature can be reduced or cut out by merely turning a dial on the voltage regulator, it is not difficult to do this at times when the number of generators operating in the station is changed. It is also possible to take the current for the series coils of the regulators from a current transformer carrying the total load of the entire station. This will give the same over-compounding for the station regardless of the number of generators in operation.

Most Advisable Amount of Over-Compounding

The question as to how much over-compounding of the voltage should be used in a transmission system is not so much a question of design as of operation, for the over-compounding will be limited in most cases to a comparatively small percentage by operating considerations.

Transmission lines over 100 miles long cost considerably more than the synchronous condensers used to control their voltage. Consequently, it pays to install synchronous condensers sufficient to maintain the line at nearly rated voltage in all parts when it is fully loaded. If the line current at the load end has a very low leading power factor, its resistance loss and, what is more important, its stability will usually be improved by putting part of the synchronous condensers in an intermediate substation.

The voltages to be maintained with long lines at light load and no load will depend mainly on the method considered desirable for starting up the transmission system; whether the generators are to be thrown on the line alone or on sections of it; whether the synchronous condensers are to be started and adjusted for lagging power factor before connecting on any load; or whether the generators are to be brought up from zero speed, together with the synchronous condensers.

With lines shorter than 100 miles, the cost of synchronous condensers becomes of greater relative importance, because the cost of the lines is proportionately less. The cost of condensers is usually compared with the cost of more or heavier transmission circuits.

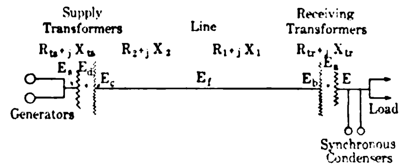

Fig. 1—Scheme of Connections of Transmission System

The question of the amount of voltage variation to be allowed on low voltage circuits depends on the standard set in different localities for different classes of load. This standard is maintained in practical operation by installing more circuits, transformers and induction feeder regulators in the lower voltage parts of the system, as well as by improving conditions in the higher voltage parts.

A certain amount of over-compounding on the higher voltage circuits will generally help to maintain the above standard. How far this can be carried is a matter on which only a small amount of data has been collected or published. An investigation on actual systems as to how much over-compounding can be used under different conditions before real practical disadvantages are encountered would be valuable.

Where there is no load to be supplied close to the generators, over-compounding up to about 25 per cent at the generators can be used. If loads are supplied directly from the generator bus-bars, a smaller amount of over-compounding must be used, the amount depending on whether the power passes once or twice through transformers before it is used by motors or lamps, and on whether the load curve of the local load throughout the day corresponds closely with the load curve of the generator load.

In conclusion, it is generally advisable to use as much over-compounding at any point as experience shows can be used without interfering with the accepted standards of good maintenance of voltage in the different low-voltage circuits of the system. A small percentage of over-compounding can be used on high-tension circuits at load points and a larger percentage, amounting in some cases to as much as 25 per cent, can be used at generating stations.

Calculation of Lines Having Over-Compounded Voltage

A very convenient method of calculating the electrical behavior of a transmission line or system provided with synchronous condensers is to draw the circle

diagram showing the reactive kv-a. required from the synchronous condensers at various loads, the step-up and step-down transformers being taken into account[2]. In the present paper, the method of calculation is extended to cover the case of over-compounded generator voltage and constant receiver voltage, for which case the diagram is a circle. An extension of the calculation is also given to cover the case of over-compounded voltage at both generator and receiver and in this case, the diagram is not circular but elliptical. Examples are given and the resulting diagrams are shown in Fig. 2.

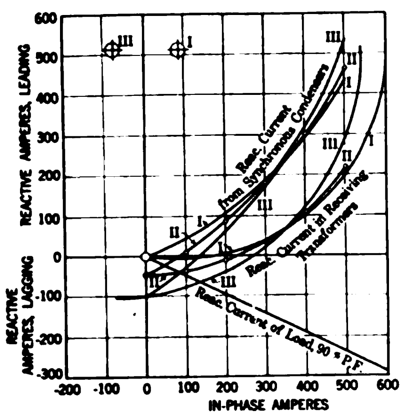

FIG. 2— I. OVER-COMPOUNDING AT GENERATOR END
II. OVER-COMPOUNDING AT BOTH ENDS
III. CONSTANT VOLTAGE AT BOTH ENDS

A solution for the case of over-compounded generator voltage and constant receiver voltage has been published using the method of the equivalent π line[3].

CALCULATION FOR LINE AND TRANSFORMERS, WITH OVER-COMPOUNDED GENERATOR VOLTAGE AND CONSTANT RECEIVER VOLTAGE

Numerical values, except for $(P + jQ)$ which always appears, are to be found for the following quantities:

Current in secondary of receiving transformers:

$$I_a = P + jQ + P_c \text{ amperes per conductor} \quad (1)$$

Voltage induced in receiving transformers:

$$E_a = E + \frac{1}{2} I_a (R_{tr} + j X_{tr}) \text{ volts to neutral} \quad (2)$$

Current in primary of receiving transformers:

$$I_b = I_a + E_a (G_{tr} + j B_{tr}) \text{ amperes per conductor} \quad (3)$$

Voltage at receiving end of transmission line:

$$E_b = E_a + \frac{1}{2} I_b (R_{tr} + j X_{tr}) \text{ volts to neutral} \quad (4)$$

2. "Electrical Characteristics of Transmission Systems," by H. B. Dwight, TRANS. A. I. E. E., Vol. 41, 1922, page 781.

3. "Regulator Settings for Long Lines," by L. F. Woodruff, *Electrical World*, August 30 and September 6, 1924.

Voltage at a point f where the conductor or spacing is changed but not where the voltage is controlled:

$$E_f = E_b \left(1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots\right) + I_b Z_1 \left(1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

volts to neutral (5)

Current at point f:

$$I_f = I_b \left(1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots\right) + E_b Y_1 \left(1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

amperes per conductor (6)

Y_1 and Z_1 are the admittance and the impedance of the line from b to f.

Voltage at supply end of transmission line:

$$E_c = E_f \left(1 + \frac{Y_2 Z_2}{2} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4} + \ldots\right) + I_f Z_2 \left(1 + \frac{Y_2 Z_2}{2 \times 3} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

volts to neutral (7)

Current at supply end of transmission line:

$$I_c = I_f \left(1 + \frac{Y_2 Z_2}{2} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4} + \ldots\right) + E_f Y_2 \left(1 + \frac{Y_2 Z_2}{2 \times 3} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

amperes per conductor (8)

Y_2 and Z_2 are the admittance and the impedance of the line from f to c.

Voltage induced in supply transformers:

$$E_d = E_c + \frac{1}{2} I_c (R_{ts} + j X_{ts}) \text{ volts to neutral} \quad (9)$$

Current in primary of supply transformers:

$$I_d = I_c + E_d (G_{ts} + j B_{ts}), \text{ amperes per conductor.}$$
$$= C + jD = \text{current at generator terminals.} \quad (10)$$

Voltage at generator terminals:

$$E_s = E_d + \frac{1}{2} I_d (R_{ts} + j X_{ts}) \text{ volts to neutral}$$
$$= A + jB$$
$$= E_{os} + L_s I_d \quad (11)$$

Equation for circle diagram:

$$E_{os} = E_s - L_s I_d \text{ volts to neutral}$$
$$= E' + jE'' + (P + jQ)(R' + jX') \quad (12)$$

Quantities required for above equations (referring to a three-phase system):

$P + jQ$ = Load current + reactive current from synchronous condensers. This is always

expressed by letters in the above calculation.

P_c = Current for average loss in synchronous condensers.

E = Equivalent high-tension voltage at low-tension side of receiving transformers, in volts to neutral.

R_{tr} = Equivalent high-tension resistance from line to neutral of receiver transformers.

If the resistance is given in per cent,

$$R_{tr} = \frac{\text{Per cent resistance} \times E^2}{100{,}000 \times \text{kv-a. per phase}} \qquad (13)$$

X_{tr} = Equivalent high-tension reactance from line to neutral of receiver transformers. If the reactance is given in per cent,

$$X_{tr} = \frac{\text{Per cent reactance} \times E^2}{100{,}000 \times \text{kv-a. per phase}} \qquad (14)$$

It is assumed in equations (**2**) and (**4**) that, so far as the magnetizing current is concerned, the transformer impedance is equally divided between the primary and secondary. If the division is more accurately known, the actual values of primary and secondary impedance can be used.

$G_{tr} + j\,B_{tr}$ = Admittance (equivalent high-tension) for core loss and magnetizing current of receiver transformers at average voltage. If these characteristics are given in per cent,

$$G_{tr} = \frac{\text{Per cent core loss}}{100} \times \frac{1000 \times \text{kv-a. per phase}}{E^2} \qquad (15)$$

and

$$B_{tr} = -\frac{\text{Per cent magnetizing current}}{100} \times \frac{1000 \times \text{kv-a. per phase}}{E^2} \qquad (16)$$

B_{tr} is a negative quantity.

The characteristics of the supply transformers are denoted by the letters $t\,s$ as in R_{ts}, etc.

The point f denotes a place in the transmission line where the line characteristics change due to different conductor or spacing. A constant load may be assumed for this point without changing the form of the calculation. However, it is not to be assumed that the voltage is controlled at this point, for if it were, a circle diagram would have to be calculated as far as f, and another diagram for the remainder of the transmission system. Other points g, h, etc., similar to f, can readily be included in the calculation.

$Y_1 = G_1 + j\,B_1$, the admittance of the line from b to f.

$Z_1 = R_1 + j\,X_1$, the impedance of the line from b to f.

The subscript (**2**) denotes the characteristics of the line from f to c, as in Y_2, etc.

The series in $Y\,Z$ are very convergent at commercial frequencies and can be quickly calculated. It may be noted that

$$1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots = \cosh \sqrt{Y_1 Z_1}$$

and

$$1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots = \frac{\sinh \sqrt{Y_1 Z_1}}{\sqrt{Y_1 Z_1}}$$

E_{os} is a quantity whose absolute value is equal to that of the equivalent high-tension voltage at the generator terminals at no load. Only the absolute value of E_{os} is made use of in the calculation in this paper. The phase of the quantity E_{os} changes as the load changes, and so E_{os} cannot be considered as a constant nor as a complete representation of the no-load voltage. The reason for this is that the automatic regulator maintains the absolute value of the voltage according to the last part of (**11**), but it has no power to alter the phase of the voltage.

L_s is a measure of the over-compounding of the voltage, or the line drop compensation. It is equal to the rise in equivalent high-tension voltage produced by one ampere of current (equivalent high tension) in phase with E_s.

Circle Diagram. Since equation (**12**) is of the same form as the equation for a constant-voltage transmission line, a circle diagram may be drawn for the transmission system with over-compounded voltage at the generator end. Since E, the load voltage, is constant, the values of current may be multiplied by

$$\frac{3\,E}{1000}$$

to give kw. and reactive kv-a. as in Reference 1. However, where the voltage is varying, it is desirable to keep account of the current and voltage rather than the kv-a., and so the circle diagram equations are given here in terms of amperes.

The center of the circle is the point (a', b') where

$$a' = -\frac{E'\,R' + E''\,X'}{R'^2 + X'^2} \text{ amperes} \qquad (17)$$

$$b' = +\frac{E'\,X' - E''\,R'}{R'^2 + X'^2} \text{ amperes} \qquad (18)$$

The radius is

$$c' = +\frac{E_{os}}{\sqrt{R'^2 + X'^2}} \text{ amperes} \qquad (19)$$

The circle shows the reactive current at the receiver end of the line plotted on values of in-phase current at the receiver end.

In order to plot the reactive current required from the synchronous condensers, first draw a straight line at angle θ below the base line, where $\cos\theta$ is the power factor, lagging, of the load. If the power factor is not the same at all loads, the line will not be straight, but will be a curve showing the reactive current of the load from no load to full load. By means of a pair of dividers add the reactive current of the load to the corresponding ordinate of the circle, thus plotting the curve of current required from the synchronous condensers. This curve is an ellipse when $\cos\theta$ is constant. (See Fig. 2).

Circle Diagram Limit of Load.

$$\text{Maximum Load} = c' + a' \text{ in-phase amperes} \qquad (20)$$

This is numerically less than c' when a' is a negative quantity, and greater than c' when a' is positive. It may be read from the circle diagram, as it is the farthest distance to the right reached by the circle. It is a useful point to locate on the diagram before drawing the circle, as is also the bottom point of the circle, $(a', b' - c')$. It assists in drawing the circle to have these two points through which the circle is to pass.

The "stability limit" of load is usually somewhat less than the circle diagram limit, and of course, in the operation of a transmission line, neither limit must be reached.

Calculated Value of Reactive Current.

A direct calculation of the reactive current is more precise than a reading from the circle diagram, and is less work than a trial and error method. The value of the reactive current in the circuit, Q, for a given in-phase current P, may be found from the following equation:

$$(b' - Q)^2 = c'^2 - (P - a')^2 \qquad (21)$$

First, find the value of the right hand side of the equation. Then take the square root and subtract b'. The reactive current required from the synchronous condensers is equal to

$$Q + P\frac{\sin\theta}{\cos\theta} \text{ amperes} \qquad (22)$$

where the in-phase current is P amperes and the lagging power factor is $\cos\theta$. It should be remembered that b' is a positive quantity and a' may be positive or negative. It is worth while checking the results of equations (**21**) and (**22**) by drawing the circle diagram and obtaining the same results graphically.

Concentric Circles. Since a' and b' which give the center, are independent of E_{o}, and since the radius c' is directly proportional to E_{o}, a number of circles corresponding to different values of E_{o} may be drawn about the same center.

Total Losses. The losses in the transmission system for a given power load are

$$\frac{3}{1000}(A\,C + B\,D - E\,P) \text{ kw.} \qquad (23)$$

P is determined by the power load. Then Q must be found from the circle diagram or equation (**21**). Then A, B, C and D can be found from equations (**10**) and (**11**), for which numerical coefficients have already been obtained.

Efficiency of the transmission system

$$\text{Efficiency} = \frac{100\,E\,P}{A\,C + B\,D} \text{ per cent} \qquad (24)$$

Kw. at supply end of system

$$\frac{3}{1000}(A\,C + B\,D) \text{ kw.} \qquad (25)$$

Kv-a. at supply end

$$\frac{3\,E_s\sqrt{C^2 + D^2}}{1000} \text{ kv-a.} \qquad (26)$$

Power factor at supply end

$$\frac{100\,(A\,C + B\,D)}{E_s\sqrt{C^2 + D^2}} \text{ per cent} \qquad (27)$$

Reactive kv-a. at supply end

$$\frac{3}{1000}(A\,D - B\,C) \text{ kv-a.} \qquad (28)$$

When this quantity is positive the reactive kv-a. and the power factor are leading, and when it is negative they are lagging.

Over-Compounded Voltage at Both Supply and Receiver Ends of System

The receiver voltage can be over-compounded when there are synchronous condensers, by using exactly the same kind of apparatus as that used to provide over-compounded voltage at the supply end. The diagram in this case is not a circle, but an ellipse, and so values of Q for different values of P are found by calculation.

If L_r is the rise in equivalent high-tension voltage at the receiver end produced by one ampere of current (equivalent high-tension) in phase with E, then

$$E_s = E - L_r\,P - j\,L_r\,Q$$

as in eq. (**12**). The phase of E_s in the above expression changes as the load changes. Its absolute value is equal to that of the equivalent high-tension voltage at the receiver end at no load. P is in phase with E.

The absolute value of E_s is equal to

$$E - L_r\,P + \frac{(L_r\,Q)^2}{2\,(E - L_r\,P)} \qquad (29)$$

$L_r\,P$ is usually less than 25 per cent of E for any load that the line is to carry. If $L_r\,Q$ is 20 per cent of rated voltage, the third term of (**29**) is less than three per cent of E. It is therefore seen that the quadrature current Q has very little effect on the voltage, and the over-compounding of the voltage or the line-drop compensation is practically proportional to the in-phase current or the true kilowatt load.

In the calculations in this paper the third term of (**29**) is neglected, and we write

$$E = E_o + L_r P \qquad (\mathbf{30})$$

Now evaluate expressions (**1**) to (**12**). The quantity $(P + j\,Q)$ will not be a factor as it was in the previous case, but P and Q will now have different numerical coefficients. The final expression as given by (**12**) is

$$E_{os} = E_s - L_s I_d$$

If a numerical value is assigned to P, this becomes an equation in complex quantities involving Q. E_{os}^2 is equal to the square of the real part of the right hand side plus the square of the imaginary part. This is equivalent to multiplying each side of the equation by its conjugate, that is, by a complex quantity equal to itself except that the sign of the imaginary part is changed. The result is an ordinary quadratic equation in Q, of the form

$$a\,Q^2 + b\,Q + c = 0.$$

Q is given by

$$Q = \frac{-\,b - \sqrt{b^2 - 4\,a\,c}}{2\,a}$$

The minus sign of the radical is to be used so as to give the normal working part of the curve, corresponding to the lower part of the circle diagram for constant receiver voltage.

Example I

Draw the circle diagram for the following line and transformers, with constant receiver equivalent high-tension voltage 200,000 volts between conductors, no-load equivalent high-tension voltage 183,000 volts between conductors at generators, and 220,000 volts at generators with in-phase current of 355 amperes.

Length of line = 200 miles.
Frequency = 60 cycles.

$$R + j\,X = 23.2 + j\,160 \text{ ohms.}$$
$$Y = +\,j\,0.00106 \text{ mho}$$

$$1 + \frac{YZ}{2^2} + \ldots = 0.91637 + j\,0.01195$$

$$1 + \frac{YZ}{2.3} + \ldots = 0.97197 + j\,0.00403$$

$$P_c = 8.66 \text{ amperes}$$
$$R_{tr} + j\,X_{tr} = 1.33 + j\,24.0 \text{ ohms.}$$
$$G_{tr} + j\,B_{tr} = 0.000{,}022{,}5 - j\,0.000{,}187{,}5 \text{ mho}$$
$$R_{ts} + j\,X_{ts} = 1.61 + j\,29.0 \text{ ohms.}$$
$$G_{ts} + j\,B_{ts} = 0.000{,}018{,}6 - j\,0.000{,}155{,}0 \text{ mho.}$$

The calculation is the same as for Example I, Reference 2, as far as the equation,

$$E_s = 107{,}050 + j\,3340 + (P + j\,Q)\ (23.9 + j\,204.4)$$

Then, the absolute value of $E_{os} = 105{,}850$ volts to neutral.

$$L_s = \frac{127020 - 105850}{355} = 59.8$$

$$E_{os} = 106{,}310 - j\,1610 + (P + j\,Q)\ (-\,31.3 + j\,203.6)$$
$$= E' + j\,E'' + (P + j\,Q)\ (R' + j\,X')$$

The center of the circle is the point (a', b') where

$$a' = +\,86.2 \text{ amperes}$$

and

$$b' = +\,509.2 \text{ amperes}$$

The radius of the circle is

$$c' = +\,513.8 \text{ amperes.}$$

See Curve I, Figure 2.

Example II

Draw the diagram for the same line and transformers as in Example I, with the same over-compounding of the voltage at the generator end, and with over-compounding at the load end from 182,000 volts at no load to 200,000 volts at 346 in-phase amperes.

$$L_r = \frac{115{,}470 - 105{,}000}{346} = 30.2$$

$$E = 105{,}000 + 30.2\,P$$
$$I_a = P + j\,Q + 8.7$$
$$E_a = 105{,}000 + j\,100 + P\,(30.9 + j\,12.0) + j\,Q\,(0.674 + j\,12.0)$$
$$I_b = P\,(1.003 - j\,0.006) + j\,Q\,(1.002 + j\,0.0002) + 11.1 - j\,19.7$$
$$E_b = 105{,}240 + j\,220 + P\,(31.6 + j\,24.0) + j\,Q\,(1.3 + j\,24.0)$$
$$E_c = 99{,}740 + j\,2760 + P\,(51.5 + j\,178.4) + j\,Q\,(22.8 + j\,178.0)$$
$$I_c = P\,(0.894 + j\,0.039) + j\,Q\,(0.894 + j\,0.013) + 9.7 + j\,90.5$$
$$E_d = 98440 + j\,2970 + P\,(51.6 + j\,191.4) + j\,Q\,(23.3 + j\,191.0)$$
$$I_d = P\,(0.925 + j\,0.035) + j\,Q\,(0.924 + j\,0.013) + 12.04 + j\,75.2$$
$$E_s = 97360 + j\,3200 + P\,(51.8 + j\,204.8) + j\,Q\,(23.8 + j\,204.4)$$
$$E_{os} = 96640 - 3.4\,P - 203.6\,Q - j(1300 - 202.7\,P + 31.4\,Q)$$

In calculating the point on the curve for $P = 300$,

$$E_{os} = 95620 - 203.60\,Q + j\,(59510 - 31.4\,Q)$$

Absolute value of $E_{os} = 105{,}850$.

Dividing by 100 and then squaring the real part and the imaginary part,

$$4.244\,Q^2 - 4267\,Q + 148{,}000 = 0$$

$$Q = \frac{4267 - 3961}{8.488}$$

$$= +\,36.0 \text{ amperes.}$$

This is plotted on Curve II in Fig. 2.

Example III

Draw the circle diagram for the same line and transformers as in Example I, except that there is to be constant voltage at both ends. This is the same as Example I, Reference 2, except that the results are expressed in amperes. The result is Curve III, Figure 2 of this paper.

Properties of the Single Conductor

New Fundamental Relations

BY CARL HERING[1]

Fellow, A. I. E. E.

Synopsis.—*The properties of a unit length of single, straight conductor, far removed from all other circuits, are investigated to endeavor to find whether such a unit is a basic, fundamental one, on which deductions and a method of mathematical treatment could be based, as was advocated by Ampere, to supplement (not to replace) the Maxwell system based on a complete circuit, and to test the correctness of some of the postulates now in common use, based on the latter system. By several new, simple, and direct proofs based only on a few well-established and accepted relations, chiefly the internal stresses in a conductor, but excluding infinities, self-inductances, induction, and any postulates, a constant is deduced for the energy stored by a current in such a unit length, which seems to be one of the most fundamental, basic constants in electrodynamics, from which many useful deductions can be made, some of which are given. This energy of the flowing current corresponds to the* $m\,v^2/2$ *energy of moving masses.*

Some of the results differ from those which have been in use; explanations are offered of the cause of these differences, and it is shown how the results may be brought into agreement, involving some changes in our previous conceptions. It is shown that with flux lines a distinction ought to be made which is analogous to that which distinguishes the wattless ampere from the one in phase, or between a true resistance and an impedance; it is shown why what might be called wattless flux, ought to be recognized. It is shown that self-inductance is used in two senses which may sometimes lead to different results, and that a distinction should therefore be made between them somewhat analogous to that between resistance and impedance or reactance. This it is believed would clear up the ambiguity now existing in that term. It is believed that some of these results could not have been obtained from the Maxwell complete circuit system, which rather leads one away from them.

* * * * *

INTRODUCTORY

IN science, as in engineering and mathematics, it is always desirable to have two independent methods of getting a result; they not only afford a very desirable check on the result and on each other, but each one often has advantages over the other in the different fields for which it is best adapted. For the analytical treatment of electric currents and circuits, the "complete circuit" system of Maxwell has been taught universally and exclusively and for so many years that the strong though wrong belief has arisen among many that it is the only possible one, and that every case must be treated from that and only from that standpoint. In some cases this has not only misled us but has sometimes even led us away from useful facts and relations.

There is a second and older system, the one advocated by that great mathematical physicist Ampere, which is based on the single conductor, and which has many advantages over the other in specific fields for which it is better adapted. Neither system should be used to completely replace the other; they should be used to supplement each other, each in its own field. An electron may start from rest, move to another point and come to rest again there, as in a bolt of lightning; while moving, it is a current and generates a magnetic field in which energy is stored, quite analogous to the $m\,v^2/2$ energy stored in a moving body. The "complete-circuit" system is a misfit in such a case and involves complications which are burdensome and confusing to the student, while the single-conductor system applies directly.

On the other hand the complete-circuit system lends itself well to integrations around a completed path. It has served its purpose well and is very useful, and in most of the usual circuits it is quite reliable. But in a search for the true, basic, fundamentals, there is no such a thing as a fundamental or unit or limiting circuit; the nearest approach to one is a circular circuit in the form of a tore or torus whose centerline radius is equal to the radius of the wire, like a doughnut with an infinitely small hole through it. This is the shortest circuit which can be made with a wire of given diameter, hence is at least a limit, but for various reasons this is not satisfactory as an ultimate fundamental.

The writer has therefore concluded that the only real fundamental is a unit length of a long straight, single, conductor, far removed from all others, as this embodies absolute ultimata; it is the form which is most free from all external influences, and besides the current, it involves the least number of variables, in fact only one, the radius of the wire, and even that one falls out in some cases, as will be shown below, for relatively to the infinite free space around it for the magnetic flux, the small finite radius of the wire becomes negligible.

The purpose of the present paper is to examine analytically the properties of such a unit length of this fundamental conductor, without involving infinities, the limitations of complete circuit mathematics, self-inductances, induction, postulates, or any but well established relations, and to deduce from these properties any useful relations and constants that may exist.

To do so by considering a straight line as a special case of a circle of infinite radius, is unsatisfactory, as it introduces that dangerous quantity, infinity, with its serious pitfalls into which many otherwise able men

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have fallen[2]. In a French book by Fleury dealing with infinity he says: "Infinity has no other property than that of being impossible. Any calculation based upon absolute infinity, or upon any function whatever of absolute infinity, is itself absurd." The writer agrees with him in this, in part. When the results of two methods fail to agree, "look for the infinity" he says, and you will probably find the error.

When absolute infinity occurs, as it does, in mathematical deductions, there are two ways in which it can be safely applied in practise. The first one applies (as Fleury admits), when it is possible to assume that the quantity is simply so large (though finite) that others which depend on it may safely be taken as the same as they would be if it were infinitely large; this is often the case. For instance, in starting a current in circuits containing some small inductance, a few seconds is generally quite safely taken to be the equivalent of the eternity required theoretically for the current to reach its final value even in very accurate tests; the currents in even sensitive tests made in New York do not appreciably affect simultaneous researches made in Philadelphia, the 90-mile distance being practically infinite. Our atmosphere should extend theoretically to infinity, according to the laws of gases, yet beyond the relatively short distance of 50-60 miles there is not enough left to consider; the moon, sun, planets and stars encounter no friction in our atmosphere, even though it should extend theoretically to infinity.

The second one applies when some *property* of an infinite quantity can be found which is finite and therefore can be practically applied; thus the 760-mm. pressure of our atmosphere is finite, though according to the theory of gases, the atmosphere must extend to infinity; or similarly, the radial magnetic pressure on the surface of a single straight conductor, by the flux surrounding it, is known to be finite, although the flux, like the atmosphere, should extend theoretically to infinity. It will be shown later that under certain conditions the flux energy is also finite, though the flux is infinite.

One of the pitfalls in dealing with infinities obtained mathematically is that sometimes the real result is that the quantity is merely indeterminate and not infinite; this may arise when a factor has been suppressed or dropped because it is unity, but it is physically still present.

By treating the circle as a special case of a straight line, instead of the reverse, infinities and their pitfalls are avoided, which is another reason for preferring to start with the straight line as the fundamental.

The Single Conductor

In dealing with the single straight conductor as the fundamental, the real underlying condition (besides the straightness of a reasonable length) is not that it must be infinitely long, but merely that the unit length is assumed be so far removed from all other currents, or magnets, that they will have no appreciable effect on it; such currents include its own return circuit. Hence in a complete circuit in the form of a large square the sides may be made so large that a unit length *l*, Fig. 1, in the middle of a side, is no longer affected by the return current in the opposite side *L*.

The only three effects which neighboring currents can have on the unit length *l*, are attraction, repulsion and induction, which decrease as the square of the distance, and although they may also increase as the length *L* increases, yet the action of both combined is always a *decreasing* function, hence a distance may always be reached at which the effects are small enough to be neglected, as is always done when two or more independent tests with complete circuits are made at different places at the same time, even though with great accuracy.

Hence such a square can always be conceived in which the field at its center may safely be taken as

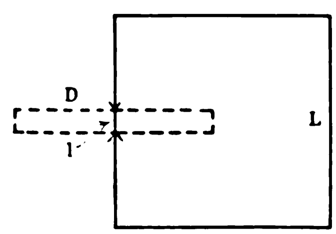

Fig. 1

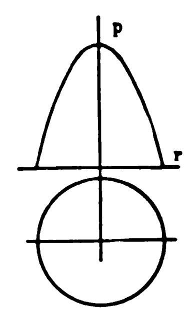

Fig. 2

zero, and therefore a unit length *l* in the middle of a side is practically as free from the effects of neighboring currents, as though it were a single conductor, and the flux and flux energy inherent with it are practically those in the disk-shaped space *D* between two parallel planes one unit apart, just as they are in a single conductor. Such a unit length *l* may therefore be taken to represent a unit length of a single conductor to any degree of accuracy desired by merely making the square large enough. Such a square circuit is therefore a connecting link between a unit length of a single, straight, conductor and a complete circuit; and the condition of infinite length, so often used in order to degenerate the single conductor to the realm of impossibilities, is no longer justifiable; some of the pitfalls of infinity are thereby avoided.

Maxwell himself determined (Art. 478) the now classic law for the flux density around a single conductor, with such a closed circuit; Northrup's determination of the internal pressures in a single conductor produced by the flux, is not based on the condition of infinite length, but as he says, merely on freedom from the effects of neighboring currents, and the accuracy of his expression was checked experimentally in a

2. This was well brought out in a discussion by Dr. C. O. Mailloux, Trans. A. I. E. E., Vol. 42, 1923, p. 328, Col. 2, par. 4, to p. 329, Col. 2, par. 2.

closed circuit. Ampere's able analytical researches with the single conductor were no doubt based on the same conditions; so is the generally accepted $i^2/4$ energy of the flux in the interior of a conductor. Many other like cases could be cited, showing that the infinite length is not a necessary condition. The same condition of freedom from all external influences is assumed in all accurate electrical tests, hence it is not an unreasonable or impossible condition.

Energy

Energy is the one physical quantity which is common to all physical phenomena and processes, and its absolute unit, the erg, applies to them all; hence it is the best and in fact the only connecting link between all the different groups of physical phenomena. Forces may be electromotive, magnetomotive, or ponderomotive (tending to move masses), each of which is physically different from the other, and their units are different and are not directly convertible. Moreover some forces are vector quantities, have components and resultants, can be generated or annulled and follow different laws, while energy is always a constant quantity no matter what form it may be in and its laws are common to all its forms. Energy is therefore the best physical quantity to use as a fundamental and the best connecting link between different physical phenomena.

Zero Resistance

In searching for fundamentals the number of factors or variables should of course be the least possible. At absolute zero of temperature the resistance of pure metals is eliminated, as it is zero; a current once started, as by induction, will therefore continue (theoretically) to flow forever, just as a body set into motion will continue to move when it meets with no resistance. Zero resistance will be assumed in the present discussion.

In the electric case this stored energy, which was stored while the current was started, is represented entirely by what seem to be stresses or strains of the ambient ether, which are called magnetism, hence it is magnetic energy and seems to be very closely analogous to the mechanical stresses or strains in compressed or stretched elastic rubber, and is static or potential in its nature. This stored energy of a current is closely analogous to the $m\,v^2/2$ energy stored in a moving body. When any of this stored energy, at zero resistance, is released, as by doing external work, the current also decreases, as shown in a paper by the writer,[3] and when it has all been released the current will become zero.

Such a condition of zero resistance simplifies greatly the considerations and conception of some electrical phenomena involving flux and energy, as there is then no external source of energy to mask the conditions when some of the stored energy has been released, as is the case when a "constant current" is specified in stating the laws, as it usually is, in which case the released energy is at once restored again, and there is also a continuous flow of energy. At zero resistance and with no connected source, the variables are reduced to their minimum, hence they are the best conditions for studying the fundamentals. The permeability is, of course, assumed to be unity, in all such fundamentals.

Unit Relations

The very basis of the absolute or c.g.s. system is to make as many as possible of the numerical relations between different fundamental physical quantities, unit relations, that is, the coefficient is unity, in which, however, the factor 2 often resulting from integrations, and π which cannot be avoided, must be included. If therefore, in the search for new fundamentals and relations between them, the latter turn out to be unit relations, the presumption is strong that they are correct, though it is not necessarily an absolute proof. A number of the relations deduced below will be seen to be unit relations.

The Fundamental Constant

One of the most basic fundamental quantities in electrodynamics therefore seems to be the energy represented by, or inherent with, or stored in, a unit length of single, straight conductor by a given steady current, under the most basic conditions; if this quantity leads to unit relations its fundamental character is confirmed.

Determination of this Constant. The problem which the writer endeavored to solve therefore was to determine this basic fundamental constant and to do so by a method which does not involve any physical quantities other than energy, mechanical forces, and currents, hence excluding completely that ambiguous quantity called self-inductance, and the theory of linkages (perhaps still incompletely proved) in the case of self-produced flux, both of which are so often relied upon absolutely in such energy calculations; nor does it involve any infinities or "postulates"[4] and it is moreover very direct and simple; there should, therefore, be no difficulty in either confirming it or pointing out precisely the error in it, if there is one. This energy should of course be the same no matter by which process it has been determined; if not, an explanation must be looked for and it ought to be possible to find it, especially if it lies in this simple proof. Fleury's advice in such cases is to "look for the infinity." While this method is new and different from the orthodox ones, it involves no new or unproven laws.

The method is based on the recently discovered and now well-known fact that when a current passes through a conductor internal stresses and strains in the form of radial pressures and longitudinal tensile stresses are produced, quite analogous to those in a magnetic field;

3. Trans. A. I. E. E. Vol. 42, 1923, p. 325.

4. A postulate is defined in the dictionary as "a proposition accepted *without proof;* something that must be *assumed* in order to account for something else." (Italics are the author's.)

but as the former act directly to tend to move the material of the conductor, they produce truly ponderomotive forces (tending to move masses), as is readily shown when the conductors are liquid and the current is large enough, as they increase with the square of the current, like most other electromagnetic forces. Being true mechanical forces they can be correctly specified and measured in dynes. Hence by letting these known mechanical forces act through known distances, the corresponding amounts of energy may be determined. Unfortunately neither Ampere nor Maxwell had the advantage of any knowledge of these internal stresses.

Internal Stresses

Many years ago the writer noticed these stresses when large currents were passed through liquid conductors in electric furnaces; the forces were sometimes strong enough to completely rupture the circuit by crushing it radially or tearing it longitudinally, and as this always occurred in one place by depressing the liquid where the cross section of the open channel happened to be least, the phenomenon was colloquially called the "pinch effect" by which term it is now generally known. These forces are now used very effectively in hundreds of electric furnaces for lifting and circulating the liquid metal.

Later, Dr. E. F. Northrup, to whom the writer had described this peculiar phenomenon, developed the mathematical formula for the quantitative value of these pressures, in a very able paper.[5] He based it on the attraction of the filamentary conductors for each other, and also on the radial force acting on each filamentary conductor due to its being in the magnetic field inside of the conductor; both methods gave the same result. It is important to note that it was also confirmed by him later experimentally to a high degree of accuracy (using, of course, a complete circuit), showing that the pressures were true, mechanical ones, and that their units in the formula are in dynes per sq. cm. This formula or law may therefore be safely accepted as quantitatively correct, reliable and accurate. The present writer showed later that in the c. g. s. system this law is a *unit relation* for the pressure at the center of a round conductor which, though it may not be a proof, is always strongly confirmatory of correctness. This easily remembered relation is $p = i^2 / S$ in which S is the section.

Northrup's general law for the radial pressure p in dynes per square centimeter at any point in the interior of a round conductor of radius R at a radial distance r from the center, and carrying a current i, is $p = i^2 (R^2 - r^2) \div \pi R^4$, the now well-known "pinch" pressure formula; all the quantities are in c. g. s. units. This gives the *mechanical* stresses or strains in the form of radial pressures in any part of the cross section of a round conductor, produced by a current flowing through it. The curve of these pressures is a parabola, Fig. 2; hence for the whole section the curved surface of the loci is a paraboloid of revolution. This mechanical pressure is zero at the circumference, a maximum at the center, and the mean over the whole section can readily be shown to be half of the maximum; the formula also shows that this radial pressure is independent of the length of the conductor. This formula is based on the condition that, as Northrup himself states it, the conductor is a part of a very long straight conductor of circular section "very far separated from its return conductor," hence is not limited to the impossible infinitely long conductor.

5. *Physical Review*, June 1907, p. 474.

Proofs

There are several proofs of this constant, $i^2/2$ ergs per cm. all of which lead to the same result and therefore confirm each other. They are rigid, being free from approximations, dropped factors, infinities, inductance, self-inductances, or mere postulates. One is based on the radial pressures, one on the longitudinal force, and other shorter ones based on what some may consider allowable assumptions. The energy referred to is that which is required to start a steady current; it is constant while the current is flowing, and is set free again when the current stops; it is quite independent of the energy which may be transmitted while the current is flowing; it is quite analogous to the vis viva or the $m\,v^2/2$ energy in a moving body, like that required to bring the cable itself up to its normal speed in a cable transmission. By the first method, based on the radial pressures, it is measured as it is set free, while the current decreases to zero; it involves only two of Maxwell's undisputed laws. By the second method, based on the longitudinal force, it is measured as it is being stored by a constant current in an increased length of the conductor; it involves only the Northrup and the so-called Kelvin laws. In both, the conductor is assumed to be a liquid, and the energy is measured by the mechanical work done by this energy.

Radial Pressure Method. A steady current is assumed to have been started by an external source, in a circuit of zero resistance, hence would continue to flow without a connected source until all its vis viva or stored energy has been consumed by transformation into some other form of energy. This stored energy is quite analogous to the $m\,v^2/2$ energy stored in a body moving at a constant velocity and without encountering any resistance.

An experimental proof that the energy stored in a body moving at a constant velocity is equal to that given by the well-known formula $m\,v^2/2$, might be obtained by opposing the motion of that body by a *constant* pressure or force until it comes to rest, when its energy is exhausted; then the product of this force and the distance over which it was applied before the body came to rest, would evidently be equal to this

$m\,v^2/2$ energy, thereby proving that this expression gives the correct amount, or that this amount might be determined in that way if that formula were unknown.

The present method is quite similar. Assume any given length l of such a straight, single, liquid conductor of circular section having a radius R and a current I (c. g. s. units); or it may be the whole circuit of length l, if only it is large enough that each unit length is far enough from the return circuit not to be affected by it. It is well known and could easily be shown, that such a liquid conductor will tend to shrink radially, due to the pressures produced by this stored magnetic energy.

From Maxwell's $H = 2\,I/R$ for such single conductors, and his $H^2/8\pi$ pressure formula, this radial magnetic pressure on the outside surface is easily shown to be $I^2/2\pi\,R^2$ in dynes per sq. cm.; this is the total, *resultant*, pressure; it will be explained below why this is the resultant and under what conditions Maxwell's $H^2/8\,\pi$ pressures are true mechanical pressures in dynes per sq. cm. Whatever may be the detailed explanation of the mechanism of this shrinkage, say through a radial distance d, it is true in any case that this pressure must have then acted through this distance d and has thereby done work. Let the outflow of this liquid due to this shrinkage be assumed to be opposed by a constant mechanical pressure on the liquid (analogously to the constant pressure referred to above opposing a moving body), as for instance by making the liquid which is ejected by this shrinkage raise a weight, as it does in hundreds of electrical furnaces in daily use.[6] This opposing constant outflow pressure is made equal to the above radial pressure.

In thus acting on the outside through the distance d this constant radial pressure has set free a known part of the energy originally stored in the flux; this is determined from the distance d and the known force, equal to this constant pressure multiplied by the mean area. Hence there is then left less flux energy and therefore of course also less current. Let this shrinkage at constant outside pressure against an equal, constant, outflow pressure, continue until the conductor has shrunk to a line, that is, to zero.

At these radial and outflow pressures, assumed to be constant and equal, it can be shown that $I^2/i^2 = R^2/r^2$ in which i and r are the current and radius after a shrinkage; for the first pressure P is $I^2/2\,\pi\,R^2$ and the pressure p after this shrinkage to a radius r is $i^2/2\,\pi\,r^2$; when these are made equal to each other the above relation follows. Hence $I/i = R/r$, that is, the currents will diminish in proportion to the radius, and therefore the current, and with it of course the energy also, will become zero, when the radius has shrunk to zero. This shows that *all* the stored energy has thus been consumed in crushing the conductor to zero. The remaining energies are proportional to the squares of the currents or radii, but this is not an essential relation in this proof.

It also follows that for any given length l of the conductor the total radial *force*, as distinguished from pressure (force = pressure $\times$ area), diminishes in proportion to the radius, that is, $F/f = R/r$ and it is therefore also zero when the radius is zero. These simple relations hold only when the outflow pressure is made numerically equal to this constant radial pressure; this outflow pressure always exists at a distance from the center equal to the outside radius divided by the square root of 2, as shown by the Northrup formula. and his experimental demonstrations show that these forces are true, mechanical forces in dynes agreeing quantitatively with Maxwell's formulas.

As the original radial pressure is $P = I^2\,2\,\pi\,R^2$ the force at first is $F = 2\,\pi\,R\,P\,l = l\,I^2/R$ in dynes, and as it diminishes in proportion to the radius, the work done by its acting radially to the center is the mean of the original and zero, hence is $l\,I^2/2\,R$, which acting through the distance R gives as the original stored energy $W = l\,I^2/2$ ergs or $I^2/2$ ergs per cm., *which is the basic, fundamental constant sought for.* This quantity was thought by our forefathers to be infinity, as deduced from the "complete circuit" system; the explanation why there is this disagreement will be given below. Attention is called to the fact that this total $i^2/2$ ergs, is just twice that long known to reside in the inside of the conductor.

The same result could be obtained by the calculus, and the liquid might then be assumed to be ejected continuously at the center where the pressure will vary from twice the radial pressure at the start, to zero at the end; the opposing outflow pressure must then be assumed to vary accordingly in order that at every moment there is equilibrium. The radial pressures will then no longer be constant but will decrease, and the current will decrease faster than in proportion to the radius. It is then analogous to stopping the movement of a body by means of a variable, instead of a constant, force.

Longitudinal Force Method. A steady current is assumed to be kept flowing in a liquid conductor of zero resistance, zero weight, and constant diameter, by a continuously applied source. Instead of allowing the mechanical stress to act radially to set free the stored

6. If necessary to picture the details (though they are immaterial and do not affect the theory involved) let the liquid be supposed to be ejected through a tube leading to a cylinder foreign to the conductor, having a piston which raises a constant weight; as the pressures in the interior of the conductor are known to be different at different distances from the center, this tube is assumed to be applied at that radial distance r from the center (namely when $r^2 = R^2/2$) at which this particular pressure exists and is constant during the shrinkage, hence it must be assumed to be moved toward the center as the conductor shrinks. When this is done, and only under those conditions, the quantitative mathematical relations become extremely simple, as will be shown. This shrinkage against an opposing pressure must of course be assumed to take place simultaneously throughout the whole of that circuit, though only a portion of it needs to be considered mathematically.

energy as before, it is now allowed to act longitudinally to lengthen the conductor of constant diameter by a specified amount, whereby the source adds to the circuit the energy stored in this added length. This added energy is calculated by letting this known longitudinal force lift a known weight through a known height while lengthening the conductor by the latter distance; the source thereby does a known amount of external work, and according to the so-called Kelvin law it then simultanously adds to the stored energy of the circuit an amount equal to the external work done. Hence the energy stored in this added length is equal to this known external work done.

The force is calculated from the pressures given by the Northrup law, which is generally recognized as correct, both relatively and quantitatively, and the pressures have been shown experimentally to be true mechanical pressures in dynes per sq. cm.; it may now be safely classed under the "classic" laws. The

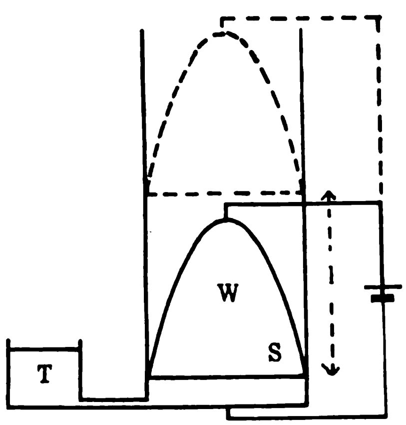

Fig. 3

Kelvin law, though not always referred to by this name, seems to be a universal law in dynamics and when properly worded, may also be safely classed under the "classic" laws. The conditions of the circuit are that only the additional length need be liquid, the parts near it must have the same diameter, the part that moves must be considered as weightless and of course it must be straight for a reasonable length and the return circuit must be far removed.

In Fig. 3, let S be conceived to represent an infinitely thin cross sectional layer of a circular, liquid, conductor of radius R. Let W be a weight, which may be shaped as a paraboloid of revolution to correspond with the pressure loci in Fig. 2, though merely to simplify the conception, as a cylindrical body of half the maximum height and the same base, would have the same weight or volume and would answer quite as well. Let a current i be conceived to be passed axially through this section, the rest of the circuit being shown diagrammatically only. Let the layer S be assumed to be connected at its circumference, where the pressure is zero, to a supply reservoir of more liquid diagrammatically represented by T; the liquid is assumed to be weightless and the supply from the outside is assumed to exert no pressure and to involve no energy.

The conductor S being a liquid the radial pressures of the Northrup formula will act equally well axially, let it be said by hydraulic action, if that is preferred; hence they will raise the weight W, the additional weightless liquid necessary to provide for the lengthening of the conductor, being supposed to be supplied from the outside under no pressure. The pressure formula will be seen to be independent of the axial length, hence these axial pressures will always remain the same as the weight is raised, that is, the total vertical lifting force is a constant, for a constant current. This axial lifting force is being used in hundreds of electrical furnaces in daily use lifting many tons per day, hence is well known and not a mere theoretical force on paper; its quantitative value is also well known.

Let the weight be lifted l cm. (Fig. 3). The surface of the loci of the pressures being a paraboloid of revolution, it can readily be shown[7] that the average pressure over the whole section is half the maximum at the axis. At the axis $r = 0$ (in the Northrup formula), hence the maximum pressure there is $p = i^2/\pi R^2$; multiplying half of this by the total area πR^2, gives $i^2/2$ as the force in dynes; that is, the total lifting force, and therefore the weight W which it will lift, is numerically equal to $i^2/2$ dynes. Having lifted it l cm. the external energy expended on the weight is: energy = force $\times$ distance = $l\, i^2/2$ or $i^2/2$ ergs per unit length. Hence according to the above mentioned Kelvin law, the stored magnetic energy of the conductor per centimeter of length, must be $i^2/2$ ergs also, the source having supplied double this energy. *This is the basic fundamental constant sought for.*

Other proofs. A given radial pressure can always be replaced by its corresponding circumferential tension. If P is the radial pressure on the outside of a conductor as given above, it can be shown that the tensional force (not pressure) in a band encircling a unit length of the conductor and producing the same radial pressure, is $P\,R$ in dynes, in which R is the radius. If a stretched, elastic band, having this tension be assumed to be developed into a straight line (equal to the circumference) and then allowed to shrink to zero length, following the law of the perfect spring, namely that the tension is proportional to its length, it can be shown that the energy set free thereby is again the same, $i^2/2$ ergs.

From the Northrup formula the pressure in dynes per sq. cm. at the center is just twice the $i^2/2\,\pi R^2$ pressure in the same units, at the periphery, from outside. As the outside pressure must also act at the center, it might be argued that the inside flux has added an equal amount, hence that the energies residing inside and

7. It is well known that the volume or weight of such a paraboloid of revolution is equal to that of a cylinder having the same base and half the height.

outside are equal, therefore the total is double the well known inside energy $i^2/4$.

At the periphery the two mechanical forces balance, as there is no tendency to movement there, according to the Northrup formula; there is no resultant there. As the forces are equal the energies should be also, as both forces must be considered relatively to the same center, hence as acting through the same distance, the radius. Again the total is twice that inside.

The very basis of the c. g. s. system is that the fundamental relations are unit relations, at least as far as possible. If it may therefore be assumed that the self-inductance (in its true, energy sense) of a unit length of the fundamental conductor, is unity, then if L in the usual expression $L\,i^2/2$ for this energy, is made unity, the energy becomes $i^2/2$. A self-inductance is stated to be physically a length, and in the c. g. s. system it is correctly measured in centimeters. Under fundamental conditions this length and the length of the conductor should be the same thing. This constant then follows directly.

Those who recognize the existence of the longitudinal force, will find that in a fundamental conductor of uniform diameter it is numerically equal to $i^2/2$ dynes, from the Northrup formula, and that in this fundamental conductor it is independent of the diameter or the length. Hence when this force acts to stretch or lengthen its conductor without doing any external work, (though generating a counter e. m. f.) the energy is being stored, just as it would be when the speed of a moving body is increased. If l is this added length, the added energy will of course be $l\,i^2/2$ ergs, which for a unit length again gives $i^2/2$.

Doubtless still more proofs could be found which are also free from the pitfalls of infinities, the ambiguous self-inductances, and the short comings of the complete circuit theories, which had misled us in the past.

Deductions from this Constant

It will be seen that this constant is independent of the diameter of the wire, and depends only on the current, both of which have long been known to be true of the flux energy residing in the interior of the conductor, $i^2/4$. For any length l the energy is $l\,i^2/2$, that is, it is directly proportional to the length. This $i^2/2$ ergs is apparently one of the most basic fundamental constants in electrodynamics, and from it interesting deductions follow.

This $i^2/2$ is the total stored energy, outside of the wire and inside. It has long been known and is easily proved, that the amount stored inside of the conductor is $i^2/4$ ergs per cm. It follows therefore that of the total, half of the energy resides in the inside and half on the outside, as one might expect nature to distribute it.

This constant also shows that the energy of the flux is finite, though the flux itself is of infinite extent, in the same sense that our atmosphere extends to infinity. It is one of those cases in which a *property* of an infinite quantity is finite and therefore affords a means of treating an infinite quantity mathematically without danger of falling into the pitfalls of mathematical infinity. Another finite property of this theoretically infinite flux is what might, in a certain sense, be called the resultant or equivalent flux, as will be described below.

Reduced to the units used in practise the general formula becomes $W = 0.00001524\ l\,I^2$ in which W is the stored energy in watt-seconds or joules, l is the length in 1000-ft. units, and I is the current in amperes. This shows how extremely small it is.

A very interesting and important deduction, showing another new unit relation, is that in the c. g. s. system each unit of current generates one unit of flux around such a conductor, in each unit of length, and independent of the diameter; it includes all the flux inside and outside. But this flux must be specifically defined, as it is a resultant, equivalent, or condensation of all the very large number of lines into which it divides itself as it spreads out into space; these resultant lines might be termed fundamental maxwells. This condensation is such that these resultant lines when combined with the magnetomotive force in common to them all, represent the true stored energy in that field. It is somewhat analogous to supposing our widely diffused atmosphere to be condensed into a thin solid or liquid layer around the earth, which has the same mass. Or these condensed lines may be imagined to be those originally generated by the current and then spread out into space according to the laws of distribution, *but without any change of energy contents*, just as the condensed atmosphere would spread out without change of mass. Such lines are a means of summing up an infinite quantity by one of its properties (energy in this case) to get something finite. They are useful in calculations of flux energy and they clear up some ambiguities, but they are sometimes distinctly different from those entering into calculations of the induction of e. m. fs. by cutting or linking. This will be further discussed below.

The proof of this equality is as follows. The energy residing in a complete circuit of flux is: ergs = maxwells × gilberts/$8\,\pi$. The magnetomotive force in gilberts around a single conductor is $4\,\pi\,i$, and as the energy per unit of length is $i^2/2$, it follows that $i^2/2 = 4\,\pi\,i\,f/8\,\pi$ in which f is the number of lines in maxwells; hence $i = f$. This unit relation is a fundamental one and applies rigidly only to the fundamental conductor, and of course, not at all to bi-filar non-inductive circuits, nor when the permeability is not unity. The "complete circuit" mathematics leads us away from it rather than toward it. It seems to mean that in the c. g. s. system current and flux are merely different physical representations of the same quantity, as far as energy is concerned, though, of course, only when the resistance energy is zero; or that magnetism

is merely an effect of current at a distance, the energy residing in the moving electrons.

For a unit length and unit radius the total radial force (not pressure) from the outside, is numerically equal to i^2 dynes, hence is another unit relation; for other radii it is inversely proportional to the radius. This force multiplied by half the radius (because it is radial) again gives the constant $i^2/2$.

The stored magnetic energy in any part of a circuit is generally calculated from the formula $L\,i^2/2$ in which L is the self-inductance of that part in centimeters. In the fundamental conductor this energy is $l\,i^2/2$ in which l is the length in centimeters. Hence in such conductors the self-inductance (in the energy sense of that term) is the same thing as the length of the circuit, that is, the distance over which the current flows; another interesting unit relation. This explains why a self-inductance is physically the same kind of a quantity as a length, a purely geometric quantity, at least under the most fundamental conditions; the permeability is of course taken to be unity in all fundamental cases. It also shows why in the c. g. s. system it is correctly expressed in centimeters, or in 10,000. kilometers for the henry. It also follows that under these fundamental conditions the self-inductance is independent of the diameter of the wire, which would seem to follow also from the long-known fact that the energy of the flux in the interior of the wire is independent of the diameter.

This stored electromagnetic energy, $l\,i^2/2$ of a current is quite analogous to the visviva or stored mass energy $m\,v^2/2$ of a moving body. In the c. g. s. system both are equal to ½ erg when all the quantities are unity, and one may write $l\,i^2 = m\,v^2$, which means that if all the electromagnetic energy stored by a current i flowing for a distance l, in such a single conductor, be converted into moving mass energy, the relation of the mass to the velocity must be such that $m\,v^2 = l\,i^2$. Thus for say 1000 amperes flowing in such a conductor, the stored electromagnetic energy in every foot, is the same as the mechanical energy stored in a weight of 0.723 or nearly ¾ lb. moving at 1 ft. per sec., or 0.181 lb. at 2 ft. per sec.; all are equal to 0.01124 foot-pounds or 152,400 ergs. This is the energy, per foot of conductor, set free when the current is stopped. For any other length of conductor this equivalent mass increases as this length.

It is of interest to note that for 1 ampere this energy stored per centimeter is equal to that of 5.10 millionths of a gram raised one centimeter, which is extremely small, and shows why the least resistance in such a conductor stops a current almost instantly after the e. m. f. ceases. Yet our forefathers claimed that this energy was infinitely large, which it seems is still being taught.

Another result which this constant, $i^2/2$, has led to, is a better understanding of the true nature of flux energy and calculations pertaining to it, as explained below.

Disagreement

When this stored magnetic energy per unit length of a single conductor is deduced by means of the mathematics of the complete circuit and by some of the older methods and postulates, or by means of self-inductance formulas (always only approximate), the result is that even for a very small current this stored energy per unit length is infinite, while $i^2/2$ is generally quite small. But as the above proofs are simple, brief, rigid, and involve nothing but well established laws, it does not seem possible to find any error in them in a long discussion since the writer's first publication of this result,[8] deduced by a similar though more involved process.

The discrepancy therefore must be looked for elsewhere. The mere fact that the result differs from our older views, cannot of course, be accepted as a proof of an error in it; if that were done in this and other cases, further progress in science would be checked.

The writer believes that this discrepancy can best be located and explained, and that the criticisms of the above proofs can best be answered, by first getting a clearer conception of the various factors and elements involved, and by endeavoring to show how and where some of our older conceptions had misled us, and which of them may be questioned and should be modified or revised if wrong. The new result, if correct, may well be used as a test of the correctness of some of the older laws and postulates.

These explanations are discussed in detail in the complete pamphlet copies of this paper; the following is merely a very brief synopsis. If in the large square circuit Fig. 4, the lengthening (in the second one of the proofs) takes place in both of two opposite sides, the only new flux will be in the parts D, D, and that in the rest of the circuit will not have been changed in the least. This answers some criticisms concerning the "rest of the circuit." If instead, such a circuit be

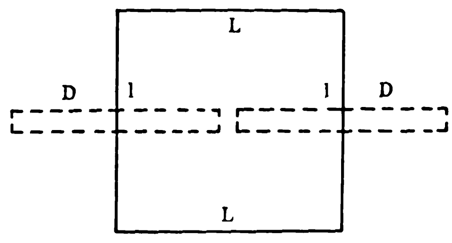

Fig. 4

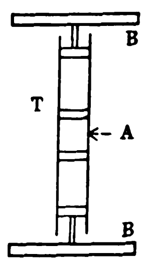

Fig. 5

forced to be shortened slightly instead of lengthened, it must set free an infinite amount of energy, according to the ideas of our forefathers; but this is evidently absurd.

Fig. 5 illustrates the same principle as that involved in lengthening a rope supporting a weight; the force in this additional past must not be added to that in the rest as it is the same force. This answers a criticism.

8. A Single Straight Conductor as a New Fundamental. *Jour. Frank. Inst.*, Feb. 1925, p. 235. In this article the first part of the paragraph forming the upper half of p. 243 contains an unfortunate arithmetical error and should be deleted.

In Fig. 6, if C is the cross section of a conductor the curve F gives the density H outside of the wire, and f that inside; at the surface they are both equal to h. The flux lines outside act by their contraction like layers of stretched rubber bands over each other; hence the radial pressure at the surface is the *resultant* of all those radially beyond; just as the 760 mm. pressure of our atmosphere is the resultant of those of all the layers above. In either case it would be wrong to add to this resultant (as by integration) the pressures of its component parts beyond; or to add the energies based on these pressures, yet this has been done by our forefathers. This is claimed to have been the chief cause of the disagreement.[9] Zero resistance should be assumed in such cases, as energies which are set free are then not continuously being restored. Although the outside and inside flux pressures balance each other at the surface where they are h, it is explained how the outer one will act when the inner mechanical pressure is reduced.

In Fig. 7 C is the section of a very thick walled rubber tube, expanded by a compressed liquid h. The stresses, strains and stored energy in this rubber wall are then closely analogous to those in a magnetic field around a conductor h. In both, the radial pressures on h are the *resultants* of all those radially beyond, which must therefore not be added to them; the energy stored in the rubber is finite, and could be measured by allowing the liquid to be ejected under pressure, as in the first of the above proofs. Flux lines exist in the space around the wire, but if the energy of the whole field has been determined from their resultant at the surface, those beyond must be considered as wattless, in the sense that their energies have already been accounted for in their resultant and must therefore not be added to it again. It is shown that the e. m. f. induced by cutting or linking of lines is independent of the energy residing in those lines, which may therefore be wattless in the above sense; hence the energies in such lines cannot be deduced from the e. m. f. induced.

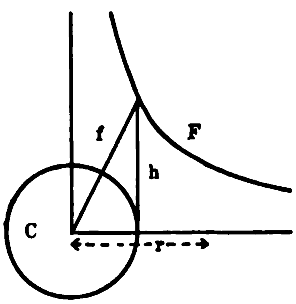

Fig. 6

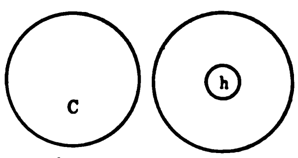

Fig. 7

It is shown that Maxwell's $H^2/8\pi$ pressures are true mechanical pressures in dynes per sq. cm. when properly interpreted. This expression seems to apply correctly only to uniform fields, hence not to those with curved lines, as in these some of the pressures are the resultants of others; or it may be applied to differentially small parts, but can then not always be added together by integration. The lack of consideration of the abutments of the forces, has led to confusion; they do not appear in calculus calculations and are often overlooked. The ether cannot act as an abutment for mechanical forces. The abutment of the encircling flux is the surface of the wire.

The propriety of using the term self-inductance in both of its two different senses (inducing e. m. fs. and determining the stored energy) is questioned. It is shown that the error of adding the energy of components to that of their resultant, enters. As all self-inductance formulas are only approximate, extrapolating them to infinity is not rational, yet it has been done. Self-inductance is generally defined as a derived quantity, flux per ampere, yet physically it is a mere geometric, independent quantity, a length, hence independent of either flux or current. That ratio may sometimes lead to errors when some of the flux should be considered as wattless just as a resistance defined as the quotient of volts divided by amperes, may lead to errors when some of the amperes are wattless. Reforms in the true meaning of the term self-inductance are recommended and reasons are given.

The error arising from adding components to their resultant, seems to be greatest for very large single turn circuits, and small for the coils used in practise; still less when iron is used, as is usual. It affects theory, especially basic fundamentals, rather than practise. Attention is called to the much discussed longitudinal force and its evident existance in this investigation; its value is given.

Conclusions

In the opinion of the writer, the above proofs, deductions, and discussion, will show that a new system of treatment of electrical problems can be based on the single, straight, conductor, as distinguished from that based on the Maxwell complete circuit; not to replace the latter system but to supplement it, and to test the correctness of parts of it. The single conductor system leads to some new and useful results and shows that we should modify some of our former conceptions; also that in flux lines there is an analogy to the wattless ampere which ought to be recognized. It also shows that the term self-inductance has been used in a dual sense and that a distinction should be made analogous to that between resistance and reactance. Some heretofore unknown and useful relations have been deduced from what is believed to be one of the most fundamental constants in electrodynamics, the value of which is determined by simple proofs. Some of the results deduced could not have been deduced from the complete circuit system, which has, in some cases, been misleading.

9. This is also discussed in an article by the writer on Magnetic Flux Energy, in the *Jour.* Frank. Inst., Dec. 1925, p. 747.

Parameters of Heating Curves of Electrical Machinery

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Synopsis.— *When a body is being heated by a uniform addition of a constant quantity of heat per unit time, its temperature above the ambient air (the latter being assumed to remain at a constant temperature) increases approximately according to an exponential law. The exponent is proportional to the ratio between the heat capacity of the body and the coefficient of thermal dissipation into the surrounding medium. In a paper read before the Institute's Midwinter Convention, 1925,* (JOURNAL, *Vol. 44, p. 142) Doctor A. E. Kennelly has proposed to include such a coefficient among other characteristics of an electrical machine. In the present paper it is pointed out that for thermal purposes an electrical machine cannot be considered as a single body, since the stator consists of two metal bodies (the winding and the core) between which there may be a considerable heat interchange, and that the rotor is also such a composite body. Differential equations of heat flow in a combinational body are established and solved. The stator winding is thermally determined by its heat capacity and its heat dissipation coefficient, and so is the stator core; further, there is a coefficient of mutual flow. The rotor also requires five similar coefficients. Thus, while an electrical machine could be defined by its thermal coefficients, and the temperature rise of the different parts predicted for a given operating regime, the number of required parameters is much larger than for a single body.*

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WHEN an attempt is made to represent, analytically, the temperature rise with the time in an electrical machine at constant losses, the time-temperature curve is usually assumed to be exponential.[2] Recently, Dr. A. E. Kennelly has extended the treatment and has shown that the curve remains exponential even when the losses themselves are linear functions of the temperature.[3]

Actual heating curves sometimes differ materially from the simple exponential form. This can be shown by plotting the differences between the ultimate temperature and the instantaneous temperatures against time as abscissas, on semi-log paper. An exponential curve should give a straight line, and this is not always the case. The principal reason for this discrepancy is that the stator of a machine cannot be considered as one "chunk" of metal; it consists of two metal bodies, the winding and the core, between which there may be an appreciable difference of temperatures. The same is true of the rotor. In a transformer, three separate metal bodies at different temperatures may be distinguished.

It is the purpose of the following investigation to show that with two metal bodies at different temperatures, and with heat interchange between them through a layer of insulation, the heating curve for each consists of two exponential terms with different exponents. Thus, each part of a machine should be characterized by at least two composite thermal time constants, and these will represent an experimental heating curve much more closely than is possible with one thermal time constant and with a common curve for both the winding and the core.

Doctor Kennelly compares the transient period of temperature rise to a transient rise of current in a d-c. circuit containing a resistance r and an inductance L. In the latter case, the rise in current is also exponential and depends upon the time constant (L/r) of the circuit. However, a stator, or a rotor, is more nearly analogous to a system of two coupled electric circuits, in which the current rise is represented by two or more exponential terms, each with a different time constant[4].

With the notation given at the end of the paper[5],

$$p_1\, d\, t = \theta_1\,(s_1 - s_{12})\, d\, t + (\theta_1 - \theta_2)\, s_{12}\, d\, t + k_1\, d\, \theta_1 \quad (1)$$

$$(\theta_1 - \theta_2)\, s_{12}\, d\, t + p_2\, d\, t = \theta_2\,(s_2 - s_{12})\, d\, t + k_2\, d\, \theta_2 \quad (2)$$

These equations are similar to Doctor Kennelly's equation (**19**), and refer to the metal Parts 1 and 2 of one of the principal members of the machine respectively,— say the stator winding and the stator core. Equation (**1**) expresses the fact that the heat $p_1\, d\, t$, developed in the part 1 during an infinitesimal element of time, $d\, t$, is used up in three ways: The part $\theta_1\,(s_1 - s_{12})\, d\, t$ is communicated to the ambient air or other cooling medium; the part $(\theta_1 - \theta_2)\, s_{12}\, d\, t$ is communicated to the Part 2 of the machine, and the remainder, $k_1\, d\, \theta_1$, raises the temperature of the Part 1 by $d\, \theta_1$. Equation (**2**) has a similar meaning for Part 2, with the term $(\theta_1 - \theta_2)\, s_{12}$ considered as part of the heat input.

Dividing throughout by $d\, t$, and introducing the "deficiencies", $\delta_1 = \theta_{10} - \theta_1$ and $\delta_2 = \theta_{20} - \theta_2$, in place of the temperatures themselves, equation (**1**) becomes,

$$p_1 = (\theta_{10} - \delta_1)\,(s_1 - s_{12}) + [(\theta_{10} - \delta_1) - (\theta_{20} - \delta_2)]\, s_{12} + k_1\, d\,(\theta_{10} - \delta_1)/d\, t \quad (3)$$

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2. For a theory of such simple heating curves see, for example, V. Karapetoff, *Experimental Electrical Engineering*, First Edition, 1909, p. 442.

3. A. E. Kennelly, *The Thermal Time Constants of Dynamo-Electric Machines*, A. I. E. E. JOURNAL, 1925, Vol. 44, p. 142.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., Feb. 8-11, 1926.

4. G. W. Pierce, Electric Oscillations and Electric Waves, 1920, Chap. 7.

5. This notation is made to agree, as much as possible, with that in Dr. Kennelly's paper referred to above.

After the ultimate temperatures, θ_{10} and θ_{20}, have been reached,
we have, $\delta_1 = \delta_2 = 0$, and $d\,\delta_1/d\,t = 0$. Hence, for $t = \infty$, equation (3) becomes:

$$p_1 = \theta_{10}(s_1 - s_{12}) + (\theta_{10} - \theta_{20})\,s_{12} \qquad (4)$$

By analogy, equation (2) gives,

$$p_2 = \theta_{20}(s_2 - s_{12}) + (\theta_{20} - \theta_{10})\,s_{12} \qquad (5)$$

Substituting these values of p_1 and p_2 in equation (3) and in a similar equation obtained from equation (2), after reduction we get,

$$\delta_1 s_1 - \delta_2 s_{12} + k_1\,d\,\delta_1/d\,t = 0 \qquad (6)$$

$$\delta_2 s_2 - \delta_1 s_{12} + k_2\,d\,\delta_2/d\,t = 0 \qquad (7)$$

Equations (6) and (7) are simultaneous differential equations for δ_1 and δ_2, and their solution gives the desired expressions for the heating curves of the two metal parts of the stator or the rotor. To eliminate δ_2, differentiate equation (6) with respect to t. This gives,

$$s_1\,d\,\delta_1/d\,t - s_{12}\,d\,\delta_2/d\,t + k_1\,d^2\,\delta_1/d\,t^2 = 0 \qquad (8)$$

Multiply equation (6) by s_2, equation (7) by s_{12}, equation (8) by k_2, and add the three equations together. The variable δ_2 is then eliminated, and the result is

$$k_1 k_2\,d^2\,\delta_1/d\,t^2 + (k_1 s_2 + k_2 s_1)\,d\,\delta_1/d\,t + (s_1 s_2 - s_{12}^2)\,\delta_1 = 0 \qquad (9)$$

The solution of this equation is of the form

$$\delta_1 = A_1\,\epsilon^{-t/\sigma} + B_1\,\epsilon^{-t/\tau} \qquad (10)$$

where A_1 and B_1 are the constants of integration, and σ^{-1} and τ^{-1} are the roots of the "auxiliary" quadratic equation[6]

$$k_1 k_2\,x^2 - (k_1 s_2 + k_2 s_1)\,x + (s_1 s_2 - s_{12}^2) = 0 \qquad (11)$$

Solving this equation for x, gives

$$x = m \pm \sqrt{n^2 + q_1 q_2} \qquad (12)$$

where

$$m = 0.5\,[(s_1/k_1) + (s_2/k_2)] \qquad (13)$$

$$n = 0.5\,[(s_1/k_1) - (s_2/k_2)] \qquad (14)$$

$$q_1 = s_{12}/k_1\ ;\ q_2 = s_{12}/k_2 \qquad (15)$$

Let, for the sake of abbreviation,

$$r = \sqrt{n^2 + q_1 q_2} \qquad (16)$$

so that

$$q_1 q_2 = r^2 - n^2 \qquad (16a)$$

Since the thermal time constants, σ and τ, are the reciprocals of the two values of x in equation (12), we have,

$$\sigma^{-1} = m + r \qquad (17)$$

$$\tau^{-1} = m - r \qquad (18)$$

The subscripts of the coefficients in equation (9) are symmetrical with respect to 1 and 2. Hence, an identical equation may be written for δ_2, and the exponents σ and τ are the same for both δ_1 and δ_2. Thus, the general expression for δ_2 is:

$$\delta_2 = A_2\,\epsilon^{-t/\sigma} + B_2\,\epsilon^{-t/\tau} \qquad (19)$$

Substituting in equations (10) and (19) $t = 0$, gives

$$\theta_{10} = A_1 + B_1 \qquad (20)$$

$$\theta_{20} = A_2 + B_2 \qquad (21)$$

Substituting the values of δ_1 and δ_2 from equations (10) and (19) in equation (6), and equating separately the coefficients of $\epsilon^{-t/\sigma}$ and $\epsilon^{-t/\tau}$, gives the following two necessary relationships between A_1 and A_2, and between B_1 and B_2:

$$A_1(\sigma s_1 - k_1) = s_{12}\,\sigma A_2 \qquad (22)$$

$$B_1(\tau s_1 - k_1) = s_{12}\,\tau B_2 \qquad (23)$$

A substitution of the same values of δ_1 and δ_2 in equation (7) will give no new relationships between the above constants of integration. Solving equations (20) to (23) as simultaneous equations, and using equation (16a), we get:

$$A_1 = [(r + n)\,\theta_{10} - q_1\,\theta_{20}]/2\,r \qquad (24)$$

$$B_1 = [(r - n)\,\theta_{10} + q_1\,\theta_{20}]/2\,r \qquad (24)$$

$$A_2 = [(r - n)\,\theta_{20} - q_2\,\theta_{10}]/2\,r \qquad (26)$$

$$B_2 = [(r + n)\,\theta_{20} + q_2\,\theta_{10}]/2\,r \qquad (27)$$

These values are to be used in equations (10) and (19).

As a check on the foregoing expression, let, in a limiting case, the two hot bodies be entirely independent of each other: that is, put $s_{12} = 0$. Then $q_1 = q_2 = 0$; $r = n$; $\sigma^{-1} = s_1/k_1$; $\tau^{-1} = s_2/k_2$; $B_1 = A_2 = 0$; $A_1 = \theta_{10}$; $B_2 = \theta_{20}$.

Hence, equations (10) and (19) become:

$$\delta_1 = \theta_{10}\,\epsilon^{-t\,s_1/k_1};\ \delta_2 = \theta_{20}\,\epsilon^{-t\,s_2/k_2} \qquad (28)$$

which agrees with Doctor Kennelly's results for a single hot body.

If the losses themselves are functions of temperature, so that p_1, instead of being a constant, is, for example, a linear function of δ_1, the general form of equation (3) remains unchanged, although the coefficients will have a different meaning. The same is true of p_2. Hence, the general expressions for δ_1 and δ_2 will be of the same mathematical form as equations (10) and (19), only the coefficients and their interpretation will have to be deduced anew, following the general method used above.

Practical Application of the Above Formulas

In order to apply equations (10) and (19) to a given machine, it is necessary to determine the thermal dissipation coefficients s_1 and s_2, the heat transmission coefficient s_{12}, and the thermal capacities k_1 and k_2. As a concrete example, consider the stator of a synchronous machine, and let the subscript 1 refer to the winding and the subscript 2 to the iron core. Let the machine be run at a certain load until the constant ultimate temperatures, θ_{10} and θ_{20}, have been reached

6. See any text book on differential equations, chapter on linear equations with constant coefficients.

and measured. Let the values of the copper loss, p_1, and of the core loss, p_2, be also known. Then, equations (**4**) and (**5**) contain three unknown quantities, s_1, s_2, and s_{12}. Let a heat run be made also at some different values of the losses, say p_1' and p_2', and let the final temperatures be θ_{10}' and θ_{20}'. Then two more equations, similar to equations (**4**) and (**5**), may be written, giving altogether four equations with three unknown quantities. If these quantities, determined from three of the equations, also satisfy the fourth, then all is well and an additional check has been obtained on both the theory and the measurements. In case of an unimportant discrepancy, an adjustment can be made of all or some of the quantities involved, to satisfy the four equations with a reasonable accuracy.

To determine k_1, equation (**6**) is applied to the beginning of the experimentally obtained heating curves of both the winding and the core. Namely, at $t = 0$, $\delta_1 = \theta_{10}$ and $\delta_2 = \theta_{20}$; $(d\,\delta_1/d\,t)_0$ is the slope of the curve (taken with the minus sign) of the lower portion of the heating curve where it is practically a straight line. Substituting these values in equation (**6**), we get:

$$k_1 = (\theta_{10}\, s_1 - \theta_{20}\, s_{12}) / (-\,d\,\delta_1/d\,t)_0 \qquad \textbf{(29)}$$

A similar expression for k_2 may be written from equation (**7**).

Knowing the foregoing five constants of the machine, the auxiliary quantities $m, n, q_1, q_2, r, \sigma$, and τ may be readily computed from the expressions given above. After this, the parameters A_1, B_1, A_2, B_2 may be evaluated for any desired values of ultimate temperature rise, θ_{10} and θ_{20}, and equations (**10**) and (**19**) used to predict the shapes of the heating curves of both the core and the winding for any desired interval of time.

The values of θ_{10} and θ_{20} depend upon the losses in the machine. Knowing the losses p_1 and p_2, and the coefficients s_1, s_2, s_{12}, the values of θ_{10} and θ_{20} may be determined by solving equations (**4**) and (**5**) as simultaneous equations. The result is

$$\theta_{10} = \frac{p_1\, s_2 + p_2\, s_{12}}{s_1\, s_2 - s_{12}^2} \qquad \textbf{(30)}$$

$$\theta_{20} = \frac{p_2\, s_1 + p_1\, s_{12}}{s_1\, s_2 - s_{12}^2} \qquad \textbf{(31)}$$

Thus, with the aid of the foregoing theory, knowing the ultimate temperature rise at two different loads, and the initial slope of the heating curves at one of these loads, it is possible to predict the complete shape of the heating curves under any load conditions for which the losses are known.

Instead of determining, experimentally, the ultimate temperature rise at two different loads, it is also possible to use only one set of heating curves (one for the core and one for the winding), even without reaching the ultimate temperatures. In this case the unknown thermal constants of the machine should be determined by the method of least squares, to satisfy equations (**10**) and (**19**)[7]. The computations will be considerably more involved, but a heat run is saved, and the only heat run to be performed need not be continued until the stationary conditions have been reached. With very large machines, these considerations may outweigh the tediousness of extra computations.

NOTATION

- A a constant, in deg. cent.
- B a constant, in deg. cent.
- k thermal capacity of a body, in kw-hrs. per deg. cent.
- m defined by equation (**13**), in (hours)$^{-1}$
- n defined by equation (**14**), in (hours)$^{-1}$
- p heat input, in kw.
- q defined by equation (**15**), in (hours)$^{-1}$
- r defined by equation (**16**), in (hours)$^{-1}$
- s thermal dissipation coefficient, in kw. per degree centigrade of temperature difference; this coefficient includes the heat loss to the ambient medium and that to the other part of the composite body.
- t time, in hours
- x auxiliary notation for σ^{-1} and τ^{-1}, equations (**11**) and (**12**)
- δ deficiency in temperature, that is, the difference $\theta_0 - \theta$.
- θ temperature rise, in degrees centigrade, above the ambient medium.
- θ_0 ultimate temperature rise.
- σ, τ time constants of a combination of two bodies, in hours.

NOTE 1. Where the subscripts 1 and 2 are used in the text, 1 refers to a copper winding and 2 refers to the iron core separated from it by a layer of insulation. The subscript 12 refers to the heat conductance of this insulation.

NOTE 2. The fundamental units assumed in the notation are the kilowatt, the kw-hr., the hour, and the deg. cent. However, the formulas hold true with any units, provided that these are consistent among themselves; for example, the watt, the joule, the second, and a degree of any desired thermometer scale.

Some recent articles on heating of electrical machinery:

E. Hughes, (British) *Inst. El. Engrs. Journal*, 1924, Vol. 62, p. 628.

M. L. Keller, *Archiv f. Elektrot.*, 1924, Vol. 13, p. 292.

W. H. Cooney, JOUR., A. I. E. E., Vol. 44, p. 1342, Dec. 1925.

See also: R. Richter, *Elektrische Maschinen* (Berlin, 1924), Vol. 1, pp. 350 to 365.

7. V. Karapetoff, *Engineering Mathematics*, Vol. III, pp. 59-66.

Alternating Current Analysis

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FOR a good many years past, I have made use of an analytic method, of solving alternating-current problems, requiring simple algebra only. Inquiry appears to indicate that it has not heretofore appeared in print, or been used by others. For most purposes, it appeals to me more than any of the usual methods. With the thought that it may make a similar appeal to others, the bases of it and a few simple applications by way of illustration are given in what follows.

Suppose we have a resistance r and a reactance x, in series; and suppose we impress upon the circuit the voltage e. The alternating voltage triangle gives us the relation:

$$e^2 = (i\,r)^2 + (i\,x)^2 \tag{1}$$

Now though equation (1) applies directly only to a circuit in which the resistance and reactance are in series, it will also apply to a circuit made up of resistances and reactances in parallel, or to a mixed circuit of resistances and reactances in any and all possible series and parallel arrangements; *provided*, the value of r in the equation is such that its effect will be the equivalent of the combined effect of the separate resistances in the mixed circuit; and *provided*, the value of x is such that its effect will be the equivalent of the combined effect of the separate reactances in the mixed circuit. That is, for any mixed circuit there are values of resistance and of reactance, respectively, which when employed in a simple series circuit will give the same results, as to current and phase, as are given by the combined action of the separate resistances and reactances of the mixed circuit.

If we multiply equation (1) by i^2 we get:

$$(e\,i)^2 = (i^2\,r)^2 + (i^2\,x)^2 \tag{2}$$

Broadly interpreted, equation (1) says that the square of the component of impressed e. m. f. in step with the current, added to the square of the component of impressed e. m. f. in quadrature to the current, gives a value equal to the square of the impressed e. m. f. While equation (2) says that the square of the "active power" added to the square of the "reactive power" gives a value equal to the square of the "apparent power." The method is based upon equation (2).

The only difference of phase there can be in the case of active power is that of 180 deg. That is, if we calculate the active power of any subcircuit[1] of a mixed circuit, it will either be in step with the active power of any other given subcircuit, or it will be directly opposed to it; *i.e.*, it will be either positive or negative with respect to it. Therefore, the active power components of the several subcircuits of a mixed circuit may be algebraically added. The same thing is true for the reactive power. The only case in which active power can be negative is that in which a component of generated e. m. f.—other than the impressed e. m. f., and opposed to the current—is included in the circuit or in one of its subcircuits. In the case of reactive power, however, the sign may be negative without an additional generated e. m. f., since we may have a negative—*i. e.*, condensive—reactance in circuit.

It follows, therefore, that we can lay down this general rule of procedure, applying to any circuit or any part thereof:

Calculate the active power of each subcircuit. Find the algebraic sum of the values of active power of the several subcircuits. This sum is the total net active power of the whole mixed circuit. Following a similar procedure relative to the reactive power, find the total net reactive power of the whole mixed circuit. The sum of the squares of these two quantities is equal to the square of the apparent power delivered to the circuit as a whole.

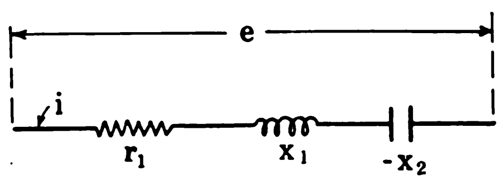

FIG. 1

By making use of this rule, alternating-current circuits may be solved by the use of simple algebra. Furthermore, only resistances and reactances, and their combinations, need be dealt with. There will be no necessity for employing their reciprocals and combinations thereof.

Applying the method to the circuit of Fig. 1, we have:

$$(e\,i)^2 = (i^2\,r_1)^2 + (i^2\,x_1 - i^2\,x_2)^2 \tag{3}$$

From this we obtain:

$$e = i\,\sqrt{r_1^2 + (x_1 - x_2)^2} \tag{4}$$

$$i = \frac{e}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \tag{5}$$

The power factor is:

$$\cos\varphi = \frac{i^2\,r_1}{e\,i} = \frac{r_1}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \tag{6}$$

1. The term subcircuit is used to indicate any one of the simplest branches of which the mixed circuit is made up. That is, a branch in which all the resistances and reactances are in series. When a circuit consists of one single series branch, then there is no subcircuit; or, the circuit is, itself, the subcircuit.

For Fig. 2 we have:

$$(e\,i)^2 = (i_1^2\, r_1 + i_2^2\, r_2)^2 + (i_1^2\, x_1^2 - i_1^2\, x_2 + i_2^2\, x_3 - i_2^2\, x_4)^2 \qquad (7)$$

But from (5) we know that:

$$i_1^2 = \frac{e^2}{r_1^2 + (x_1 - x_2)^2} \qquad i_2^2 = \frac{e^2}{r_2^2 + (x_3 - x_4)^2}$$

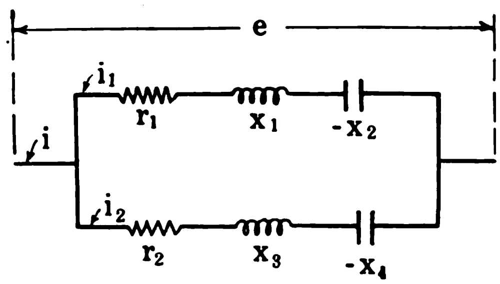

FIG. 2

Substituting these values for current in (7) and reducing

$$i_3^2 = \frac{e_3^2}{r_3^2 + x_3^2} \qquad i_4^2 = \frac{e_3^2}{r_4^2 + x_4^2}$$

We know from (8) that:

$$e_1^2 = \frac{i^2}{\left(\frac{r_1}{r_1^2 + x_1^2} + \frac{r_2}{r_2^2 + x_2^2}\right)^2 + \left(\frac{x_1}{r_1^2 + x_1^2} + \frac{x_2}{r_2^2 + x_2^2}\right)^2} = \frac{i^2}{a^2} \qquad (13)$$

$$e_3^2 = \frac{i^2}{\left(\frac{r_3}{r_3^2 + x_3^2} + \frac{r_4}{r_4^2 + x_4^2}\right)^2 + \left(\frac{x_3}{r_3^2 + x_3^2} + \frac{x_4}{r_4^2 + x_4^2}\right)^2} = \frac{i^2}{b^2} \qquad (14)$$

In which a and b are used to indicate the quantities in the denominators in order to avoid the repeated

$$i = e\sqrt{\left(\frac{r_1}{r_1^2 + (x_1 - x_2)^2} + \frac{r_2}{r_2^2 + (x_3 - x_4)^2}\right)^2 + \left(\frac{x_1 - x_2}{r_1^2 + (x_1 - x_2)^2} + \frac{x_3 - x_4}{r_2^2 + (x_3 - x_4)^2}\right)^2} \qquad (8)$$

The power factors of the whole circuit, the upper subcircuit and the lower subcircuit are, respectively:

$$\cos\varphi = \frac{i_1^2\, r_1 + i_2^2\, r_2}{e\, i} = \frac{\frac{r_1}{r_1^2 + (x_1 - x_2)^2} + \frac{r_2}{r_2^2 + (x_3 - x_4)^2}}{\sqrt{\left(\frac{r_1}{r_1^2 + (x_1 - x_2)^2} + \frac{r_2}{r_2^2 + (x_3 - x_4)^2}\right)^2 + \left(\frac{x_1 - x_2}{r_1^2 + (x_1 - x_2)^2} + \frac{x_3 - x_4}{r_2^2 + (x_3 - x_4)^2}\right)^2}} \qquad (9)$$

$$\cos\varphi_1 = \frac{i_1^2\, r_1}{e\, i_1} = \frac{r_1}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \qquad (10)$$

$$\cos\varphi_2 = \frac{i_2^2\, r_2}{e\, i_2} = \frac{r_2}{\sqrt{r_2^2 + (x_3 - x_4)^2}} \qquad (11)$$

From these values of $\cos\varphi$ we may obtain the phase angles between the currents and between them and the e. m. fs.

In the preceding, a positive and a negative reactance is assumed in each subcircuit, in order to illustrate the method more clearly. A single reactance might have been employed as representing the algebraic sum of the reactances in each subcircuit, just as the single resistance represents the algebraic sum of the resistances. In Fig. 3 such an expedient has been adopted, in order to simplify operations. In the following equations, therefore, while the reactances are all shown as positive, they may be either positive or negative.

For Fig. 3 we have:

$$(e\,i)^2 = (i_1^2\, r_1 + i_2^2\, r_2 + i_3^2\, r_3 + i_4^2\, r_4)^2 + (i_1^2\, x_1 + i_2^2\, x_2 + i_3^2\, x_3 + i_4^2\, x_4)^2 \qquad (12)$$

But we know from (5) that

$$i_1^2 = \frac{e_1^2}{r_1^2 + x_1^2} \qquad i_2^2 = \frac{e_1^2}{r_2^2 + x_2^2}$$

writing of them. Substituting these values of e_1^2 and e_3^2 in the equations for currents we have:

$$i_1^2 = \frac{i^2}{(r_1^2 + x_1^2)\, a^2} \qquad (15)$$

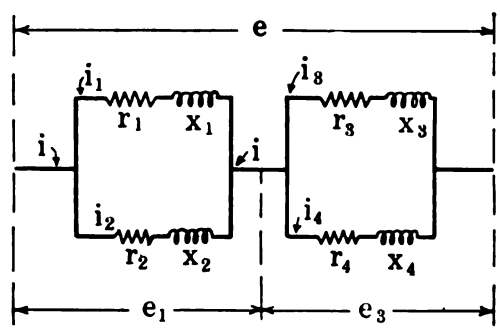

FIG. 3

$$i_2^2 = \frac{i^2}{(r_2^2 + x_2^2)\, b^2} \qquad (16)$$

$$i_3^2 = \frac{i^2}{(r_3^2 + x_3^2)\, b^2} \qquad (17)$$

$$i_4^2 = \frac{i^2}{(r_4^2 + x_4^2)\, b^2} \qquad (18)$$

Putting these values of i_1^2, i_2^2, i_3^2 and i_4^2 in (**12**) and reducing we get:

$$i = \frac{e}{\sqrt{\left(\frac{r_1}{(r_1^2+x_1^2)a^2}+\frac{r_2}{(r_2^2+x_2^2)a^2}+\frac{r_3}{(r_3^2+x_3^2)b^2}+\frac{r_4}{(r_4^2+x_4^2)b^2}\right)^2+\left(\frac{x_1}{(r_1^2+x_1^2)a^2}+\frac{x_2}{(r_2^2+x_2^2)a^2}+\frac{x_3}{(r_3^2+x_3^2)b^2}+\frac{x_4}{(r_4^2+x_4^2)b^2}\right)^2}}$$

$$= \frac{e}{c} \qquad (19)$$

Where c is used to avoid repeating the quantity under the radical.

Substituting this value of i in equations (**13**), (**14**), (**15**), (**16**), (**17**) and (**18**), we get:

$$e_1 = \frac{e}{a\,c} \qquad (20)$$

$$e_3 = \frac{e}{b\,c} \qquad (21)$$

$$i_1 = \frac{e}{a\,c\,\sqrt{r_1^2 + x_1^2}} \qquad (22)$$

$$i_2 = \frac{e}{a\,c\,\sqrt{r_2^2 + x_2^2}} \qquad (23)$$

$$i_3 = \frac{e}{b\,c\,\sqrt{r_3^2 + x_3^2}} \qquad (24)$$

$$i_4 = \frac{e}{b\,c\,\sqrt{r_4^2 + x_4^2}} \qquad (25)$$

The power factors of the circuit as a whole and of the several sub-circuits are found after the manner previously employed. From them can be obtained all the phase angles.

In Fig. 3 let:

$r_1 = 0$	$r_2 = \infty$	$r_3 = 0$	$r_4 = r_4$
$x_1 = x_1$	$x_2 = \infty$	$x_3 = -x_3$	$x_4 = x_4$

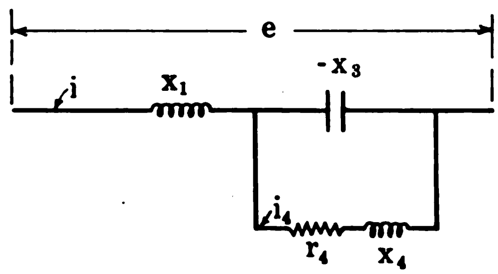

Fig. 4

Then Fig. 3 resolves itself into Fig. 4. And if these values be substituted in equation (**25**) we have:

$$i_4 = \frac{e}{\sqrt{r_4^2+x_4^2+\frac{((x_1-x_3)^2+r_4^2)\,x_1^2}{x_3^2}-\frac{2\,(r_4^2+x_4^2)\,x_1}{x_3}+2\,x_4\,x_1}} \qquad (26)$$

Now let x_3 be numerically equal to x_1. Then equation (**26**) becomes:

$$i_4 = \frac{e}{x_1} \qquad (27)$$

That is, i_4 is constant for all values of r_4 and x_4.

This is Boucherot's beautiful scheme for obtaining constant current from a constant voltage source, and vice versa. Unfortunately, it cannot be fully realized in practise, because we cannot have r_1 and r_3 equal to zero. That is, we cannot obtain a condenser and an inductance with no losses in them. However, the condition of constant current may be closely approximated over a limited range, the closeness of approximation and the extent of the range depending upon how low the losses in the condenser and the inductance, respectively, can be kept.

THE LUMINOUS FOUNTAIN OF PARIS

During a recent exposition in Paris some spectacular performances on the River Seine were carried on by means of a specially built and installed array of luminous fountains. Along each side of the Alexander Bridge a steel pipe 1 ft. in diameter with 9000 small holes was suspended, and a 200-h. p. motor pump delivered water under pressure to these two pipes. The closely spaced water jets formed a parabolic curtain on each side of the bridge. A large number of 2000-cp. floodlights, arranged under the bridge and out of sight, illuminated these two curtains brilliantly. As it was necessary to point all of these floodlights downward, their reflectors had to be watercooled to prevent overheating.

Near the bridge several floating luminous fountains were installed. These were specially designed for the purpose and entirely self-maintained. They consisted of round steel caissons of 23-ft. diameter, containing two motor pumps for the high-pressure water and three rings of floodlamps, throwing beams of light through water-tight glass panels upward upon the rising jets of water. There was room within the caisson for an attendant who changed color filters on the floodlamps. Harmonious color effects were assured by means of telephone interconnections between the fountains and to the shore.

Study of Time Lag of the Needle Gap

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Member, A. I. E. E.

and

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Synopsis.—*The study of high-voltage, steep-wave-front transients is difficult from the experimental standpoint because of the very short times involved. Due to the improvement which the cathode-ray oscillograph has enjoyed in recent years, a device is now available, by the use of which transients occuring in times as short as one-millionth of a second or less may be photographed. In the paper, the authors used an oscillograph developed by Dufour in France, with which a brief study was made of the time lag of needle gaps and of a needle to a plane.*

A description of the oscillograph is given including a discussion of the method of operation. The photographic film is placed inside the tube so that the electrons impinge directly on the film. The wave is drawn out along a time axis by the combined action of a sweeping motion and a perpendicular oscillating motion imparted to the electron stream by the action of proper electromagnetic fields.

Tests were made with a wave which was nearly perpendicular, reaching its maximum in about one microsecond. Such a wave was obtained by the discharge of a condenser through a suitable circuit. An oscillogram which shows the wave front used is given, and attention is directed to the 20,800 kilocycle oscillation which appears superimposed on the wave front.

The results of tests in which this wave front was applied to gaps are given and it is shown that with any given gap setting and sparking voltage that the time lags vary through wide limits. It is also shown that, for the same voltage, increased gap settings mean increased lag. The per cent overvoltage, required to keep the lag to two microseconds or less, decreases as the gap spacing increases.

* * * * *

THE STUDY OF TRANSIENTS

ONE of the most difficult and perhaps also one of the most fascinating problems which the electrical engineer of today is called upon to study is that of the transient phenomena occurring in electrical circuits. Failure of apparatus, caused by the puncture or flash-over of insulation due to overvoltages, the duration of which may be of the order of a few micro-seconds, has made desirable the use of lightning arresters which limit the voltage to safe values. Since in practise many of the steep front traveling waves are the result of the sudden releasing of a bound electrostatic charge, lightning arrester laboratories have used the discharge of a suitable condenser to simulate the actual line condition. For this purpose, and for the study of the action of insulation and gaps, impulse generators have been built which may be charged to values as high as 2,000,000 volts.

The limitations and some, at least, of the possible sources of error involved in the use of the impulse generator have been recognized by lightning-arrester engineers for some time. Three years ago the authors began to search for means of recording, on a photographic film, transient phenomena the frequency of which might be a million cycles per second or more. As a result of this search of the literature, the device described in this paper was found.

OSCILLOGRAPHS

A satisfactory oscillograph for the delineation of the volt- or current-time characteristic of a short-time transient must satisfy the following conditions:

1. The device must have no appreciable inertia and must be capable of operating at a frequency of at least one million cycles per second.
2. The device must use little energy in its operation, so that its use will not appreciably disturb the original circuit.
3. The device should be capable of registering both voltage and current simultaneously.
4. The apparatus must be so arranged that a single impulse will be sufficient for a satisfactory photographic impression.
5. The oscillograph should be as simple as possbile and have sufficient accuracy so that the results may be used with confidence.

The first point can be satisfied only by some device using the flow of electrons. When thinking of the available devices, one naturally turns to the Braun tube which has been used for many years as an oscillographic device. As originally developed, the Braun tube consisted of a cathode and an anode in an exhausted tube, together with a fluorescent screen. Unidirectional voltage from a static machine causes a flow of electrons from the cathode to the anode, some of which pass through a small hole in the anode and are deflected by magnetic or electrostatic fields produced by the phenomena being studied, The rays then pass on to the fluorescent screen where a graph is traced the coordinates of which are determined by the deflecting fields. If the phenomenon repeats itself, the graph appears as a stationary pattern, and may be recorded photographically using an exposure of several seconds.

The Braun tube has negligible inertia, and very little energy is required to cause the deflection of the cathode beam. Its speed is the speed of the electron which may be varied between quite wide limits especially if using a heated cathode as in the Western Electric tube. The upper limit of velocity is perhaps one-half that of light.

The fourth condition mentioned, that of recording a single impulse, may be satisfied by placing the photographic film inside the tube in such a way that the electron stream impinges directly on the film. This has been done by several investigators with marked success.

The literature of the Braun tube is quite extensive, and but a few of the available references are given at the end of this paper.

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Abridgment of paper presented at Regional Meeting of Dist. No. 1, Swampscott, Mass., May 7-9, 1925, and at the Annual Convention of the A. I. E. E., Saratoga Springs, N. Y., June 22-26, 1925. Complete copies to members on request.

To a Frenchman, Alexander Dufour, belongs the credit for adapting the Braun tube to the study of transient phenomena. This development is characterized by means whereby a photographic film is placed inside the vacuum chamber and also an arrangement for drawing out the transient along a time axis so that the highest frequencies may be studied.

The Dufour Oscillograph

A description of this oscillograph which was used in the needle-gap lag tests is given in the following paragraphs.

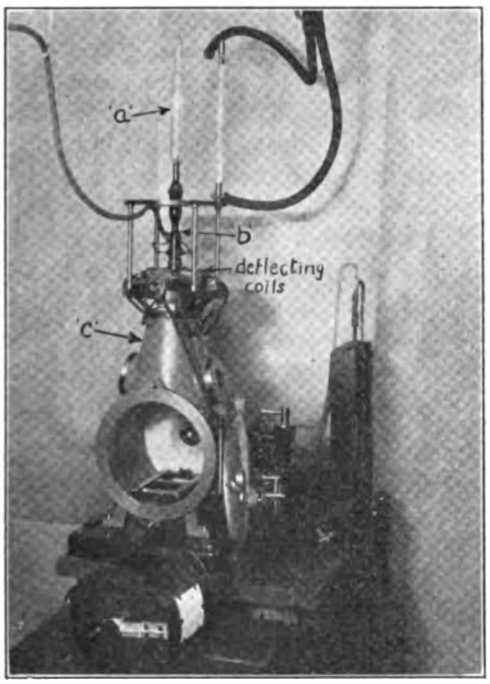

Fig. 1—Dufour Oscillograph

Referring to Fig. 1, the oscillograph consists essentially of glass tubes *a* and *b*, fitted by means of a ground joint into the bronze chamber *c*. The upper glass tube *a* carries the cathode and anode. The tube *b* has one pair of deflecting plates for electrostatic deflection of the electron stream. For magnetic deflection two sets of coils, 1—1 and 2—2 (Fig. 2), perpendicular to each other, are placed external to the tube and located slightly below the deflecting plates. The coils are arranged so that they may be rotated about the axis of the tube, thus allowing adjustment of the angle between the axes of the deflecting fields.

To operate the oscillograph expeditiously, easy means must be provided for changing films quickly. It is also necessary that a fluorescent screen be arranged so that it can be removed when making an exposure. How this is done in the Dufour oscillograph may be seen by referring again to Fig. 1. The drum, which in the illustration appears in the foreground, is provided with a film magazine which allows six films to be taken in succession. When viewing the phenomena, a fluorescent screen is turned up into position covering the opening into the interior of the drum so that the films are not exposed when using the screen. After placing the films in the drum, it is placed inside the bronze chamber and locked in position. The opening is closed by a door having a very carefully constructed joint so that the tube may be made air tight. Three cocks, turning in ground joints placed in the door, serve to operate the mechanism for changing films and moving the fluorescent screen. Two glass windows, one on either side of the bronze chamber, permit of easy view of the fluorescent screen.

Operation of the Oscillograph

For slow speed work a moving drum to take the place of the magazine drum may be used. This drum is driven by means of an external motor and magnetic clutch. A simple calculation shows that such a drum cannot be rotated at a sufficiently high velocity to draw out the oscillations so that they may be studied. To draw out a one million-cycle wave in a manner similar to that used with the ordinary Duddell oscillograph, so that two millimeters are allowed per cycle, would require a film velocity of 2000 meters (6650 feet) per second.

This problem has been solved by Dufour in a very satisfactory manner. Rather than move the film,

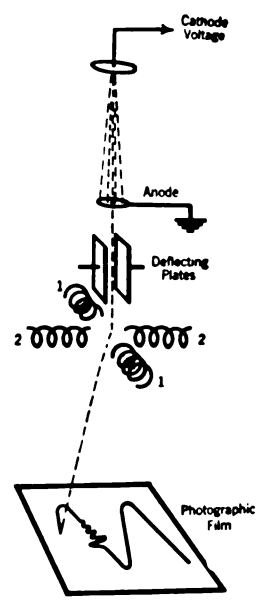

Fig. 2—Diagramatic Representation of Oscillograph Operation

the electron stream is subjected to the action of auxiliary fields which draw out the wave without the limitations of a mechanical system, as shown in Fig. 2. The method by which this is accomplished may be understood by reference to Fig. 3. In I is shown the effect of passing a transient current through coils 1—1. With the proper circuit arrangements the beam is held off the film at the top until ready for the photograph to be taken, when a transient takes place which sweeps the beam across the film holding it off the film at the

bottom. This transient current will be referred to as the sweeping current.

A source of high frequency (a vacuum tube oscillator) is connected to coils 2—2, which are mechanically spaced 90 deg. from coils 1—1. With coils 2—2 energized, the oscillator traces a straight line on the film, the amplitude usually being adjusted to utilize the entire width of the film. When coils 1—1 and 2—2 are operated together the oscillator waves are drawn out as seen in III. If the oscillator frequency is 50,000 cycles and the effective width of the film 100 mm. (3.9 in.), then the average distance corresponding to one microsecond would be 10 mm. (0.39 in.). This means that if a million-cycle wave was impressed on the deflecting plates so that the beam was deflected thereby in the same direction as by the sweeping current, it

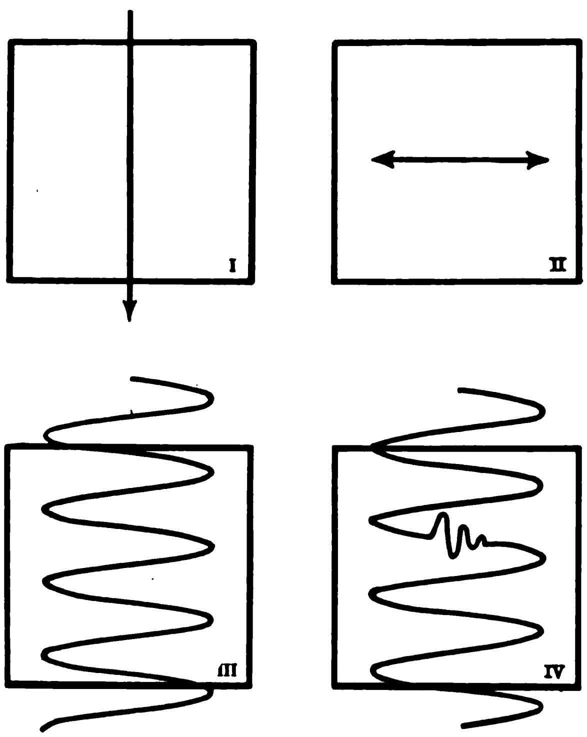

FIG. 3—METHOD OF REGISTERING TRANSIENT PHENOMENA
I. Sweeping III. Sweeping and Oscillator
II. Oscillator IV. Transient superimposed on III

would be drawn out sufficiently so that the wave form could be determined and IV shows the effect of the combination of the three fields. The oscillator wave is the zero line for the transient being studied and it is a time axis whose unit of measure is varying according to the sine law. The speed of sweeping is always a compromise between drawing out the oscillator wave and the difficulty of getting the unknown phenomena timed so as to appear on the film. With much slower speed phenomena, the sweeping field may be placed 90 deg. from that of the unknown transient, so that the time axis becomes a straight line across the film. This axis may be conveniently calibrated by superimposing a known high frequency using the oscillator coils.

Thus it is possible to get volt-time or ampere-time curves with a time axis which can be calibrated with considerable accuracy. Volt-ampere characteristics may be taken by applying to the cathode stream, fields proportional to the voltage and current and spaced 90 deg. apart.

THE CATHODE STREAM

The best registration on the film is obtained when conditions are such that a fine pencil of rays strikes the film only when required. Not only is it desirable to hold the rays off from the film before and after the transient, but the operation of the tube is much improved if the cathode voltage is applied for just sufficient time to allow the proper registration of the unknown transient.

The necessary cathode potential may be obtained by the use of either a high-voltage direct current, or a few degrees of the crest of an alternating potential The latter method may only be used with phenomena which are fast compared to the change of potential. during its registration. This method was mentioned by Dufour as being particularly adapted to the study of very short time transients, and as this method is very convenient it was adopted for use in this study of gap characteristics.

TIMING THE TRANSIENT

The spot made on the photographic film by the electron stream may travel as fast as 80 km. (50 mi.) a second across the film; and since it is not feasible to get a developed registration length of more than 10 or 12 meters (32.8 to 39.2 ft.) on the film, the transient must be initiated during the very short interval of time in which the spot is sweeping across the film.

A rotary switching device has been built which makes the necessary contacts so that voltage is applied to the cathode, the sweeping started and the unknown phenomenon so timed as to appear on the film. The oscillator is connected before voltage is applied to the cathode, and remains connected until after the exposure has been made. The arrangements are such that only the pushing of a button is required to set in operation a mechanism which makes all connections automatically.

TIME LAG OF NEEDLE GAPS

It is known that a needle gap shows considerable lag when subjected to steep wave front impulses. The brief study which is presented herewith measures definitely the lags encountered under the given conditions. The results are not complete, but do give for the first time, as far as the authors are aware, a direct measurement of lags as short as a few micro-seconds. The methods used here are being applied to the study of the problems encountered in lightning arrester practise and will yield results of great importance.

The time lag of a gap may be taken as the time elapsing until breakdown occurs during which the applied potential exceeds the low frequency spark potential. For a voltage only slightly in excess of the

low frequency spark potential the time lag may be long, while with steep wave fronts of high voltage it will be extremely short. The lag with any given gap is determined not only by the voltage at the time of spark-over, but also by the shape of the wave front used.

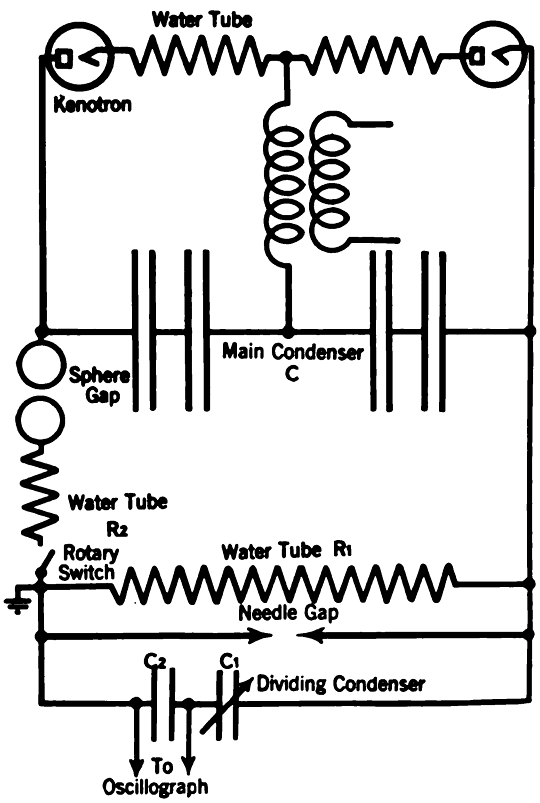

FIG. 4—CONNECTION DIAGRAM

The purpose of these tests is to find the effect of successive increments of overvoltage on the time lag. To avoid the complication of a sloping wave front, it was thought best to use as nearly rectangular a wave as could be obtained. It is impossible to produce a perfect rectangular wave but if the time required for the voltage to reach a constant value is small in comparison with the time taken by the gap under test to spark over, the error will be negligible.

TEST ARRANGEMENTS

An impulse generator, which was built for use in connection with the testing of lightning arresters, was used as a source of voltage. This generator consists of two hundred glass plates with tinfoil coatings divided into four groups connected in series, each group consisting of 50 plates in parallel, giving a capacity of 0.13 microfarads. A connection diagram is given in Fig. 4 and shows the limiting sphere-gap which determines the voltage at which discharge will take place. The water tube resistance, R_1, allows the sphere-gap to charge up properly, while R_2 is used to control the wave front as will be shown later. The dividing condensers, C_1 and C_2, were used for reducing the voltage to the proper value for the deflecting plates on the oscillograph.

The oil-immersed dividing condensers are shown in Fig. 5, together with the needle gap being tested. The capacity of C_1 at the setting used on the tests was about 20 micro-microfarads. Variable stray capacities to ground and inductive effects between the condenser and the oscillograph were eliminated by using a ground shield around the dividing condenser.

Voltage calibrations were obtained from capacity measurements, and more directly by taking oscillograms when holding a known 60-cycle voltage on the dividing condensers.

WAVE FORM

Fundamentally, the circuit shown in Fig. 4 represents the discharge of one capacity into another with small series inductance and considerable series resistance. The circuit is of course complicated by the use of series gaps, wires leading to oscillograph, etc. With such a circuit, the series resistance R_2 will increase the time required to charge the capacity of the dividing condenser and connections.

The effect of changing R_2 may be seen by referring to Fig. 6, which shows the wave fronts with three different values of resistance. The method of registration used is the same as that described in connection with Fig. 3 and consists in applying an upward sweeping motion, combined with the horizontal motion of the oscillator. Superimposed is the discharge of the condenser which is initiated by the action of the rotating switch.

On the oscillograms given in Fig. 6 will be found two sets of oscillations, the first being damped out rather quickly. This oscillation, which has a frequency of approximately 20,000 kilocycles, occurs when the rotating switch sparks and is followed by another when the limiting gap sparks. There is a certain variable time interval between the sparking of these two gaps.

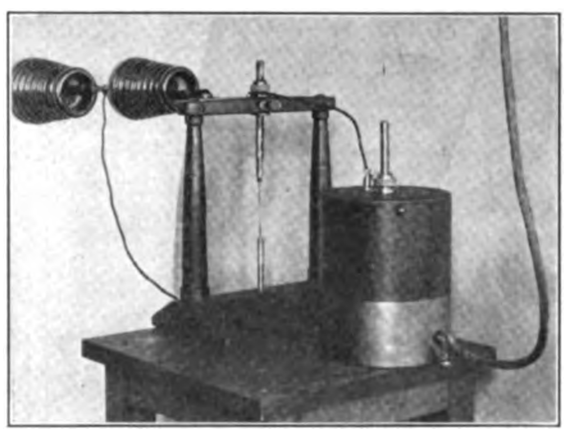

FIG. 5—DIVIDING CONDENSERS AND TEST NEEDLE-GAP

In making these tests the aim was to obtain a steep wave front but at the same time to prevent the voltage from over shooting. Film 300 (Fig. 6) shows the main

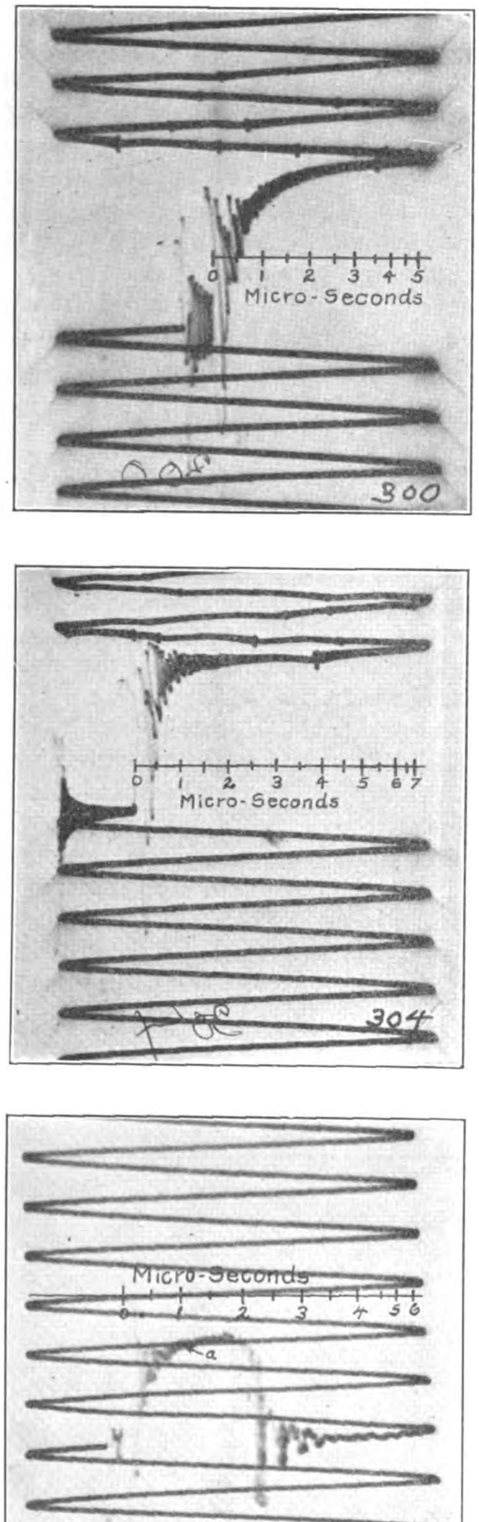

FIG. 6—OSCILLOGRAMS SHOWING THE WAVE FRONT USED ON NEEDLE GAP TESTS

Film 300—Oscillator frequency 42.6 kc showing wave form with 1100 ohms series resistance. Voltage reaches constant value in 2.5 micro-seconds.

Film 304—Oscillator frequency 42.6 kc. Wave form with 570 ohms series resistance. Voltage reaches constant value in 0.4 microseconds.

Film 593—Oscillator frequency 50 kc. Wave form with 700 ohms series resistance. Voltage reaches constant value in 1.0 microseconds. Needle gap sparks after 0.83 microsecond. Gap setting 65mm. voltage 75 kv.

transient rising to its maximum value in about 25. micro-seconds. Superimposed on this wave front are oscillations which are made up of a combination of several frequencies. Film 300, which was taken with 1100 ohms in series, shows that none of the oscillations has a voltage exceeding the maximum value of the main transient.

The series resistance was reduced to 570 ohms and film 304 taken. This film shows that the main transient rises to its maximum in about 0.4 micro-second. This resistance is too small however, as some of the crest values of the superimposed oscillation exceed the final voltage. A value of 700 ohms was chosen as being the best compromise between the steepness of wave front and the condition of overshooting. Film 593 was taken, using this series resistance, and it was found that a time of one micro-second was required for the voltage of the main transient to reach its full value (marked *a* on the film). This film is interesting as it shows the sparking of a needle-gap 0.8 micro-second after full voltage had been applied.

RESULTS OF TESTS

The time lags under most test conditions used exceeded two micro-seconds, which made the use of the oscillator undesirable except for timing purposes; therefore, nearly all results were taken with the sweeping only, as this allowed several exposures on one film. With six films and five tests per film, it was possible to get 30 tests before releasing the vacuum and changing the magazine drum. The use of the sweeping also gives a uniform time scale for the measurement of the lag.

The results of nine representative tests are given in Figs. 7A and B. As this type of oscillogram is probably new to most of the readers of this paper a brief explanation is given. The different tests are numbered in the order in which they were made. In the first test, for instance, which is at the bottom of the film, (No. 543), the cathode spot comes on the film from the left, being swept across the film at a uniform rate corresponding to 4.5 micro-seconds per mm. About 190 micro-seconds later the voltage is applied by the operation of the rotating switch. The cathode beam is deflected upward and traces a horizontal line, parallel with the zero axis, until after 140 micro-seconds the needle-gap under test breaks down and the cathode spot falls to zero and so continues, passing off the film at the right. Although the wave front in this film appears perpendicular, it is really as shown in Fig. 6, film 593.

Four needle-gap breakdowns are given in film 558, Fig. 7B, the voltage being 5 kv. with a needle gap spacing of 60 mm. This film shows a 50-kilocycle timing wave which fixes the time calibration. Fig. 7A film 543 shows the result of tests on a 15-mm. needle-gap with 22 kv. applied. These oscillograms show very nicely the steepness of the wave front compared with the time lags; and also how well the cathode ray oscillograph is adapted to the study of short time phenomena.

Results were obtained from a series of oscillograms for three different voltages and with different needle-gap spacings. Tests were also made with a needle to a plane and between needles having different degrees of sharpness. Some of the results are given in Table I.

An analysis of the results brings out certain relations which are briefly discussed.

For each voltage used, the gap setting, corresponding to infinite lag, will be slightly above the 60-cycle setting for that voltage. The per cent overvoltage above the 60-cycle spark potential necessary to obtain lags of one micro-second or less was found to decrease with increased spacing.

With spacings of 10, 40 and 65 millimeters the per cent overvoltages are 75, 40 and 29 respectively. It is, of course, to be expected that the greater the per cent of overvoltage the shorter the time lag. The results show that this is true, in general, although wide variations in time lag occur with every setting and at all voltages.

An examination of the results discloses the existence of time-lag zones, which indicates that breakdown is more likely to occur within these zones than outside. The existence of these zones is doubtful in some cases, while in others it seems well defined, as for instance at 75 kv. with a 95-mm. spacing (Table I).

In general, the tests show that dull needles give shorter time lags than sharp needles, although more tests should be made to be certain of the relationship.

Comparing the point-plane tests (Point negative), with the needle points having the same spacing the data show that the lags are of the same order of magnitude although the maximum lag with the point-plane is considerably greater than the corresponding value for the points. Tests made with the point positive show that the lag is less than two micro-seconds while with

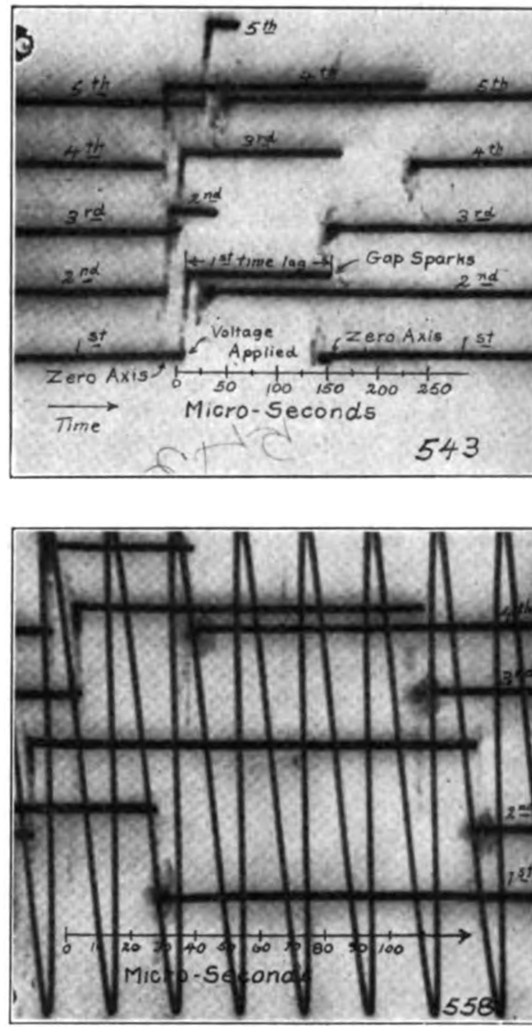

FIG. 7—OSCILLOGRAMS SHOWING THE TIME LAG OF NEEDLE GAP

Film 543—Five tests on needle gap at 15 mm. 22 kv.

Film 558—Four tests on needle gap at 60 mm. spacing 58 kv. 50 K C Timing wave.

TABLE I—TEST DATA
LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE
VOLTAGE 75,000

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per mm.	Time Lags in Micro-seconds	Max. Min. Av.	Per Cent Sparking 1st Range	2nd Range	3rd Range	4th Range
95 mm. Needle Gap 70 per cent sparking at this setting	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	8.5	120- 21- 88- 42- 25 491-406- 34-340-466 339-440-400-460-400	Max. 491 Min. 21 Av. 260	40	0	14	46
80 mm. Needle Gap	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	5	35- 45-280-240-250 35- 40- 30-235- 30 35- 30- 35- 35-335 235- 40- 15-210-230 300-200-250- 45- 30 35- 35- 40- 35-210	Max. 335 Min. 15 Av. 120	58	0	28	14
72 mm. Needle Gap	Relative humidity 26 per cent Bar. 28.8 in. Temp. 19 deg. C.	2.4	38- 38- 43- 48- 26 43- 29- 38- 21- 48 29- 45- 29- 29- 29 29- 2- 17- 55- 60 31- 53- 41- 31- 31	Max. 60 Min. 2 Av. 35	4	48	28	20

the point negative with the same spacing and voltage an average lag of 62 micro-seconds was obtained. When the point was negative with a spacing of 13 mm. sparking occurred with approximately 50 per cent of the voltage applications. With the point positive a similar condition was obtained with a spacing of 19 mm. These results give some conception of the effect of polarity on the lag of a point-plane gap.

Conclusions

An oscillograph is now available, as represented by that made by Dufour, by the use of which single transients may be photographed, without being limited by the inertia of a mechanical system. By its use, wave forms have been photographed having measurable oscillations up to 20,000 kilocycles. The authors have worked with an oscillator frequency of 250 kilocycles which allows the registration of a frequency of 100,000 kilocycles. As the frequency increases, the problem of the characteristics of the circuit used become increasingly important and great difficulty is experienced in keeping the oscillograph circuits free from disturbances emanating from the main impulse circuit. The cathode-ray oscillograph, as used here, becomes a tool of the greatest value in the study of transient phenomena.

The lag tests, with constant voltage on the needle gaps, show that the lags vary between wide limits, the average lag increasing with increased gap settings. The limits could probably be narrowed considerably by the use of careful control of air and electrode conditions. The per cent overvoltage, required to keep the lag to two micro-seconds or less, decreases as the gap spacing increases. The lag is shown to depend on the condition of the needle, the dull needle tending to have the shorter lags.

The authors are continuing the use of the oscillograph, intending to apply it to the study of transients on transmission lines due to lightning and other causes. The breakdown of insulation and the operation of lightning arresters is also being investigated. Acknowledgment is gladly given to the work of Alexander Dufour, who constructed the oscillograph used by the authors in the work described in the paper.

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Discussion at Pacific Coast Convention

220-KV. TRANSMISSION TRANSIENTS AND FLASHOVERS[1]

(Wood)

Seattle, Wash., September 15, 1925.

Percy H. Thomas: This paper appears to clear away definitely the persistent suspicions that there is some source of mysterious overpotential inherent in 220 kv. or in very long lines, that does not appear on the surface—something involving an unrecognized principle and jeopardizing reliability of service.

The subject of surges and high-voltage breakdowns has long been a *bête noir* for transmission operation. When power transmission first became of importance, one of the first serious sources of shut-down other than the ever-present lightning was the frequent short circuit of transformers in high-tension service. While this proved to be due partly to moisture and inadequate insulation, it was, nevertheless, necessary that the now well-known but then almost unknown effect of the steep-wave-front surge on windings be studied out[2] and this led to radical change in the method of insulating high-tension windings. While the theory of the propagation of surges or waves in transmission lines was academically known, nobody knew what the real effect in an actual line practically was and this led to a certain feeling of uncertainty as to what might be expected with plant extensions. This led to a series of investigations in 1902 in the middle west on a number of high-tension plants, similar in object to those reported by Mr. Wood and leading to a somewhat similar conclusion.[3] In the old investigation, the voltages were lower and the apparatus cruder but the interest was much the same.

At still a later period, with the advent of larger systems and higher voltages, still another experimental study was made, this time based largely upon the oscillographs covering the action of switching and surges in the system of the Pacific Gas & Electric Company[4] and still again with the result of disproving the existence of any new or unexpected phenomena.

Mr. Wood's work goes over the research again, taking up all possible sources of excessive surges and using perfected apparatus. This makes clear the conclusion that the explanation of mysterious surges even on 220-kv. lines must be sought among the well recognized laws of electric phenomena.

Considering, now, the detail of the paper, it may be pointed out that the results of the klydonograph appear to agree with the old fundamental rules of wave motion, e. g.: (a) When a potential is abruptly applied to a transmission line, a wave equal in crest to the applied potential passes along the line until it reaches a reflecting point when it is reflected back toward the start, reaching *double potential* at the *reflecting point*, neglecting losses. (b) When a small-capacity branch line leads from such a reflecting point, the wave starts off in the branch line at the maximum potential reached at the reflecting point and is subject to reflection at the end of the branch line with another doubling of the potential. (c). Whenever a condenser is charged

1. A. I. E. E. Journal, November, 1925, p. 1211.

2. See paper Percy H. Thomas, Trans. A. I. E. E., "Static Strains in High Tension Circuits and the Protection of Apparatus," Vol. XIX, 1902, p. 213

3. See paper Percy H. Thomas. *An Experimental Study of the Rise of Potential on Commercial Transmission Lines Due to Static Disturbances Caused by Switching, Grounding, etc.*, Trans. A. I. E. E. Vol. 1905, p. 317.

4. Guiseppe Faccioli, *Electric Line Oscillations*, Trans. A. I. E. E. Vol. XXX, Part III, p. 1803.

through reactance (neglecting resistance) the potential will rise to double the charging potential and only gradually settle down to equilibrium after a series of oscillations.

As Mr. Wood properly says, in considering surges in a line, the effect of distance of travel is only to weaken the surge. Other things being equal the effect of a switching operation is greatest nearby.

It is particularly gratifying to find that no abnormal *sustained* high-frequency potentials exist in the line, as these might be exceedingly troublesome.

F. W. Peek, Jr.: Mr. Wood's findings, which are quite in accord with theory, show no mysterious high voltages at sustained high frequency causing arcs of indeterminate distance. The expected highly damped switching surges occur but never of sufficient voltage to cause trouble. The cause of many arc-overs is dirt. In the tests made most of the dirt trouble was a purely mechanical one due to birds and as easily understandable as the effect of a fuse wire dropped over an insulator string. This investigation shows conclusively that there need be little fear from transient voltages originating in a grounded-neutral system.

Thus, in the part of the country where the lines of the Southern California Edison Company are located the chief cause of insulator arc-over is a weakening of the insulators by dirt or other mechanical means.

Other important points brought out are that high-voltage switching may be done without fear, and that with quick-acting relays insulator arc-overs may be cleared without interruption of service. Of course, in addition to quick-acting relays, it is important to have grading shields or rings on the insulator to direct the arc away from the string while the relays are operating.

While dirt is the principal cause of arc-over in certain parts of the country, in other parts its effect may be practically negligible and lightning may be a very serious factor.

To illustrate how well Mr. Wood's conclusions are in agreement with our laboratory investigation I would draw your attention to a recent discussion of mine[5] at the Annual Convention which shows that our conclusions are very similar to Mr. Wood's.

C. L. Fortescue: Klydonograph is derived from two Greek words which mean wave and record. It is a device for making a record of surges. The klydonograph is a very simple instrument which consists merely of an electrode which is connected to the line through a potentiometer device, and measures a voltage proportionate to the tension of the line. This electrode passes over a sensitized plate or film in contact with the insulated surface of a grounded plate. Now the oscillation passing over the line makes a record on this sensitized plate which, after development, shows a figure possessed of certain peculiarities. A figure for a positive wave in any direction is different from the figure for a negative wave, so that it is possible to tell what the polarity of the wave is. One can tell whether it is an oscillating wave and, with certain arrangements, know not only the character of the wave, but also the steepness of the wave fronts and the direction in which the wave is traveling. So, with this device, it is possible to obtain very complete information about surges.

The method of determining the amplitude of the wave consists in measuring the diameter of the figure. The diameter is very closely proportional to the actual amplitude of the wave within the range in which this measurement is useful. In other words, for the higher voltages where the surges are of some concern, the calibration is very close, within 15 per cent.

The first klydonograph consisted merely of an ordinary sensitized photographic plate rotated under the electrode and the plate had dials which would register time on the record. The complete rotation occupied one day. This, of course, was not very convenient inasmuch as the plates had to be changed every day. The present klydonograph is a much more suitable instrument. It consists of the same arrangement except that it has a roll film which goes over an insulated grounded cylinder. The roll needs to be changed only once a week and provision can be made for longer or shorter periods as desired.

Now, so far as possible, we are giving klydonograph service to those who have problems requiring investigation. We have about twenty of these seven-day instruments in operation. We have two experts whose work is devoted solely to looking after the instruments and giving this service. We have investigated quite a large number of systems in the east.

Of course, in carrying out this work we aim to do our field work as much as possible during the summer months when we have lightning, etc., so that we have been able to make only a preliminary analysis of the results. The preliminary analysis shows that in no case were there any signs of high frequency and, in fact the highest frequency we obtained was something less than 30,000 cycles per second. The duration of these surges is very brief. They don't travel very far. They very quickly become damped so the bogey of sustained high frequency does not exist. We haven't found it anywhere. Our experimental work has extended particularly over such portions of the United States in which lightning is very frequent and severe.

Lightning has proved to be the most prolific source of high voltages, but even lightning has caused nothing we need fear. The highest voltage hasn't gone beyond the possibility of insulation.

We expect to carry on this service to the best of our ability, but of course, we are limited as to men and also as to number of instruments. On a large system it is pretty hard to do with less than a dozen instruments; to carry out investigations properly, one should have more.

We expect to do some theoretical work in the winter months, analyzing results of the investigations of the previous months; and we probably shall have to do some work on cable systems during the winter. Cable systems have been very free from surges and that, of course, from theory is what we expect. We wouldn't expect to have the surges in cables due to effects outside, and surges from cables connected to outside lines don't amount to anything at all. I don't think that the trouble with cables can be attributed to outside sources. The troubles with cables are inherently inside the cables themselves; surges may come about due to the trouble in the cables, possibly.

I may state that grounded-neutral systems have been very free from surges due to short circuits and other abnormal operations.

J. H. Cox: Mr. Wood's instructive paper leaves little to be said to lay the ghost of alarming abnormal conditions on the 220-kv. lines of the Southern California Edison Company. As pointed out, the tests were sufficiently extensive to be truly representative of conditions on those lines. Since Mr. Wood's paper tells the whole story so far as his system is concerned, it seems appropriate to present information gathered more recently with the klydonograph on other lines.

During the year 1925 surge investigations have been made on quite a number and variety of systems, both open-wire and cable. The causes of abnormal voltages on transmission lines may be classed under three headings, switching, short circuits and grounds, and lightning.

Switching. For the most part the experience with surges resulting from operating activity has been much the same as that on the Southern California lines. Switching surges in general are less than two times normal in terms of crest voltage to ground. Only two types of operations caused higher surges. One of these was the opening of an idle but energized line on a 15-mi. free-neutral line and caused surges as high as 4.3 times normal. The other was synchronizing with a high-voltage switch at the end of a 150-mi. free-neutral line. These surges reached a maximum of 4.6 times normal.

5. A. I. E. E. JOURNAL, October 1925, p. 1151.

Short Circuits and Grounds. Experience with short circuits and grounds on other grounded-neutral systems has agreed with that on the Southern California Edison lines. No major surges on such lines have resulted from short circuits and grounds either accidentally and intentionally produced. Short circuits and grounds on free-neutral systems have, in general, produced high-voltage oscillations reaching a maximum of 4.5 times normal. These voltages were recorded on the two ungrounded phases in the case of a single-phase ground.

Lightning. As would be expected, lightning has thus far proven to be the best generator of high-voltage surges though in the California Edison System high voltages due to this cause were absent. No differentiation is made by this source between types of systems but it varies widely with locality. In one case a voltage of 1000 kv. to ground was recorded. Many other surges caused by lightning were recorded, ranging from 400 kv. to 700 kv. Some of these were oscillating and others unidirectional. The unidirectional surges were positive in polarity. The oscillating surges were usually recorded at times when an interruption was caused by the stroke.

R. W. Sorensen: During the past twelve years I have been much interested in these line flashovers. Some of our first theories as to the cause included mechanical means, such as spider webs, dirt, soiled insulators, etc. As a basis of the spider-web hypothesis there were found many big spider webs attached to the lines and it was supposed that these webs might become wet and cause some of the flashovers. The possibility of these flashovers being caused by birds was also considered. But, at that time, there was never sufficient conviction to warrant the expense of erecting devices to keep the birds away from the towers as has been done recently.

It is my endeavor in this discussion to encourage the idea of trying to solve our difficulties by doing simple things first, although it seems to be human nature to first apply complicated methods and later simple methods to problem solutions. One of the objects of engineering education should be to teach us, as engineers, to avoid a complicated method of attacking problems.

It must be borne in mind that, although it has not been mentioned in Mr. Wood's paper, he is dealing with a line to which are connected transformers with delta connections so that on this line there is no probability of getting effects such as arcing grounds might produce on Y-Y connections if these connections are not properly supplemented with tertiary windings connected in delta.

G. R. F. Nuttall: Perhaps it would not be out of place to mention the 220-kv. tie line between the Great Western Power Company and the San Joaquin Light & Power Company.

The design and tests on the standard towers have just been completed and Mr. J. A. Koontz, of the Great Western Power Company has taken particular care to shield all points on the towers so that no corona will form near the wires. In order to reduce eccentricity in the joints, it is better to place the bracing in the cage of the towers alternately inside and outside. This inside bracing ordinarily offers quite a sharp edge which is a point where corona might form. Therefore we have bolted a small angle to the outside brace which exposes its flat side to the wire.

Mr. Wood mentioned that they used a dynamometer in stringing their cable, I wonder if we could have information as to the type used, as the spring type is unreliable at the higher tensions.

I should like to present for discussion the question of insulation, not of the line itself but at the ends of the line. Mr. Wood's paper has given us useful information on transient voltages and 220-kv. operation and I wonder what the manufacturers' views are as to the rating of their bushings for oil switches and transformers.

In the case of the Pacific Gas & Electric Company and the Southern California Edison Company I think I am right in saying that the A. I. E. E. ruling (Sept. 1922) has not been upheld. The switch bushing ought to be tested for $2\frac{1}{4}$ times the line-to-line potential which equals 495 kv. for 220 kv. operation, and the transformers (three single-phase, auto-transformers with grounded neutral) at an induced voltage of twice line-to-line potential plus 1000 which equals 481 kv. for 240 kv. at the sending end.

L. N. Robinson: In connection with Mr. Wood's paper, the most effective cure for the flashovers seems to be the bird guards. I wish Mr. Wood would give us a description of them.

D. I. Cone: I wish to comment on a by-product result of Mr. Wood's paper. The table on the seventh page and the oscillograms, tells of the investigation of the normal residual currents of the system, which were found to be without features that would aid in the explanation of transients. This record, if supplemented by data regarding the sizes of transformers, their characteristics and connections, will be of considerable value to the Joint Committee of the National Electric Light Association and the Bell Telephone System, which is studying the distribution of such residual currents in systems of this kind. A special project committee is doing work with a view to enabling us to predict these residuals and their resulting inductive effects upon neighboring lines.

Roy Wilkins: In the discussion on Mr. Wood's paper the question is brought up regarding the insulation on the oil switches and bushings and transformers used on the 220-kv. line. The transformers and switches themselves are tested for 2.73 times the normal voltages to ground; the bushings at 2.25 times line voltage. There is before the Institute's Standards Committee at the present time the proposition to change the requirements for the potential tests on grounded transformer equipment to some such value at 2.73 times line voltage.

H. Richter (communicated after adjournment): The paper states that, on the small overhead networks, the transformers are of the type having a network protector in the same case. This form of network protection has been abandoned on the two systems where it originated, because of faulty operation and lack of real protection. Experience shows that these devices are excellent transformer protectors but cannot be relied upon for network,—that is, service protection. I am rather inclined to ascribe the excellent record of 0.7 per cent transformer burn outs mentioned on the seventh page to the lightning protection offered by the common system neutral, as emphasized on the fifth page. As these protectors are so designed that they do not protect against trouble in the primary or secondary lines, their cost of about $3 per transformer-kv-a. makes a rather high insurance rate against transformer trouble. The substitution of carbon circuit breakers tripped by reverse-power relays in the underground area of Minneapolis is in line with the latest methods of network protection where real reliability of service is demanded.

In general it may be said that the loop method of primary feed is particularly applicable to bulk loads of 300 kv-a. up and fed at the higher primary voltages of 11,000 volts and above. This is because of the high cost of spare capacity in feeders and substation apparatus, high rupture capacity, loop-sectionalizing switches, and pilot-wire control. For underground areas where transformer banks, serving miscellaneous distribution loads, range from 75 to 300 kv-a. each and are spaced on the average 500 ft. apart (but may be up to a maximum of about 1000 ft. apart) there is being installed in six large cities and planned for many others, a very simple system of a-c. distribution. This is the secondary-network system with automatic network protection that was described by A. H. Kehoe[6] and by W. R. Bullard,[7] and that has been in successful operation in New York City for almost three and a half years.

6. Underground Alternating-Current Network, by A. H. Kehoe. A. I. E. E. TRANSACTIONS, 1924, p. 844.

7. A Study of Underground Distribution Systems, by W. R. Bullard. A. I. E. E. TRANSACTIONS, 1924, p. 856.

In this network system the feeders are radial, no primary protective or sectionalizing devices being necessary. The secondary mains are spliced together to form a solid mesh which requires no junction boxes and a compact triple-pole network unit, inserted in the transformer-secondary connections to the network, protects for every type of fault that might interfere with continuity of service except failure of the prime source of power. Advantage is taken of the elimination of primary switches, cut-outs and disconnecting potheads, to employ higher primary voltages such as 13,200 volts. Thus may be saved the cost of either station step-down transformers and lower voltage switches, or even of the entire substation. By limiting the feeder capacity to 150 amperes, each feeder can carry about 3000 kv-a. and be confined to either a small or a large area depending on the load density.

The system of multiple street lighting introduced in Minneapolis is undoubtedly a step ahead both from an operating and economic point of view. However, some electric service companies object to pilot wires for control and others to mercury switches. One manufacturing company has developed a system of control by a form of carrier current over the primary feeders. This dispenses with both of these features and also the reenergizing contactors. The switching units are sturdy, comparatively simple, will not be expensive and are small enough to mount in the vase of an ornamental post. They can also be used in conjunction with a primary switch, for controlling pole-mounting constant-current transformers feeding series lamps. The sender at the station is likewise simple and substantial. Further, there are practically no losses in the switching units.

The system has had a successful trial equivalent to a year's service. It is anticipated that this method of control, together with multiple street lighting, will be the standard street-lighting system of the future.

R. J. C. Wood: There was a question asked about possible slipping of aluminum on steel with changes of temperature. I have given that matter quite a little thought and have come to the conclusion that there is no longitudinal motion between the two metals. Imagine a piece of cable, steel inside and aluminum outside; somewhere it has two ends clamped together, so that the two ends cannot move with respect to each other. If you make it sufficiently hot the aluminum expands away from the steel, but in an actual line, the tension of the cable is sufficient to stretch the steel so that the aluminum does not become loose. In actual construction, I doubt if you will find separation of the aluminum from steel. They will act together as a unit with this exception: with changes of temperature the stress passes from one to the other. The hotter the metal, the greater the stress in the steel; the colder the metal, the more stress in the aluminum.

In closing my paper: the design of the bird guards has been a matter of trial and error. We equipped a portion of the line with what is known as Mr. Barre's bird pans. The bird pans consist of a horizontal tray of metal lying on the lower member of the top crossarm, the idea being that it would form an efficient mechanical shield between the bird and the conductor. Apparently they have worked quite successfully, the only objection being that they are rather expensive, and unless they are very well anchored to the members of the tower, the ordinary vibration sets them imitating big drums, so that there has been some complaint from real estate agents trying to sell property in the immediate neighborhood.

There is another kind of bird guard which is simply an exaggerated saw-toothed, galvanized iron, the points being perhaps 1½ or 2 in. apart and with a height of some 6 in. so that it is a very acute point which is not comfortable to the bird. These were fastened along the members of the tower for a distance of approximately 5 ft. on each side of the center conductor. This line, by the way, is of horizontal construction, and similar pieces of metal were fastened to the sloping portion of the crossarm in the outer positions.

When we first put up these bird guards as mentioned in the paper, we didn't know what a clever fellow the bird was, and we put up one kind of a guard to protect the place we thought he was going to roost upon, but, driven out of there, he took the next best thing. He even goes so far as to climb into a little piece of 6-in. channel which is underneath the main crossarm, a piece only about a foot long, which is a part of the structure from which the center string of insulators is hung. When prevented from getting on the main body of the crossarm, he flew underneath and got into this little cage place, so we have had to protect that too.

Regarding the residual currents and the situation of the transformers and auto-transformers, the information Mr. Cone asked for can be given him, but it really will not be of very much use since it refers to a line which is not transposed. We have been trying ever since the line was built to find time to transpose the conductors, but we have never had time to take the line out of service and do this work. As soon as the third line is in, we expect to be able to take out the other two lines, one at a time, and transpose them. This will balance them, statically, against ground, and will reduce to a considerable degree that residual current.

THE LINE OF MAXIMUM ECONOMY[1]

(KIRSTEN AND LOEW)

SEATTLE, WASH., SEPTEMBER 16, 1925.

C. E. Carey: It seems to me that the authors have laid down a premise which at this time I would like to question, whether or not it is the fundamental premise of this paper.

I question the statement which reads: "Therefore, the basic assumption is made that for maximum economy all lines should be operated at an average voltage slightly below the critical disruptive value of the conductor used. To make the assumption more specific, 90 per cent of the critical disruptive voltage will be assumed as the correct value of the average line voltage in all cases."

When we consider an economic transmission line, we balance the annual cost against the losses, or, in other words, we strive to develop a line which gives the lowest annual operating expense per year, including interest, depreciation and losses. Why is there no voltage above the critical corona voltage which is the economical voltage? The losses due to corona enter into these annual charges as a fixed charge and therefore have a proper place in arriving at an economical voltage.

I would like to ask the two gentlemen if they have established, as a fact, that the economic line voltage is always under the critical corona voltage.

F. G. Baum: I should say the authors started out with the wrong assumption; that is, that the voltage is fixed. If you follow the theory given, in every line you would have a voltage depending on the length of the line. Can you imagine the maze of voltages we would have in the country if such a principle were followed? You can fix the voltages and then, by taking aluminum or copper lines, get exactly the same economic results. That is shown by the City of San Francisco, which put in a line recently of 150,000 volts for 150 mi. They used that old factor of 1000 volts per mile. There has been no good reason for that rule. Someone said it one time, and it was untrue then, and has been untrue ever since.

They applied Kelvin's law to the design of this line, and the work done in the paper I think is very commendable, but Dr. Kelvin didn't say what values to use for the line loss. I would like, when they get ready to build some of these lines, to supply the line losses at very much reduced figures, under the figures they give. The figures which we use in California are practically one-half the line loss per kilowatt hour that they use in this paper. That, I think, will make a material change in

the results. The cost per kilowatt-hour of line loss decreases and not increases with length of line.

A diagram similar to theirs on regulation has been in use in my office for a good many years, and a similar diagram was recently published in the *Electrical World*. The fundamental basis of it was given in May, 1900, in the A. I. E. E. JOURNAL.

E. A. Loew: I wish first to reply to Mr. Carey's question with reference to the 90 per cent corona factor. I may point out in answering that we don't care what factor is used, so long as he uses some factor, be it unity, or a little more, or a little less. Every engineer is free to choose whatever value seems best. It doesn't affect the general scheme outlined. It is difficult for me to see, however, how you are going to increase the economy of a line by increasing the voltage above the corona value, because the corona loss is proportional to the square of the overvoltage, and as the voltage is increased above the critical value the loss soon becomes excessive. We have made no test to determine whether introducing corona would yield a value for the most economical voltage, above the critical disruptive value for the conductor used. It hardly seems necessary to make such a test.

If I interpret Mr. Baum's statement correctly, he made the assertion that we predicate a voltage which is proportional to the length of the line. That is exactly what we do not do. If Mr. Baum will examine equations (**21**) and (**64**), he will find that there is no such thing involved. In equation (**64**) the length of the line is involved only as a factor in the last term of the denominator, and then only to the extent of the 6th root of $(1 \div L)$. In the numerator is involved the root-mean-square kw. transmitted over the line to the one-third power. Therefore, the amount of power that is transmitted over the line is by far the greater influence, and the length of the line has very little to do with determining either the conductor diameter or the voltage used.

In other words, if one were to transmit 100,000 kw. for example, over a single line 100 mi. long, it is quite likely that the voltage required would be higher than for 50,000 kw. transmitted over a 200-mi. line.

A statement was made relative to the assumed power loss. I wasn't very sure what the speaker had in mind, but it is true and it is stated very emphatically in the paper that any assumption as to power loss on a transmission line as a basic criterion upon which to determine the proper design of the line is more than likely to be erroneous. It so works out in these problems that we have used as illustrations, that the percentage power loss increases with the length of the line. In other words, an economic line for 100 mi. would probably have a power loss, (an average power loss) of about 4 or 5 per cent. The 200-mi. line might have 7 per cent, and the 300-mi. line probably 9½ or 10 per cent, but the loss does vary with the length of the line.

With reference to the diagram which is alleged to have appeared in 1900, I wish to state that many diagrams have appeared from time to time, among them one by Mr. Baum. The diagrams in this paper have, we believe, certain new and valuable features. We offer no apologies for the diagrams.

IMPROVEMENT IN DISTRIBUTION METHODS[1]

(HOOD)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

R. E. Cunningham: I have particularly noted the first paragraphs of Mr. Hood's paper regarding the necessity of thoroughly grounding secondaries and I want Mr. Hood to know that I concur with him in his statements.

I believe that too many of us have been content to drive a pipe or two connected to each secondary system and call it good enough. We all know what may happen to such grounds, particularly in dry districts. I think we should arrange through local ordinances to have a ground connection made at each customer's service which would be installed at the same time the house is wired by the contractor. This should be a water-pipe ground.

Now, as to using a common neutral, Mr. Hood, no doubt, has a condition where, as he has stated, his plan has worked satisfactorily. Whether it would work under conditions obtaining in Southern California is a little doubtful. We have a long, dry season and a good ground is hard to get: in some cases it is impossible. There are very few districts where we have continuous water-piping systems and in some cases cement is used in making the joints in the pipes.

Thus far on our 4-kv., four-wire systems we have adopted the practise of grounding the primary neutral at frequent intervals, generally by the use of a driven pipe. We have not tried the plan of using the same wire for a secondary neutral.

I might say that in most cases we do not have secondary systems continuing throughout the primary circuits, so that possibly there is not the same opportunity for economy as exists with Mr. Hood. With the system as I stated, using the driven-pipe grounds connected to our neutrals, we have had a number of cases during the dry season when the phase wire has fallen and lain on the ground without kicking out the circuit breaker at the station. We are particularly concerned as to how to take care of such a hazard.

We have recently built a new substation in a district where the system was being changed over to 4-kv. four-wire and are trying out the scheme as shown in Fig. 1 herewith. Here the neutral wire is isolated from the ground except at the station and there the connection is through a current transformer, the secondary of which is connected to an ammeter and relay. This relay in turn can actuate an alarm bell. Any current in the neutral due to unbalanced load will not indicate on the ammeter or cause the relay to function, but any current returning to the station from a phase wire which might fall on the ground must flow through this current transformer.

The current transformer is provided with taps and the relay so adjusted that it will operate when one ampere flows through the ground connection. Tests have been made which show that about that amount of current would flow when a coil of bare wire connected to a phase wire was thrown into a patch of green grass at a distance of about one mile from the station. Normally adjustments are for a much higher current so as to protect against a full ground and then once each hour the operator makes a test using the one-ampere adjustment.

We hope with this device to discover cases of phase wire on the ground under such conditions as not to cause sufficient return current to trip the circuit switch.

I would like Mr. Hood's advice on our situation and also wish to inquire whether with a phase wire down he usually gets enough current through the ground on his 4-kv. circuits to release the circuit switch.

E. R. Stauffacher: The ground relay mentioned by Mr. Cunningham will ring an alarm only when a current of one ampere or more goes back to the station from the line lying on the ground, whereas, our test indicates that only 0.3 or 0.4 ampere actually flows back to the station when a line is down on a 4000-volt distribution circuit about one mile from the substation. This, or course, applies to the dry soil condition. The equipment would indicate properly and give an alarm if the wire happened to be lying in green grass or in wet soil or against a green tree. However, there is every reason to expect that it will be rather difficult to develop equipment which will indicate when a line is lying down in dry soil or on a concrete or asphalt pavement. This leads me to believe that it would probably be better practise to install numerous grounds along the distribution line in addition to the ground at the substation, and to make every effort to see that the circuit breaker tripped out in case a wire dropped to the ground, rather than attempt to develop some type of ground detector which would indicate this hazardous condition.

1. Complete paper available in pamphlet form only.

C. A. Heinze: In Los Angeles, we have made use of grounds to water pipes for some years past. Our method is to select at least three services on each secondary and ground the neutral of each service to the local water pipe on consumers' premises.

It seems that ten or fifteen years ago the water department of our city experienced considerable trouble and difficulties with electrolysis. I imagine that a number of members know the full meaning of that word when applied to water systems, and the difficulties with electric railroads. To protect itself, the water department in Los Angeles constructed mains with cemented joints, thus preventing the possibility of getting a good ground by attaching directly to the main itself. However, on a three-wire service if we can obtain permission from the consumer, we bring down the neutral, connecting it directly to the water service. For mechanical reasons sometimes we use a piece of conduit, bonding it at each end.

I am a bit surprised to learn that Mr. Hood would like to have us go back to the multiple street-lighting system. It seems to me off-hand that we would be taking a step backward. I remember quite well that years ago we all, more or less, had multiple street-lighting systems, and we gave them up for the supposedly more efficient series system. Now, I find there is a tendency to go back to the multiple system again. I don't know whether the telephone engineers have had anything to do with this or not. At the same time I can't believe that it is a step in the right direction. Mr. Hood proposes and does install a contactor for connecting each lamp to the secondary bus nearest to the location of the lamp. From his paper I gleaned that it will require twelve watts of energy to keep this contactor energized during the daylight hours, and of course, during the hours when the lamp burns, the contactor is out of circuit or de-energized.

In Los Angeles, excluding the ornamental post lamps, we have 10,000 street lights of the suspension type. Now, if the contactor were to be provided for each one of these lamps in order to operate it on a multiple system as recommended by Mr. Hood, our loss in energy, valued at one cent per kilowatt hour would amount in a year to practically $7000. I don't know what Mr. Hood's company receives for energy for street-lighting purposes in his city, but surely none of us in the West are making sufficient money on street lighting to stand a yearly loss of any such amount; in our case, amounting to $7000.

I can't see what the future holds for us if we go to a multiple system. I would like Mr. Hood to explain the reason for going to the multiple system. I have always been given to understand that the multiple lamp, toward the end of its life, greatly decreases in candle-power, while the series type tends to burn at full candle-power until it burns out. I feel that this will result in a large number of lamps being continued in service at reduced candle-power and not being replaced until they actually burn out, resulting in decreased illumination on the streets. I think we, as utilities, should strive to give the public all they are paying for and the best street lighting possible.

M. T. Crawford: I notice that the neutral return path described by Mr. Hood is apparently largely in the secondary neutral grid. I would like to ask if single-pole switches are used or three-pole switches on the outgoing feeders at the substation. It would appear that if single-pole switches were used and single-phase short circuits occurred, opening one or two switches, the neutral would be called on to carry the full-load current of the phase which remained in service, greatly increasing the duty of the neutral path, and I should think increasing the troubles that might come from using only a relatively light-capacity neutral grid.

Rather extensive use is made of fuses in the secondary main for sectionalizing in case of trouble. I would like to ask Mr. Hood what method he has for finding out when these secondary sectionalizing fuses blow. If secondary sectionalizing fuses should blow and no knowledge was had of the fact, they might stay open for some time and interfere with the proper interchange of load current.

Mr. Hood refers to the fact that the primary-neutral return current sometimes will split and take the paths of the secondary outside wires, rather than all go through the common neutral. I would like to ask if he has made any test which would determine whether or not this disturbs the voltage regulation on the secondary at such points. It would seem that it might have considerable effect on the voltage drop on the secondary bus and would affect the consumer's service.

In regard to the underground system, I would like to ask if Mr. Hood has experienced any operating difficulty in connection with the relay contacts. On the underground distribution system in Seattle where a large number of power-directional relays are installed, we have found it necessary to periodically inspect and clean the relay contacts. The gases and other substances in the subways appear in some way to cover these contacts so that they do not always function.

D. K. Blake: I find a large number of people who are strongly in favor of the common neutral and just as many who are strongly opposed to it, but the chief cause for opposition seems to be the telephone interference.

As to the multiple lighting circuit, there are a large number of eastern companies who are going into that, studying it and applying it. I was very much surprised to find in Denver that the business section was supplied with multiple circuits with cascade pilot-wire control.

Mr. Hood referred to his polyphase secondary network for the business section which is a seven-wire system. There is a somewhat different type of system used by a large southern city of about 200,000 population. They have the same idea, that is, they do not want to supply an off-standard voltage to their customers' devices so they take the secondary winding of the transformer and extend it to 133 volts, which gives 230-star volts for the motors, and of course, a seven-wire system.

As to the matter of neutrals carrying load current, you might be interested in knowing that there is one large company which makes the practise of connecting distribution transformers from one wire to the grounded cable sheath and in that way they have the cable sheath carrying a number of amperes of load current.

D. I. Cone: As already stated, the subject of distribution systems is of great interest to telephone engineers: one item in particular in Mr. Hood's paper presented today is of importance from that point of view; that is the question of the use of a common neutral for the primary and secondary ground connections and, also, the question of the multiple grounding of primary neutrals. I shall not undertake a discussion of that problem because we have attempted to cover the subject pretty thoroughly in the paper by Dr. Trueblood and myself.[2]

Mr. Heinze referred to the interest of the telephone engineers in the street-lighting problem. There is a paper by Mr. McCurdy which discusses series street-lighting systems from this point of view[3]. As to the multiple street-lighting arrangement, I think, without having had experience with it, that the multiple scheme would make coordination with the telephone plant much easier.

G. H. Smith: I would like to say a word in discussion of Mr. Hood's multiple street-lighting system. We have been living with an overhead series system in Seattle for twenty years and for the last five or six years we have been trying to find some way to dispose of it. The underground lighting

2. Power Distribution and Telephone Circuits, by H. M. Trueblood and D. I. Cone, A. I. E. E. Journal, December, 1925, page 1353.

3. Induction from Street-Lighting Circuits, by R. G. McCurdy, A. I. E. E. Journal, October, 1925, page 1088.

system in Seattle is multiple, and the lamps are low-voltage, fed by transformers in the pole bases. We are averaging about 4000 hours' life on these lamps. It is hard for us to believe that we should use a 120-volt multiple lamp for that service athough I believe that is the lamp manufacturer's recommendation. We hope before long to install an overhead multiple lighting system very similar to the one described by Mr. Hood. We have been working on it for years, and believe that it will justify itself from the standpoint of safety alone. Also, our figures seem to show that it will be fully as cheap and more reliable.

S. B. Hood: Mr. Cunningham has brought up the point as to whether the common-neutral system was suitable for California. I think probably the best way to find out would be to try it. The main thing in the common-neutral system is to have sufficient neutral copper so that the earth does not form a part of the return, not an essential part. Therefore, if the air conditions are very dry, all that is necessary is to equalize the potential between the neutral system and the earth, so I rather think that the point of safety would be just about on a par with the dryness of the earth. If the earth is absolutely dry, it is a perfect insulator, so if you maintain your neutral at earth potential at the interconnection, you never would get any appreciable difference between that neutral system and the earth, even though the earth conditions give very high resistance.

On the question of the opening of the circuit breakers in case of a fault to ground, I suppose what Mr. Cunningham meant by ground was the conductor lying on the ground. My experience has been that it doesn't make any difference what kind of a system you use, isolated-neutral or common-neutral, you cannot depend on opening a circuit breaker on contact to ground. The artificial ground connection such as a driven pipe, will not have less than 100 ohms resistance. Now, you can readily see that 8 or 10 ft. of 3¼-in. pipe, will not give a good ground. The contact resistance of a wire on the ground may be up in the thousands of ohms. So I don't think it makes any difference; you can't depend on opening the breakers through accidental contact with the earth.

Mr. Heinze brought up the question of the individual house grounds, and the difficulty of getting continuous grounds through the water main. I think that is probably common all over the country, possibly not to as great an extent as in Los Angeles, but you get the benefit of the buried pipe which forms a service pipe from the main, including the section of main in which that service pipe is tapped. So in the aggregate you have a fairly good surface of water pipe in contact with the earth, certainly much better than you could ever expect by an artificial ground. When you interconnect all of those grounds by a system neutral, you can count on pretty good protection.

I am sorry I can't agree with Mr. Heinze about the multiple system being a backward step. We think it is the greatest step forward we have ever made. I have felt for a great many years that the practise of running series circuits, which may have potentials up to 6000 volts, through alleys, and out to every street corner, networking your whole area much more highly than your primary circuits can, comes pretty near to being a crime, and there are probably more accidents to the public and to the utility's operating staff through those high-voltage series circuits, than any of the other circuits you operate. The only trouble in the past has been to get the same efficiency in transmission with the multiple system. That can be solved by utilizing the distribution transformers, and the relay control system. Our experience with the maintenance of candle-power in the lamps has been remarkably good. I have always criticized the series system on a basis that the lamps, unless you break them up, will get so dim that you can't see whether they are burning or not.

Regarding the contactor losses in the multiple system, I think you ought to get the right point of view. You must consider that the series constant-current transformer at best will have only an efficiency of about 85 per cent, whereas the contractor uses 12 watts only for initial action, and as soon as the core rises it chokes the consumption down to 8 or 9 watts. That represents less than 2 per cent on a 500-watt lamp, and in a great many cases a group of five or six lamps may be found on one contactor. You can readily see the contactor losses are almost negligible compared to the losses in the series type of transformer.

The principal advantage we found in the multiple lighting system has been the better service during storm conditions. It frequently happens during a bad storm that lamp outages on the series circuits will run 17 to 20 times as high as on the multiple. As soon as the storm starts you will see the multiple lamps winking like stars all over the city. It can readily be seen with the series system that each accident or effect of the storm which has lit the multiple lamps would have put out of business the series type of circuit.

The question of maintained candle-power is one which I think we shall have to leave to the engineers of the lamp association. We picked the series type of lamp and adopted the multiple system, believing that the series lamp was the best of the two lamps. Now, they tell us that the series lamp was a poor lamp at its best, and we should use the multiple lamp, so I don't know which is right. Experience will have to show. I think, however, that one feature in favor of the series type of lamp particularly in our large cities, is its longer life. They claim series lamps used on multiple system will give 2160 hours' life. We are getting 3000 hours on ours and better, and very well maintained candle-power. They also claim the multiple type of lamp is good for 1300 hours. My experience with the large systems is that if you get 1000 hours life out of it you are lucky.

Now, where you have cars parked along the streets all day and most of the night, when are you going to get a maintenance car up to the ornamental lamps? The men must go around before sunrise, and even then you will find many cars.

Mr. Crawford asked whether we use single-pole or three-pole switches on our feeders at the substations. Originally all our lighting feeders, before we converted to the common neutral, were the two-pole. So the only change we made was to change the original double-pole switches; the two poles were put in series giving twice the breaking capacity. Those circuits, however, were almost entirely lighting circuits and we found that the action was substantially that of a one-wire single-phase circuits. They didn't act as three-phase circuits at all. However, all our three- phase power circuits had three-pole switches, and as we cut to combination feeders, we found the single-pole switch had no advantage, due to the fact that among the other peculiar things we do, we always ground the neutrals of our three-phase power transformers. When you get a single-phase short circuit, the closed secondary delta transfers the short circuit to a very considerable extent to the other two phases, so that all three switches, would go out in the same way as though they were on a three-pole switch. For that reason, as we rebuilt our substations, we conserved substation space by putting in entirely three-pole switches. In the modern substation with automatic closing equipment, it is the fact that almost always a circuit will not lock-out but will burn the fault off.

The matter of locating blown section fuses is largely checked up by periodic inspections made just before the fall peaks. During the summer season most of the load in the interconnected districts being residential load, it doesn't make much difference whether those fuses are in or out, except in some places where the range load is heavy. We make careful inspection just prior to the fall peak, and from then until we pass the overlapping period, the spring of the year, we depend on the customer to let us know when those section fuses are out. Generally he doesn't waste much time in doing so. In other words, our transformers

will carry the load with those fuses out as well as with them in, but the regulation would be very much poorer; therefore, we almost invariably get a complaint from a customer when a section fuse is out.

We have never had any trouble with the effect on secondary regulation caused by flow of current in the neutral. There is under certain rather abnormal conditions a tendency to unbalance voltage, but you must have a very abnormal condition to bring out that effect.

Regarding Mr. Crawford's question as to relays in the underground a-c. system, our condition is possibly just a little different from what he may have in mind in that our transformer vaults are to all intents and purposes substations. We don't have the dampness and the gases found in an ordinary manhole vault. We are particularly fortunate in Minneapolis because we can put vaults under the sidewalk, and they are just as dry as the basement of a building; in fact, they are virtually the front of the basement. We use the same type of relays and equipment as used in the ordinary substation, and they are inspected periodically; in most cases once a week.

In Mr. Blake's remarks, he referred to a system in the South which used 133-volt transformers. That is the type of transformer with the 133-volt secondary tapped at the 115-volt point. We had considered that, but the objection we saw was that it made a semi-special transformer which is objectionable from the standpoint of simplicity in warehouse stock were it is necessary to stock one type of transformer for overhead distribution and another for underground. If the underground required a special type of transformer, probably that tap would be all right, but in our case we have adhered to standard equipment throughout.

THE STUDY OF IONS AND ELECTRONS FOR ELECTRICAL ENGINEERS[1]

(RYAN)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925.

R. W. Sorensen: Professor Ryan says, "There are two varieties of electrons, positive and negative." On this he can find much authority; in fact in his book, "The Electron," Dr. Millikan speaks of positive and negative electrons, but I much prefer in this particular to follow the practise of those who define the electron by saying it is a cathode particle such as is found in the cathode rays. I choose this path of thinking about electrons because we all know something about cathode rays. These rays have been found to be made up of negatively changed particles, and the particles are called electrons.

This definition makes the electron a single individual, always negative, rather than twins, one positive and one negative, and it is, as a consequence, more easily recognized. If the electron cannot be a twin, we must provide it with an affinity from which it wishes never to be separated, and in this form of nomenclature the term proton has been applied to the same individual that Professor Ryan has called the positive electron.

More frequently than not, these electrons and their protons are found in large groups, but, in the case of the hydrogen atom, they are alone, this atom being made up of one electron and a single proton nucleus. That points out one question to which we might refer in Professor Ryan's paper where he stated, I believe, that the positive electrons were not found alone; but this is the one exception. If one of these hydrogen atoms encounters a disturbing influence, such as an electric field, powerful enough to detach an electron, the electron becomes free and there is left the single proton.

Proceeding in the direction of complexity of structure, we could discuss the helium atom which has two electrons attached to a nucleus that appears to have four protons.

When one or more of these electrons or negative particles is taken away from an atom the remainder behaves in such a way as to indicate that it has a positive charge, and is known as a positive ion. Thus atoms become ions when they have a deficiency or excess of electrons.

I see no reason why protons as defined cannot exist in a free state in a hydrogen arc, but it is, of course, true that compared to the number of times one can find free electrons, such an occurrence is very limited.

I had planned to question the statement that "under all ordinary conditions approaching quiescence, free electrons adhere to atoms, otherwise neutral." But now, although a number of physicists think they are free, I am inclined to think that we shall get into less trouble if we take Professor Ryan's statement that these electrons are likely to attach themselves to neutral atoms, making them negative ions.

Something is said about electron travel. In regard to that, when we measure an electric current as so many amperes we are measuring the sum of the positive and negative ions passing through the ammeter.

I should like to suggest that perhaps as engineers we would clear up Professor Ryan's statements as to the movement of electrons, by saying that the electrons or ions may be moved mechanically, electrically or magnetically; that is, you can move them by mechanical means by placing them in what we call electrostatic field, or in a magnetic field. I know that is exactly what Professor Ryan intends to say, but I think it would be better to say magnetically rather than electromagnetically.

On the second page Professor Ryan has divided conduction into three groups. I think we should add something to these. An electric current made up of these ions or electrons will also travel through a vacuum, and I do not believe that this has been included in these three sections. Also, I am not quite sure that these three groups as listed show conduction through an arc.

To the paragraph at the top of the second column on the second page I am inclined to add the idea that every atom has electrons; therefore, how can one have a fluid which does not have atoms and hence does not have electrons? Correspondingly how would it be an insulator under Professor Ryan's definition?

Considering practical engineering application, I am one of the many who have a feeling that air, pure and unadulterated, if not a nearly perfect insulator, is at least a pretty good one and one which will serve us for a long time. In the final analysis, all our transmission lines are air-insulated, the porcelain bead chains with which we decorate our transmission towers being, after all, only decorative suspenders which serve to keep the lines from falling. The insulator is the air.

I think the reason Professor Ryan and I differ in this is because he says a thing is not a thing unless it is at least 99.44 per cent pure. Air, then, is an insulator just as oil is an insulator. If we introduce into the air, free electrons or ions, the air as an insulator becomes defective in exact proportion to the amount of impurity introduced. In undertaking our engineering problems we call oil an insulator. It never is a perfect one and it ceases to be an insulator at all if moisture is added to it, its value as an insulator decreasing in proportion to the amount of water added.

I might also add that in the sense which Professor Ryan has spoken of an insulator, a vacuum is not an insulator. Current can and will go through it. To my way of thinking, a high vacuum is an insulator, but it is not a perfect insulator; therefore, Professor Ryan says it is not an insulator.

When two conductors are brought very close together, a potential of 1,000,000 volts. per cm. or even greater potentials may be required to break down the gap. Also, cold electrodes in high vacuum require potential gradients of this magnitude as ionizing potentials, but charged electric conductors in air at sea level and separated practical distances will arc over one

1. A. I. E. E. JOURNAL, SEPTEMBER, 1925, p. 964.

to the other if the potential gradient in the air between them is 30,000 volts per cm.

However, on this point I must assure you that though we are using different words, Professor Ryan and I understand each other thoroughly in this matter, and in conducting experiments involving these things, we would use in many cases the same strategy and anticipate the same results.

C. E. Magnusson: There is, one factor—in fact a vital factor in the electron theory—the physical characteristics of which are seldom discussed while the attention is focused on the several forms of mass units involved. I refer to the electric charge. What is the innate nature of positive and negative charges, which take possession of, or are possessed by, electrons, ions, protons, corpuscles, or by whatever name the mass units may be designated? How can the charge, if located on or attached to an electron or other mass unit of definite size, produce action at a distance or be attracted or repelled by other charges attached to far away mass units? What is back of Faraday's lines or tubes of force? May I ask Professor Ryan to give us his concept of the electric charge?

C. L. Fortescue: I think one of the reasons why electrical engineers have difficulty in following and applying the electron theories is because it is the first time they have come up against the subject of statistical mechanics, a subject with which physicists have become very familiar in their study of the dynamic theory of gases.

Now many laws of physics, dynamics and physical chemistry were found before the kinetic theory of gases was well established, and these laws prove to be true under practical conditions.

Electrical engineers have been accustomed to think of air as an insulator which breaks down, under ordinary conditions, at about 30,000 volts per cm. This, of course, is a very convenient way of looking at it, but we know by the electron theory that this isn't at all true except under certain specific conditions.

The electron theorists tell us that the air will break down at any point where the rate of ionization and the rate of recombination are equal. I believe the rate of recombination depends upon the mobility and the rate of ionization depends upon the density of the air and also upon the total value of applied potential or the difference of potential between electrodes; but we have two quantities there that have to be taken into account. As a consequence we find for a very small separation, as Mr. Sorensen points out, a breakdown strength of the order of 1,000,000 volts per cm. In a larger space the breakdown strength of the air becomes less and less. In the ordinary spaces the engineer uses, we find it averages around 30,000 volts per cm.

In Professor Ryan's paper, I was a little disappointed when I read his remarks about the three sorts of insulators. Unfortunately we are likely to generalize and think of these things practically as hindering our methods of insulation. For instance, Professor Ryan makes his statement in such a way that one would think, reading it superficially, that barriers were absolutely indispensable in connection with all insulators. We know by actual experience if proper care is taken to prevent the formation of corona, or putting it in terms of the electron theory, when local ionization is avoided, we can use air without applying barriers, and the strength of the air will follow the avarage law which I have mentioned, breakdown taking place at about 30,000 volts per cm.

Certain conditions occur when the bounding surface between solid dielectric and air apparently does not follow the law of breakdown in air. I think these discrepancies have been attributed to the effect of the absorption of gases or moisture on the surface, but if you have a perfectly clean surface of proper conformation, the path along the surface will have the same breakdown strength as the air has.

I should like to ask Professor Ryan to clear up this difficulty in the interpretation of this paper. We are sure as engineers that the air is still a medium for insulation.

F. G. Baum: For many years (since 1911) Dr. Ryan has exhorted us to study the electron. I am here as a missionary today to try to help show the importance of studying the electron. For many years the subject of electrostatics has been taught in schools. In my opinion, there is no such subject as electrostatics except as you get down to an extreme vacuum where you have no ions injected into the vacuum; otherwise you have "electron mechanics," and I believe in a very short time you will find that our textbooks will be rewritten and the term "electrostatics" practically eliminated. It is wrong and we must get another proper term and realize that we are dealing with objects moving at very high speed and causing entirely different conditions from those which we thought true when we studied electrostatics.

Ordinarily, we take two bodies and draw lines between and say that is an electrostatic field. It is an electrostatic field only because electrons are moving from one of those bodies to the other; and our higher voltage insulation problem is dependent on a knowledge of handling this electron flow.

H. J. Ryan: Replying to Professor Sorensen: I can accept, if necessary, the use of *proton* in lieu of *positive electron* as proposed by some physicists. It is simply a choice of terms. Personally, however, I like Doctor Millikan's use of *positive electron* to emphasize the fact that all matter is substantially made up of cathode and anode particles. As implied, it is true that experimental facilities are as yet more abundant or convenient for the liberation of cathode particles than for anode particles. These cathode and anode particles surely are twins of just the character referred to. They carry elemental charges equal in amount and opposite in sign. The positive electron or proton is much smaller in diameter and has a correspondingly greater mass than the negative electron. The same elementary electric field or charge centers in the electron whether positive or negative,—the one and only known difference being that of direction or polarity. I do not feel that the use of the term "proton" is adapted to the presentation of these facts as well as the term "positive electron." It is helpful to have been reminded of the stripped hydrogen atom which can be produced and which must behave as an isolated positive electron, proton, or anode particle as we may variously call it.

I quite agree with the idea put forth in regard to the movement of ions and electrons mechanically, electrically or magnetically. However, it should be remembered that they may be moved also by any combination of these agencies. For example, ions in the air that is blown along between the poles of a magnet and between metal plates maintained at a difference of potential, will be moved mechanically, magnetically and electrically. It may be that it is not helpful to compound these terms and say that the ions were moved electromagnetomechanically. I am quite agreed to say that they were moved electrically, magnetically and mechanically.

I am glad to accept *vacuum* for a place in the list of electrical conductors. I had left it out originally because in the first place a vacuum is not anything, anyway in the ordinary sense and, therefore, can not assist or hinder the migration of ions or electrons; in the second place, as Mr. Wood brought out in the talk referred to, as soon as ions or electrons are admitted to the vacuum it may in a sense be thought of as having ceased to be a vacuum.

I can see no difficulty with the statement "No fluid of any sort pervaded with a supply of ions or electrons can properly be regarded as an insulator. Correspondingly, every fluid in which ions and electrons are absent must function as an insulator." Of course, each molecule of neutral transformer oil is made up of complete or neutral atoms that in turn are made up each of an equal number of positive and negative electrons bound together, forming neutral aggregates. Such oil is not a supply of ions and will not conduct under an impressed electromotive force of moderate value. If, however, the oil con-

tains impure water in suspension it is pervaded with a supply of ions and will conduct.

I cordially admit the powerful revulsion of feeling that must come to one when first confronted by the fact that it is the wall of the metallic conductor when immersed in air that is really the insulator and not the air. Take away the air, as one may do in a vacuum, and the conductor will be insulated just as well as before. This is the fact that made me doubt the wisdom of putting "vacuum" in the list of conductors. It does not really matter, though, as long as we can agree as to the circumstances in which it does or does not conduct. Years ago, when the idea prevailed in my own mind that air is one of our best insulators, with dielectric strength greatly enhanced by compression, I undertook to provide a powerful dielectric by means of air compressed to 1500 lb. per sq. in. I was greatly perplexed by the results because I was wholly unaware of the fact that air will permit ions to pass through it freely if one will but provide a source thereof, such for example as a hot carbon electrode. We did not know then, as we know now, that in all ordinary circumstances electrons cannot escape from the wall of a conductor which is the basic reason why we were made to believe that the air was the real insulator. Furthermore, we did not know then, as we do now, that at extraordinarily high electric intensities at the surface of an electrode conductor (1,000 kv. per cm. approximately) electrons or ions will escape from the wall of the conductor and be driven freely through the air to the opposing electrode where they will be discharged. With a knowledge of these facts twenty years ago we would not have been perplexed by the anomalous behavior of air as an insulator when put to a real test.

I cannot agree that it is a matter of degree to be covered by such a small item as the departure of 99.44 from 100. It is not a question of purity or impurity any more than it is in the case of water. Water will conduct as long as it has ions suspended in it. Being a fluid it ceases to conduct only when the supply of ions has been eliminated. And this will cover also the reference to oil.

Doctor Magnusson asks the question "What is the innate nature of positive and negative charges which take possession of or are possessed by electrons, ions, protons, corpuscles or by whatever name the mass-units may be designated?" This question and the form in which it is put are helpful even if one has not a ghost of an answer. I can only discuss this question, I cannot begin to answer it. I can only offer what appears to me to be a reasonable conjecture in regard to the perhaps most important attribute of the electron. This is that all electric fields are made up of unit-fragments alike in constitution. Each field fragment terminates on an electron from which it extends radially and expands uniformly, and so far as we know, indefinitely. These field fragments are the same, whether positive or negative, differing only in polarity and in radius of the electron surface at which the field terminates, being much smaller for the positive electron which must, therefore, have a correspondingly greater mass, the measure of the energy that was used in the extra concentration of the field. Whatever else they may be, electrons are surely these field fragments. All greater electric fields are merely aggregations of these unit-field fragments. The electric intensity through any field volume is the vector sum of the radial field fragments attached to the electrons that constitute the charges to which the field is attached. Maxwell understood the composition and resolution of electric fields and taught us to locate "tubes" of electric force by drawing diagonals through the parallelograms that are formed by the radial lines which represent the electric fields that extend uniformly in all directions from charges located at a point. It is the vector composition of superimposed fields terminating upon the positive and negative electrons that forms the "tubes of force" of an electric field. It is in the presentation of these facts that I find the term *positive electron* more helpful than *proton*.

It is also helpful to have Mr. Fortescue emphasize the importance of *statistical mechanics*. I trust that all who are interested in the new knowledge will read thoughtfully what he has said. He also refers to the extremely short space that must exist between metal electrode faces before electrons will leave them and the vacuum, or gas-filled space between them, will become conductive. If the fact is allowed to stand in that light I fear we shall give our more general audience the impression that this action is the result mainly due to the close proximity of the metal electrode-faces. In fact it cannot primarily be due to the nearness of such faces as Hayden and Steinmetz have shown in their A. I. E. E. paper on the dielectric strength of the vacuum.[2] The preparation of my paper was only possible by the use of old terms with new or modified meanings. I had to count, therefore, upon precisely such disappointment as that of Mr. Fortescue because I have referred to air as a conductor instead of as an insulator. I have no thought of proposing that we stop calling air an insulator. What I do want to see established is a better understanding as to how it can be made to conduct abundantly. With that, and with more of a background in the subject which will come with experience, the choice of terms with no doubts on important difference, will be readily accomplished. I am a hearty advocate of the high value of the *Fortescue principle* wherein air insulation barriers of powerful solid dielectrics are applied, having boundaries coincident with those of the tubes of electric force in the air adjacent. Such barriers displace the air in regions of dense electric fields that would otherwise ionize and afford prolific conduction. We do not differ as to the facts and in the end we shall have put new meaning into old terms or adopted new terms by which all who use them will apply helpfully the new knowledge of these things.

Mr. Baum has declared rightly that electrostatics are hopelessly inadequate for understanding and for effective control of electrical states and actions. This I know to be the case even though we cannot agree as to facts when he says that a quiescent electric field between two charged bodies is such "because electrons are moving from one of these bodies to the other." Of course, this brings us face to face with the age-long problem of "action at a distance" and my question to myself is: "has Mr. Baum made some progress toward the definition and solution of that problem?" Most of us have not,—we face a high wall and cannot see what is beyond. To me the static electric field between two bodies is the composition of the two field aggregates of opposing polarity that terminate on the corresponding free positive and negative electrons that are bound to the surfaces of such bodies.

SOME FEATURES AND IMPROVEMENTS ON THE HIGH-VOLTAGE WATTMETER[3]

(CARROLL)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

R. W. Sorensen: When I first saw the diagram of connections shown in this paper I was awed by the apparent amount of large apparatus necessary to construct such a wattmeter. However, I have had the opportunity to stop at Professor Ryan's laboratory and became acquainted with the equipment described in this paper. An acquaintance with the equipment eliminated the impression of bigness which I had received from the diagram and which was perhaps due partly to the high voltages which the equipment will measure. In place of this impression I received a definite picture of the cleverness exhibited by Mr. Carroll and Professor Ryan in handling this problem. For example, the transformer of three windings and a split core, which seems in the diagram to be so large, is actually very small, in fact, it can easily be held in one hand.

2. High-Voltage Insulation, by J. L. R. Hayden and C. P. Steinmetz, A. I. E. E., TRANSACTIONS, 1923, page 1029.

3. A. I. E. E. JOURNAL, September, 1925, p. 943.

The water column, about 16 ft. long, is so arranged between the shielding plates at the ends as to occupy a space approximately 3 ft. in height. The small transformer and the indicating instruments are all mounted on a small table surrounded by a wire cage the dimensions of which approximate 4 ft. high, 6 or 8 ft. wide and perhaps 12 ft. long.

With this knowledge, I found it much easier to read the paper and appreciate what has been done in Professor Ryan's laboratory toward producing practical wattmeters and voltmeters for high-potential measurements.

H. V. Carpenter: Mr. Carroll mentions the integrity tests by which he established the fact that he was able to read with accuracy loads of a watt or two, with a voltage of 150,000. It seems to me the condition is so critical there that a word in relation to his method of establishing the integrity would be interesting. Also regarding the formula given for the resistance of the water column, I would like to ask whether he established it over a wide range of densities and for any materials except common salt.

J. S. Carroll: Ordinarily the man in a measurements laboratory thinks of errors in measurements as a few tenths of a per cent. However, in this case where we are measuring one watt of power at 150,000 volts and the apparent power is of the order of 6000 watts, I frankly admit that we are very well satisfied with an accuracy within 25 per cent of true values. As the load increases the accuracy greatly increases so that at 40 watts we expect the error to be not over two or three per cent. One of the integrity tests used is described in the present paper, that is the double-conductivity test. Another test is described in the Oct. 1924, A. I. E. E. JOURNAL in the paper on Power Measurements at High Voltage and Low Power Factor, by Carroll, Peterson and Stray. In this test a shielded resistance was inserted in the connection to the line, the value of this resistance was known as well as the line charging current through it from which the power absorbed by it was computed; this increase in power was also measured by the wattmeter. The agreement between the results of the two determinations was very satisfactory. The double-conductivity test was also used in connection with the above test.

In regard to Professor Carpenter's second question, I might say that we have so far tried only a common salt solution and have not gone farther than checking the formula given in the paper in an overall way for the purpose of finding any serious error. We measured the cold resistance of a solution and then calculated what the hot resistance of the water column should be, this result agreed very well with the value obtained under actual operating conditions. On some of these things we wish to make a closer follow-up as soon as we have time.

INDUCTION FROM STREET LIGHTING CIRCUITS-EFFECTS ON TELEPHONE CIRCUITS[1]

(McCURDY)

SEATTLE, WASHINGTON, SEPTEMBER 18, 1925.

R. R. Cowles: The present tendency of the Pacific Gas & Electric Company is toward the use of small series street-lighting loops with incandescent lamps only. These series loops are 6.6-ampere and are supplied from a multiple-series constant-current transformer installed on the pole in the same manner as any other distribution transformer. These constant-current transformers are of the moving-coil type, fundamentally similar to those formerly used inside of stations. In size they range from 5 to 20 kw. each, depending upon the average size of the series incandescent lamps which are connected to the circuit. It is the aim to avoid long loops and to restrict the number of lamps per circuit to approximately 60.

These transformers are connected on the primary side to a 4000-volt, four-wire, three-phase, star-connected feeder circuit, said circuit being switched from the substation just as any other 4000-volt commercial feeder. Where the primary neutral is available no additional neutral is extended for the street-lighting feeder. Single-phase lines are run in various directions to supply the territory in the same manner as single-phase lighting feeders are branched from a three-phase feeder for commercial light and power consumers. The effect of the above arrangement is greatly to improve the reliability of street-lighting service through the elimination of long series loops and the resulting reduction in potential on these series loops. Multiple 4000-volt feeders have proven their reliability on the system of the Pacific Gas & Electric Company; hence no new features are involved in this type of feeder circuit. The constant-current street-lighting transformers are furthermore removed from the substations, thereby providing room for other apparatus which cannot conveniently be placed outside of the station.

The 6.6-ampere series street-lighting incandescent lamps are standard for 4000-lumen lamps and less. This is a slight departure from previous practise which indicated the desirability of using series transformers or auto-transformers with lamps larger than 2500 lumens. An improvement in lamp manufacture, however, has made it practicable to use 4000-lumen lamps at 6.6 amperes. Lamps larger than 4000 lumens are operated at 20 amperes, necessitating the use of series transformers or auto-transformers installed on the same pole or in the same fixture which supports the lighting unit. The film cut-outs are used with all 6.6 ampere lamps, operating without auto-transformer or series transformer.

The use of series circuits with currents in excess of 6.6 amperes has been considered by the engineering department of this company but no action has as yet been taken. Small series loops supplied from individual constant-current transformers, with lamps of higher intensity spaced fairly close, would permit of operation at 15 or 20 amperes if the characteristics of these lamps demanded it. Consideration should also be given to methods of switching street-lighting circuits from a remote point which would make possible the use of even smaller loops and considerably simplify the apparatus involved therein. There are a number of types of remote-control apparatus already developed and a number more in process of development. It appears to the writer that the use of radio control for this purpose might be worked out to a practical and economic application at some future time.

C. A. Heinze: Any power engineer who has had relations with the American Bell Telephone Company will notice that the telephone engineers all tell the same story. The main thought in all of their papers is cooperation between the power engineers and the telephone engineers.

I want to state, first, that the electric utilities want to cooperate with the telephone company. We recognize the fact that we have mutual services to render, but I should like to ask Dr. Trueblood just how far the American Bell Telephone Company will go in cooperating with the electric utilities in sharing part of the expense in safeguarding the telephone companies' equipment.

S. B. Hood: Mr. McCurdy recommends some of the usual remedial measures, principally isolating transformers. That is the 100-per cent remedial measure of telephone engineering, and in most cases it is a 100-per cent remedial measure, but in very few cases is it the measure which the power man wishes to adopt. It adds to the investment, adds to the losses in the system, more or less interferes with the regulation, and has a great many objectionable features.

Another recommended cure on series circuits is the straight-series lamp. That is very nice until we get to the higher candle-power. We are all developing "white ways" that require higher densities of lighting. Therefore, recommending the type of lamp which the lamp manufacturers are not prepared to furnish is looking far into the future.

It seems to me that possibly a better recommendation which they could make—particularly since Dr. Trueblood is so enthu-

1. A. I. E. E. JOURNAL, October 1925, p. 1088.

siastic over the multiple system—the better cure where inductive exposure is used, would be to change the lamps in that particular exposure to multiple, using a series relay for controlling. Of course, the recommendation for closed loops and balancing the lamp on a loop is very effective, but when you put a series street-lighting system with both wires looped on the same street, as far as the investment goes, it is practically getting back to a multiple system.

It seems to me, however, that in all these papers the indication is that no matter how far apart our past differences of opinion have been, we are all gradually coming closer together; the telephone men and power men are gradually getting down to a uniform system which I think is a very promising outgrowth.

R. G. McCurdy: The tendency of the development towards the use of smaller series street-lighting loops as described by Mr. Cowles in his discussion of the Pacific Gas and Electric Company's practises, from the standpoint of inductive coordination, is in the right direction. Because of the smaller number of lamps per circuit and since the constant-current transformer is closer to the lamp load, the length of any given circuit is much reduced and in case of failure of lamps equipped with individual transformers, the length of circuit upon which the harmonic voltages are impressed, and which may be involved in inductive exposures, is much less than when circuits of a large number of lamps are employed. In many cases also, this method of operation would facilitate supplying separately "white ways," where lamps of high candle-power equipped with individual transformers are used, and outlying sections where in many cases, only straight-series lamps are employed.

Mr. Hood referred in his discussion to the disadvantages of the straight-series lamp, especially in districts where high-density lighting is required. As brought out in my paper, however, it is very often the case that these high lighting intensities occur in the densely populated sections of cities and towns, where both the telephone and lighting circuits are in cable. In such cases the occurrence of "out" lamps equipped with these transformers is unimportant from the inductive standpoint. In other cases, where the "white-way" section may be of limited extent, it will often be practicable to connect the high-current lamps to circuits not involved in telephone exposures, having as far as possible, only straight-series lamps on the circuits involved in the inductive exposures.

Many of the difficulties of coordination discussed in the paper are inherent with the series system, and it would doubtless be less difficult to coordinate with multiple systems. The remedy suggested by Mr. Hood, therefore, of changing the lamps in a particular exposure section to multiple, using a series relay for controlling, would probably be an effective one. As far as the incandescent systems are concerned, however, it is felt that the difficulties existing with the series circuit, would be overcome by the use of a reliable form of cut-out with lamps equipped with individual transformers or auto-transformers.

DISTRIBUTION PRACTISES IN SOUTHERN CALIFORNIA[1]

(CUNNINGHAM)

SEATTLE, WASH., SEPTEMBER 18, 1925

F. O. McMillan: There are two questions I wish to ask. Mr. Cunningham states he is using some three-phase, Y-Y-connected transformers; are these core-type or shell-type and if shell-type, has any provision been made for the third-harmonic magnetizing currents in the transformers so connected?

S. B. Hood: In connection with the paper by Mr. Crawford and the one by Mr. Cunningham, we note that they are both using the ground as a stabilizing medium. I think the general tendency is indicated all the way through that that is what we are after. We are trying to stabilize our systems; not to use the ground as a conductor.

Mr. Cunningham brought up the point that in a great many cases the selection of the system was due to local conditions, and therefore, we shouldn't judge one system by that of another in another part of the country. I think that is absolutely correct. There is one point that I have heard in these discussions and papers, and I hear it all over the Coast—you question some particular practise, and instead of defending that practise from an engineering standpoint, somebody will say, "The state law doesn't allow us to do that."

I am wondering whether some of these state laws are not really placing an unjustified economic burden on the public. I think some of these laws probably were passed long before these newer developments were made. A notable instance of that is the law which apparently forbids the use of a secondary rack.

I don't think we pay enough attention to the esthetic appearance of our distribution systems. The secondary rack improves the appearance of the lines very much. Now, Mr. Cunningham, by using the one arm for both primary and secondary, with the pole intervening as a barrier, gets a relatively neat construction, but not as neat as the secondary rack. I think on the point of investment it would probably be an even break, but it seems that where the practise is quite common in one section of the country, and forbidden by law in another, there should be some equalization made.

There is another instance that is somewhat out of line with these papers: I have noticed further down the Coast there is apparently another state law which requires boxing-in an iron pipe on a pole. I have seen some poles where the box around the pole was larger than the pole itself. It is unfortunate that there are laws which require practises of that kind, such transgressions on the esthetics of construction, and sooner or later the utilities are going to be forced underground, before it is economically justified.

M. T. Crawford: Mr. Cunningham's reference to one-arm construction coincides very closely with our experience in suburban territory, where our primary is placed on one end of the crossarm and the secondary on the other. By placing the primary on the street side always, and the secondary wires on the property side, it makes for uniformity and obviates misunderstanding. By hanging the transformers on buck arms, crosswise of the pole, the primary leads come out straight and turn up and the secondary leads come out straight and turn up, making a very orderly arrangement.

In the city we have found it not so practical, due to the necessity of providing space for a number of feeders, and at times having polyphase primary and secondary requiring more wires.

R. E. Cunningham: The matter of third harmonic in the three-phase Y-Y transformer was brought up this morning. This was considered when we first thought of using this type of transformer. The high side of transformers is not grounded. The low side ordinarily working at 460 volts, we wanted Y-connected so as to ground the neutral and not have more than 260 volts to ground from any wire, as a safety precaution. Seldom, is there more than a single service to each transformer possibly not over 25 ft. of wire, so that the third harmonic has never caused any trouble.

Something has been said about the esthetic appearance of pole lines, and attempting to improve the appearance. At best a pole line is not a thing of beauty—we all know that. We can, of course, in some ways help its appearance. Our practise in this regard is, as far as possible, to keep pole lines, particularly in the residential districts, in the rear of property lines, and Fig. 4 of my paper shows such a line. In fact, none but the main lines need be along the streets, and we find this is a great help in keeping down agitation for underground lines in residential districts.

1. A. I. E. E. JOURNAL, November 1925, p. 1196.

ENGINEERING RESEARCH—AN ESSENTIAL FACTOR IN ENGINEERING EDUCATION[1]

(MAGNUSSON)

RELATION BETWEEN ENGINEERING EDUCATION AND ENGINEERING RESEARCH[2]

(SORENSEN)

AND

A NEW DEPARTURE IN ENGINEERING EDUCATION[3]

(PENDER)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

L. N. Robinson: Professor Magnusson emphasizes the point that engineering courses should teach students to think if nothing more. If that is so, why do engineering curriculums, in general, not include courses in the mental sciences, particularly logic and allied subjects? However, it is not my present purpose to argue for or against the inclusion of any particular subject in the curriculums. What should be pointed out is that present conditions indicate a general lack of scientific treatment in the design of engineering curriculums as well as in their application.

We insist that scientific methods should be employed in designing engineering structures. Engineering students have an equal right to insist that scientific methods be employed in designing the curriculums of engineering schools.

When electric generating stations are designed by the same methods that are employed in laying out many engineering school courses, hybrid plants are produced in about the same proportion as our engineering schools turn out bond and automobile salesmen.

In designing an engineering structure, it is customary to decide first what is to be designed, whether it shall be a bridge, an office building, a locomotive or something else. Next we determine which parts shall be of steel, which of copper, etc., then we prescribe methods of fabrication and assembly. In other words, every step from the inception of the enterprise to the finished product is worked out with utmost scientific care.

Is this method followed in designing engineering curriculums and in training engineers? Before it can be said that engineering courses, themselves, are scientifically designed, we should at least first determine what the product of an engineering course should be. Then the elements that should constitute the course can readily be determined, with equal care to deciding how the courses shall be conducted.

Last June, at a commencement the chancellor of a university said that the world is full of people who know all about education except what it is for. This is a challenge to the engineering fraternity and to the engineering schools in particular; it demands a scientifically sound justification for our college courses and especially for our engineering courses. And, since we profess to be scientific in our engineering work, we should be better able than the humanists to answer the challenge. In doing so, however, we must be especially careful not to mistake consensus of opinion for sound scientific truth else we shall class ourselves with those who scoffed at Christopher Columbus because his views differed from generally accepted notions.

J. C. Clark: It seems to me that Professor Magnusson has lost a grand opportunity in his paper to bring out one of the main reasons why we should have research in engineering colleges. He has stressed the value of the educational aspect of research almost exclusively, and has pointed out that it nearly goes without saying that research has an indispensable part in technical education. Professor Sorensen also emphasized very strongly the educational value of research in the colleges. In other words, it is for the good of the colleges and the students that research is carried on in the colleges.

I believe that it ought to be pointed out by Professor Magnusson that the industry needs engineering research in the colleges as much, if not more, than do the colleges. As Professor Magnusson has so emphatically stated, it is true that the large corporations of today have millions to spend in research. They have large and well trained staffs to carry on industrial research, and they carry it on successfully and efficiently. On the other hand a great many of the smaller concerns have very meager appropriations with which to work and carry on research.

It follows that most of us very much need to have a place to have scientific facts revealed. Not only is this true in the smaller manufacturing industries, but it is even more vital for the public to have these independent public laboratories of research which the colleges and universities can so well maintain. It really is not so much the amount of work done that matters, as it is the unbiased check that such laboratories can give upon the results that are revealed and published by the larger corporations.

We do not charge that the large corporations color what they print about their laboratory results, but it is human and almost inevitable that they show the best side of what they find out, and somewhat neglect the unfavorable aspects of those things they are trying to promote.

By doing a very little work sometimes with small funds, the smaller college laboratories can aid industry and the social body a great deal. The exact amount of money at their disposal is not of prime importance although it is true that they need a vastly greater support than they now have.

The professor who has one thousand dollars a year to spend for all his equipment, including its repair, and maintenance, is so handicapped that he can surely do but little with the energy that he puts into the work.

I should endorse what Professor Magnusson said: Industrial establishments of any size that do no research have "signed up for the exit." However, industrial research in smaller establishments may not be carried on because they have not the facilities, and thus they have to depend upon the colleges.

I find much in Professor Sorensen's paper which is of interest. Professor Sorensen starts out with an assumption which surely needs no argument,—that research and engineering are inseparable. Research *must be* a part of engineering education. He takes the same attitude as Professor Magnusson does in pointing out the necessity for it from the standpoint of education. This is self-evident indeed.

Professor Sorensen gives the time honored definition of engineering that I believe was given by Tredgold, the first President of the Institution of Civil Engineers in England; "The art of directing the great sources of power and nature for the use and convenience of man," etc., running through many, many words. It starts as a catalogue of the functions of engineers and thus its weakness is obvious. It can, of course, only begin to catalogue the functions of engineers, but I think that in this very definition, a part of the weakness of modern engineering education lies. Educators and engineers have been more or less hypnotized by such definitions of engineering, emphasis being placed entirely upon the technical aspect of engineering, the scientific, and the big and glorious things to be done by engineers.

I should substitute a very much shorter definition for engineering. I define an engineer as one who directs the economic use of matter or energy. I should let it go at that because I believe that we have among us as great engineers who are directing the destinies of banks or steamship companies, from the standpoint of executive officers, as we have in any other capacity. In other words, technique should not be stressed exclusively in the work that is done in the colleges. There should be a little more emphasis placed on economics. There are very few colleges today that devote any great amount of time to the study of engineering economics. I do not see how it is possible to turn out men with a proper attitude toward

1. A. I. E. E. JOURNAL, November, 1925, p. 1243.
2. A. I. E. E. JOURNAL, December, 1925, p. 1288.
3. A. I. E. E. JOURNAL, November, 1925, p. 1208.

engineering without giving them much study of the principles of engineering economics; not the old social economics, but the engineering student does need a very considerable amount of engineering economics if he ever becomes a true engineer.

I wonder how much deleterious effect this long-drawn-out definition of Tredgold's has had upon engineering education. Has it not hypnotized the profession somewhat into thinking too much about the imparting of information about technical things; perhaps information about the things that can best be learned by the man after he is out of college?

In Professor Sorensen's paper I found one thing with which I think many men in practical research would particularly take issue. That is the standpoint that the undergraduates thesis was wisely eliminated. Professor Sorensen says "it was therefore wisely eliminated." The very next sentence takes the curse off, "But we should not forget that the thesis is symbolical of research—a function which must be the keystone of engineering education if the engineer is to occupy the place for which he is ambitious."

I think that is certainly true. The thesis is needed to support the idea of research, to give some little practise in the methods of research, with the object of bringing out latent research talent in the student.

Professor Sorensen reveals that he has some such idea in a latter part of his paper, since he speaks of the honor sections that are established at Pasadena where the better men are permitted some chance to help in advanced and special work, assisting research men. I think he has there revealed his true attitude toward the research that may be done by undergraduates.

It seems to me that the practise of segregating the students into the ordinary and the extraordinary,—the latter class including these so-called honor men,—is one of the very best developments I have ever seen. I wonder if the real reason for eliminating the undergraduate thesis was not rather the difficulties that were encountered in lack of equipment or lack of time and energy for the administration of the theses than the lack of educational and developmental value in them?

In the paper by Dean Pender and the one by Professor Sorensen there are two quite distinct methods given for the selection of engineering student material. Of the two, I think the one that is the more hopeful is the one that is being tried out in Pennsylvania. The statement that Harold Pender made is quite true; that a boy fresh from high school is usually just a boy,—and I think it does require the few years of college which are a part of the Pennsylvania plan to bring out the judgment of a student and too, to weed out the defective material found among students. It is not defective material except that it is unfit for engineering although possibly very fit for some other, perhaps higher, walk of life. At any rate, there is a great difference among students in their fitness for engineering.

I am somewhat in doubt as to the real value of the physical examination in the Pasadena plan because we have in our electrical history so many able men who might have had difficulty in passing the Pasadena physical test. Is it not going to eliminate an occasional man who has great latent ability in analytical ways?

H. V. Carpenter: This matter of engineering education is one that we shall always talk about I suppose. The Society for the Promotion of Engineering Education is at the present time spending something like a hundred thousand dollars, and I don't know how many dollars' worth of time, in analyzing methods of engineering teaching.

It seems to me that one of the most difficult problems we have before us in that study is this matter of research. You remember that some Roman ruler said, "All right, if we destroy the Greek statuary, we shall send some men out and have it replaced." If we aren't careful, we shall put our research work on that same mechanical basis. I believe that a research man is born. Maybe Dean Magnusson can make a research man, but I am afraid I cannot. I think it is more a matter with us of being able to discover the research man when he comes along in our classes, rather than being able to take an entire class of students and turning them all into first-class research thinkers.

What we need to do is to teach these men to think, and research is only one of the better methods of teaching a man to think. A large share of these boys will never be research thinkers, but they will be very effective engineering thinkers in the ordinary sense of being able to go out and size up a job and put through the best design for it. They may not be research men, but they will be thoroughly useful men on straight engineering propositions.

It is our business to give the man who can do original thinking the inspiration to go ahead to develop his abilities in that line, and to give him a chance in the laboratory. Professor Sorensen's scheme is a very good one; they have adopted a similar one at the Massachusetts Institute of Technology where the honor men are to be given a chance to do as much as they please. The smaller institutions have always done that to a considerable degree in an easier way, having a much simpler problem.

Dropping the thesis was a good thing, I think. I agree with Professor Sorensen on that as a requirement for every student, but for the student who shows interest, I think the thesis should be maintained, and carefully nursed along. We cannot expect revolutionary things from the senior, but perhaps if we start a real genius to thinking he may turn out a revolutionary piece of work in later years.

L. J. Corbett: Doctor Magnussen describes the tendency to take research away from the colleges. I think we need not fear for that, as times are changing. As he states, the large companies are doing a great deal of research, but there is another factor; they also need men—and one of the ways to develop men is through this very research work. I believe this is being recognized by some of our large companies, as evidenced by the assistance which has been given recently, to both the California Institute of Technology and Leland Stanford, Jr., University, in the way of aid in the establishment of high-voltage laboratories. These, no doubt, will give a good account of themselves in contributions to engineering research, and some students will receive valuable training in this field.

From Mr. Sorensen's paper I note that they are omitting the engineering thesis at the institution he represents. However, from the discussion which took place, I see that there is still some opportunity given for the honor men to investigate along the lines of their special inclinations, thus recognizing work on such theses.

To return to Doctor Magnusson's paper, we must recognize the tendency of the companies of today to require specialization in their men. This, I think, has been the inference in the advice which has often been given to engineering colleges to have actual departments of research where some men of the staff could go ahead and do research only, without the change in mental attitude which is necessary when a man does some research and also teaches a group of undergraduates, old, well-known material.

I think the work of the teacher, as Professor Carpenter has stated, is inspirational. I think that if you can inspire a student to make the best use of his faculties, and not to consider his education complete when he has his degree, but to go ahead with his studies and research—you will do a greater work than merely filling him with information and making an encyclopedia of him. I think this quality is particularly exemplified in the man we have with us in the person of Professor Ryan. I believe that all his students will vouch for the inspirational quality of his work

There is one feature in Dr. Pender's paper that struck a discordant note. In one of his conclusions there is the statement that the student should recognize that engineering is a profession, and not a job. That is all very well for us to recognize, but I think we should not emphasize it too strongly to the under-

graduate student, because it is due to such thoughts that we have men who are reluctant to don overalls after getting their degrees. I think a man would get farther in the engineering profession if he were willing to don overalls for a time after his graduation and learn the rudiments of practical work.

J. S. Bates: I once heard an engineer defined as a man who is skilled in the use of the word "approximately." There is really a great deal in that because no matter to how many decimal places we carry our calculations, there is always one more; one or a vast multitude makes no difference. For that reason we should say a very important part of an engineer's education is to determine what percentage of error is to be allowed.

G. S. Smith: In the University of Washington we still have the thesis work scheduled as an elective but it has been virtually discarded, since it is seldom chosen by the student. However, I believe we have found other ways more effective in obtaining the results aimed for in the usual thesis work.

Several of our courses scheduled for upper classmen and graduates, are presented in such a manner that each student, or more often a group of two or three students, selects or is assigned some individual problem to be worked out completely. These prob ems are usually of such a nature that they require a considerable amount of thought, reference work, or experimental work, and thus arouse in the student any latent inclinations toward research work.

As an example I should like to mention a course to which we have paid a good deal of attention in our institution; that of electrical transients as a prescribed course of undergraduate study. In the laboratory part of this course a certain number of topics are assigned to the student for which he must obtain representative oscillograms. This is the more or less routine or practise part of the course. To satisfy the remainder of the requirements, the student must select some problem or topic, acceptable to the instructor, to be investigated by the taking of oscillograms. This problem must be one which has not been previously chosen by other students who have taken the course. Thus their work is, to a certain extent, original.

The response on the students' part is usually more than gratifying. They not only put more energy and thought into this part of the work than in the routine portion, but they also show a strong tendency to attack it from the investigational point of view; that is, they try to find the best method of attack, try to determine the results they expect and then attempt to verify them experimentally, watching all the while for unexpected results. At times, of course, they make complete failures, but more often they are very successful.

H. H. Henline (communicated after adjournment): I wish to emphasize the importance of full and frank discussion of the problems of engineering education by members of engineering faculties as well as by executives in industry. These authors have pointed out some very serious defects which are found in many curriculums.

Most of the engineering curriculums now in effect were planned twenty or more years ago, and changes made since have not altered in any essential details the general plans followed originally. Therefore, we find that most of the curriculums furnish excellent preparation for certain types of work which some of the graduates enter. However, this number seems small when compared with the total. On account of the extremely rapid progress which has been made in many branches of engineering during the past few years, we find ourselves living in a period when the applications of engineering knowledge are so many and diversified in character that any curriculum designed to meet directly certain needs in industry may indeed prepare men in a most excellent manner for those needs, but it fails utterly to prepare them for the great range of engineering problems, both executive and technical, which all graduates will be called upon to solve.

There is a strong and growing tendency to choose executives from the men with engineering training, since the problems which executives in industry must meet are becoming so complex and so closely allied with fundamentals of engineering that great dependence must be placed on the judgment of engineers in order to reach the correct solution. Obviously the schools cannot train men directly for executive positions, since qualifications for such positions depend greatly upon inherent characteristics, and any amount of training would not make capable executives of men who do not possess the necessary characteristics. However, if we wish the engineering graduates who do possess such characteristics to have opportunity to enter the management side of engineering, we must give them the broad, general foundation so absolutely essential.

One of the most noticeable features in the large amount of discussion of curriculums occurring in recent years is the fact that many of our largest employers of technical graduates now wish to secure men who have had a broad training in general subjects and the fundamentals of engineering rather than men who have specialized in a particular branch of engineering. Thus we find that the old situation in which teachers wanted to adhere to fundamentals, and many executives in industry advocated certain specialized courses, is rapidly reversing. Now we find the leaders in industry not only frowning upon specialized courses, but even considering many courses as too highly specialized which are given with the excuse that they are necessary from the standpoint of fundamentals.

In the planning of an engineering curriculum, certain decisions must be made as to the types of activity for which it should prepare men. In the present stage of development it seems necessary to recognize the needs of two distinct groups of students. Those who expect to spend their lives in highly technical design or research must have a more extended technical preparation than those who will be engaged in commercial or industrial phases of engineering. Both groups need a broad foundation on such subjects as English, economics, biology, geology, history, business law, etc., and a thorough training in chemistry, physics, mathematics, mechanics and other subjects which make up the heart of engineering. Such training should be mixed with, and followed by courses giving the fundamentals of all of the principal branches of engineering, and there should be a reasonable amount of time available for elective subjects. Thus far there is no serious difference between the wishes of executives in industry and teachers of engineering. It, therefore, seems that the chief cause of argument is the relatively small group of men who will engage in research and other highly technical phases of engineering. This group must have better opportunities for the development of research ability and specialized study than can be provided in any four-year course which makes necessary the provisions for training in the fundamentals.

It seems that the best solution of the problem may be a four-year course following the general outline mentioned above and leading to some such degree as Bachelor of Arts or Bachelor of Science in Engineering. This curriculum should be so planned that students may have good opportunity to develop powers of initiative and judgment to the maximum extent, and to determine the kind of intellectual effort for which they are best qualified. In order that they may see how they can best fit into that field, it should give them a broad outlook and an excellent perspective of the whole engineering field. Graduates of such a curriculum would be prepared for commercial pursuits and for many types of technical work in which employers prefer that specialization be deferred until after the entry into industry. It is believed that they would advance more rapidly in either commercial or technical employment than if they had graduated from the narrower four year engineering curriculum.

For those who wish to prepare for research and other highly technical branches of engineering, there should be provided opportunities for two years of graduate study. Having completed the liberal four-year curriculum, they would have the

broad foundation which should precede advanced study. The graduate curriculum should be planned with the idea of developing ability in research and permitting specialization in analytical studies, design, or other branches of engineering. Since the number of students in the graduate classes would be relatively small, the effectiveness of the training would be maximum. The progress would be much better than could possibly be made in the same work with undergraduate classes containing many students not really qualified for or genuinely interested in such subjects.

I believe this combination of four years liberal curriculum for all and two year graduate curriculum, for those who are properly endowed for and desire it, would result in producing men better qualified to take their proper places in the world than are those who complete most of the present-day curriculum.

All engineering students should realize that it is impossible to escape passing through an apprenticeship period of some sort. A university curriculum cannot possibly replace the apprenticeship period except in the cases of the comparatively small number of persons who are preparing for research and highly technical progress. Therefore, it is extremely important that the curriculum be such as will aid in choosing the proper kind of apprenticeship to fit the individual's mental endowment and his aptitudes. There should be fewer misfits because the first four years' training would give them an excellent foundation, and they could choose the type of work most interesting to them. This would eliminate a very real difficulty now in common existence. For instance, a boy before graduating from high school has built radio sets, worked in a local power plant, or had some kind of electrical experience. Perhaps electricity appeals to him more strongly than any other subject. He wants a university education because he has been told that it will enable him to earn a good salary immediately after graduation, and will go far toward insuring success in later life. What then is more natural than for him to register in electrical engineering, because here is the opportunity, in his opinion, to secure the university education he wishes and at the same time specialize in his favorite subject. Naturally he has considerable pride in his choice and is reluctant to make any change even though the first year or two may prove that he does not possess the necessary types of ability to succeed in engineering. He may eventually graduate and begin work, still determined to be a successful electrical engineer. The result is in many cases an employe who has not the ability and characteristics necessary for his work. He must then work on as best he can and be a failure or only a mediocre success in electrical engineering, or find something to which he is better adapted. In so far as possible, a young man's interests and abilities should be determined before he graduates. If this can be fairly well accomplished and he can be sent out either with the broad four-year training, or better, with both it and the two-year graduate study, his chances of success should be greatly improved, and he should be a happier man in later life.

R. W. Sorensen: I would like to add to the list of books given at the end of Professor Ryan's paper one entitled, "Ions Electrons, and Ionization Radiations" by J. H. Crowther, published by Edward Arnold, London. That book is easy to read and it presents in a reliable manner much of the information about ions that engineers wish to know.

In the three papers bearing directly upon education, you will, of course, find differences of opinion, and so there should be. The biggest crime educators could be guilty of would be that of making a standard curriculum, which would be the same for all engineering colleges. In fact, we often remind ourselves at California Institute of Technology that we must not simply add to the group of good engineering courses in California just another course like the one at our State University or like Professor Ryan has developed at Leland Stanford. We at the Institute are spending annually about $700 per year per student enrolled, to carry on our work. That money has been given us by individuals for a specific purpose and should not be used to duplicate the work of other institutions.

Dr. Magnusson has sounded a keynote when he says every faculty man should do enough research work to show that he has the ability to inspire students in that direction. Some undergraduates are qualified to do research work along with their regular undergraduate work. Such men should be given an opportunity to do that work. Also, there should be graduate students, the more the better, doing research work, and the college should make such provisions for such a plan. In this way, every student has a chance to come in contact with research work, learn what it is and methods of procedure. Every engineer will, to a large extent, have his success determined by the amount of research enthusiasm which he can develop, even though that enthusiasm is not applied to the type of problem ordinarily classified as a research problem.

As to the senior thesis for all, the discontinuance of that plan was due to several factors; one being lack of time on the part of faculty to supervise many students and assign each student a problem of just the proper magnitude to fulfill the requirements for graduation. In place of the thesis, certain problems are assigned students, the problems selected being tempered by the circumstances under which the student is working. Such a problem does not have to be written in thesis form, thus allowing all the available time for work on the problem.

Why do we include four years of English in our curriculum? We have had complaints that the engineers are underpaid, and underpaid chiefly for one reason; that the engineer confines most of his contact with men to those who talk only engineering language, and there is no use to try to sell engineering information to other engineers unless you are a much better engineer than the other man, which doesn't happen very often. On the other hand, there are thousands of people in the world who want engineering information and who would take it if presented to them so they could understand it. You can't present engineering data to the artist in a way that he will understand it unless you know his language; you can't present it to the doctor, lawyer, or merchant in a way that they can understand, unless you know something of their language.

Therefore, we have a department of English which runs through five years of our five-year course, and we must have a large department in order to keep the type of instructors we have, instructors whose business it is to inspire men and cause them to make of themselves all-round men. That is the reason we think it worth while to put in a five-year humanity course right along with a five-year technical course. Many of us would not do the things we do if some seemingly insignificant thing had not inspired us to go in an inviting direction. Without the instruction we would have failed in finding the doorway to new and interesting fields of endeavor.

In reply to the comments made by Messrs. Robinson, Clark, Henline and others, there are many details about which we could argue, but each exception only makes plainer the fact that all individuals should not be required to follow the same course of preparation for engineering work. Some men should prepare a thesis, some should not, some should have five years of education in the field of English literature, including some history and economics, others should find it more profitable to plan a different use of their time, but in nearly every case, I would conclude that in the essential things there are no differences of opinion—except as to relative values. This condition could not be otherwise because engineers differ as to details even in designing machines, when a much smaller number of variables are encountered than is the case when we attempt to form the character of the youth who will in the future be our engineers.

Reference to values in character building prompts me to direct attention to the value of the training obtained on the athletic field as evidenced by the success of many of our engineering students who participate in athletics. A survey of the condition

governing athletics at many of our educational institutions indicates to me that the advantages of athletics are for the most part lost to engineers because training for athletics has become such a time-absorbing specialty as to make it almost impossible for an engineering student to be on his college team. Our educators in the technical field, and those who are our friends, should help correct this condition of affairs.

C. E. Magnusson: Mr. Robinson's remarks lead me to think that I failed to state clearly what I had in mind. I meant to say that education is essentially training to think; that engineering education is training to think along engineering lines; that the main purpose of engineering students during their four years in college should be to gain clear concepts of the basic physical laws underlying engineering and acquire the ability to apply these laws to the solution of quantitative practical problems. The rest of their college work is accessory to this backbone of engineering education and may vary widely for different individuals. It goes without saying that all live engineering colleges frequently revise their curricula. At the University of Washington, the revision of curricula in the college of engineering comes regularly on the calendar every four years, and many changes both in regard to required courses and their content have been made during the past twenty years. I am grateful to Mr. Clark for emphasizing the value to industrial establishments of research in our engineering colleges although this phase of the problem does not come under the title of my paper.

FUNDAMENTAL CONSIDERATIONS OF POWER LIMITS OF TRANSMISSION SYSTEMS[1]

(Doherty and Dewey)

AND

ANALYTICAL DISCUSSION OF SOME FACTORS ENTERING INTO THE PROBLEM OF TRANSMISSION STABILITY[2]

(Fortescue)

Seattle, Washington, September 16, 1925

P. H. Thomas: The paper by Doherty and Dewey emphasizes even more than those of previous date the part played by the terminal apparatus in stability of operation. Of course, it matters not what the electrical equations show as to the theoretical capacity of a long line if when terminal apparatus be applied to supply power and receive load the combination is unstable to operate, as might easily be the case with loads anywhere nearly approaching the theoretical capacity of the line should the usual present designs of synchronous apparatus be used.

However, we have this fact to remember; the capacity of the line as shown by equations is an absolute limit without power of change until some of the physical constants of the line are changed, while the limitations of the terminal apparatus are merely matters of economy and cost. The very long transmission line may well represent $125 per kilowatt of delivered power, while the terminal apparatus costs much less; at least so far as the securing of suitable stability characteristics is concerned. If the choice lies between limiting the maximum duty of the long line and adding to the terminal-apparatus cost, the latter course is to be chosen, generally speaking.

The proposal to correct by simultaneous and automatic support of the field magnetizing turns the falling field strength when a line is suddenly overloaded, is a significant and important proposal and the analysis offered is clear and to the point. No doubt there are other ways of accomplishing this same result.

The 28 per cent greater load carried by the rectifier-excitation test as reported over the regulator test in the experimental line, is very encouraging. At the critical point of the regulator test it is evident that a further increase in power transmitted would require a higher actual field magnetism both on account of the higher load and on account of the less favorable power factor that the line will demand and temporarily also greater on account of the initial drop in terminal voltage. It should be noted that the motor end must drop behind on the increased load before anything at all happens in the electrical circuit. But this regulator cannot act until the voltage actually has dropped and by that time the system has dropped out of step and the regulator never gets a chance to try. With the rectifier, however, an excess of exciting power is added in the field before the motor drops back to the new position for the greater load and the field is ready to support the necessary additional power current.

I think the authors are a little too severe in their reflections on the line charging current. While it may be true that with certain set-ups due to the limitations in machines, the total theoretical maximum power which can be delivered by the line will be slightly less over the line having its normal electrostatic capacity than over a hypothetical line with no capacity, nevertheless it is not likely that charging current will be a detriment under practical operating conditions.

The statement that a certain 300,000-kv-a. station may deliver more power over two lines than over three and none at all over nine lines is not so significant as it might seem. It simply means that, for the three or nine lines, the system is so proportioned that machine capacity which should be devoted to carrying kilowatts is absorbed in carrying charging current or that the ratio of synchronous condensers to number of lines is not favorable. Either the kv-a. of the station should be increased by building the machines to operate at a lower power factor or shunt reactance or other means used to neutralize a part of the charging current. It goes without saying that it would not be economical to use an unnecessary number of lines.

With regard to the authors' Fig. 3 and the discussion of the part played by field current, I should like to point out that, with a heavily loaded line, there is very little choice as to power factor, for this is definitely fixed by the load and the terminal voltages and will inevitably be high at the generator end. However, there is this advantage of power factor near unity; the effect of added lagging current due to increase of load on the drop from internal impedance within the machine is small with high power factor. This is an important matter.

Since the power factor changes with every change in load on the long line, the curves of Fig. 3 should be supplemented by other curves showing the effect of such change of power factor, and these modified curves might easily show a different best relation between low-power-factor and high-power-factor loading, from that indicated by the uncorrected curves.

One other point; the authors state that the scheme of using divided line conductors to reduce reactance and increase capacity has not found favor partly because of the increased charging current. As I see it, this increased charging current is, on the whole, no disadvantage, for on any useful loading it greatly improves the line power factor. While it is true that leading current will tend to reduce the field-current setting in generators, this is a matter affecting only the performance of the generator, subject to correction in a number of ways. If the rectifier excitation scheme proposed in the paper or any equivalent scheme is available, this objection to the high charging current disappears. Meanwhile the reduction of line reactance which accompanies the increase in capacity with divided conductors, means an increase of substantially the same proportion in the maximum load the line will carry, assuming the percentage of line resistance loss to be kept constant. With a 20 per cent increase in line capacity in a 350-mi. line and with a favorable line power factor, any generator difficulties from the additional charging current would no doubt be cared for in the same suitable way. As a matter of fact on any full loading no charging current would appear at the terminals as the reactance energy of the line would absorb it.

1. A. I. E. E. Journal, October, 1925, p. 1045
2. A. I. E. E. Journal, September, 1925, p. 951.

F. L. Lawton: In the paper by Messrs. Doherty and Dewey, considerable emphasis has been given the question of voltage regulation of the synchronous equipment of transmission systems. This, however, is in line with the papers[3] and discussions[4] at the last Midwinter Convention when the subject of high-speed excitation was given prominence.

As the method of regulation outlined by Messrs. Doherty and Dewey—viz., the use of mercury-arc rectifiers as adjuncts in the excitation circuits of transmission-system synchronous equipment—is probably the most promising development looking toward increased system stability, it seems wise to discuss it somewhat in detail.

During the course of various investigations of the stability of power-transmission systems, it was realized that considerably greater stiffness in a system would be desirable; also, that such greater stiffness could be secured by the use of excitation systems having a time constant much smaller than usual. As a consequence, Messrs. Fortescue and Wagner discussed results they had obtained with a so-called high-speed exciter, at the 1925 Midwinter Convention.[5]

While it is true that less voltage fluctuation will occur during load or short-circuit transients, when the synchronous machines of a power system are excited by high-speed exciters, it must be remembered that such exciters are inherently not different from any other exciter, so far as behavior under transient conditions is concerned. That is, when lagging load is suddenly added to a generator so equipped, the terminal voltage drops. The decrease in voltage energizes the Tirrill-regulator relay which short circuits the exciter field resistance, permitting the generator field current to increase.

After an appreciable time, the alternator terminal voltage is restored to the normal value. *Inasmuch as the alternator armature reaction is not compensated for at the time it occurs, the power limit,* for slowly applied loads, of any system equipped with high-speed excitation equipment, *is no greater* than for a system provided with normal exciters. Furthermore, as it is now realized that a power-transmission system is inherently stable for any load up to the steady-state power limit, no matter how added, there is of comparatively little advantage in the use of such high-speed exciters beyond the reduction of voltage fluctuations.

Let us consider the case of an alternator equipped with an ordinary excitation system with the addition of a mercury-arc rectifier, excited from the line, as an adjunct. When a lagging load is thrown on such an alternator, the rectifier supplies an excitation current proportionate to the line current, varying simultaneously with it. *As a result of the simultaneity of action, the alternator armature reaction is at all times counterbalanced by a proportionate field current.* That is, *the armature reaction is effectively neutralized.*

As Messrs. Doherty and Dewey have indicated, a reduction of about 50 per cent in effective armature reaction was obtained. While this reduction was not so great as theoretically possible, nevertheless it resulted in an increase of 28 per cent in the steady-state power limit of a 250-mi. miniature system.

It is worthy of note that this gain was maintained during tests involving the sudden addition of loads when if ever, it might be expected that the rectifiers would be ineffective. Not only were increased power limits obtained, but practically no decrease in voltage occurred when a large load was suddenly added to a system equipped with mercury-arc rectifiers; but as much as a 20 per cent momentary drop in voltage occurred when the same load was added in the same way to the system using normal Tirrill-controlled excitation systems.

The advantages of rectifiers as adjuncts in the excitation circuits of transmission-system synchronous equipment are probably most marked in the case of system short circuits. Tests similar in all respects except the excitation circuits, have been made on the systems illustrated by the accompanying Fig. 1 to determine the maximum amount of power which could be transmitted with stable operation under the condition of a half-second, single-phase, dead, line-to-line short circuit at the mid-point. It has been found that the system with rectifiers

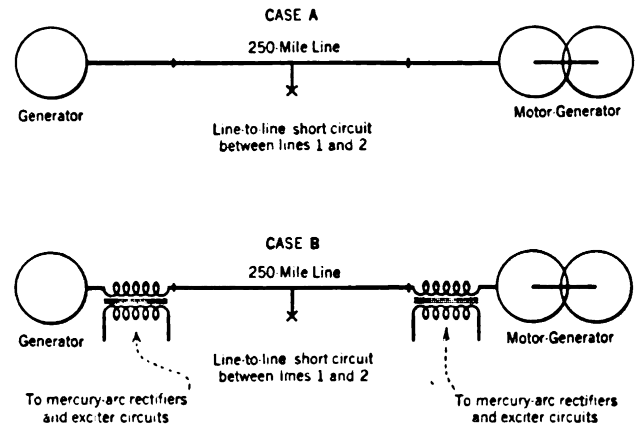


FIG. 1—SCHEMATIC DIAGRAM OF SYSTEMS USED FOR SHORT CIRCUIT TESTS

could carry 50 per cent greater load with much less fluctuation in voltage. To illustrate the comparative voltage fluctuations, Fig. 2 herewith has been prepared. Case A, Fig. 2, shows the three receiving-end voltages for the system of Case A, Fig. 1, while Case B gives the corresponding voltages for the other system. While the duration of short circuit for Case B was somewhat less than for Case A, the load being carried prior to the short circuit was 35 per cent greater and the initial short-circuit current 50 per cent greater. In spite of these unfavorable factors, the decrease in voltage was less with the system of Case B; virtually no over-voltage occurred when the short circuit was cleared. With the system of Case A, considerable excess voltage occurred some time after the clearance of the short circuit; a much greater time was required for the restoration of normal voltage.

FIG. 2—VOLTAGE DISTURBANCE DURING A SINGLE-PHASE, LINE-TO-LINE SHORT CIRCUIT ON A 220-MILE SYSTEM

The above facts illustrate the very important advantages which may be gained by the successful application of mercury-arc rectifiers in the excitation circuits of the generators and other large synchronous equipment of power-transmission systems. There appear to be no disadvantages beyond the possible necessity for oil circuit breakers of a somewhat higher rating, at a few points.

3. Power System Transients. V. Bush & R. D. Booth, A. I. E. E. JOURNAL, March 1925, p. 229.
4. Discussion. A. I. E. E. JOURNAL, July, 1925, pp. 766-771.
5. A. I. E. E. JOURNAL, pp. 767-770.

In conclusion, it appears that the only high-speed excitation system which will enable the securing of increased system power limits, for all conditions of operation, must be such that the armature reaction of the synchronous machines is effectively neutralized by the addition of field ampere-turns in the proper space-phase simultaneously with the occurrence of the armature reaction.

I believe the mercury-arc rectifier, properly applied as an auxiliary in the excitation circuits of synchronous units, is the first development giving promise of *a real increase in the power-transmitting capacity of transmission systems.*

S. B. Griscom: The statement by Messrs. Doherty and Dewey that, during transients, "the synchronous apparatus becomes inherently more powerful" is not clear. The field transient accompanying an increase in armature current is of such a nature as to tend to prevent the main field flux from decreasing, but it does not strengthen it. Actually, the magnetic flux starts to decrease immediately upon an increase in armature current; and consequently the field becomes weaker. Another way of stating it is that the very presence of the additional field current, flowing through the field resistance, is *due* to a decreasing field flux.

Under "Regulation," it is stated that the slope $\frac{dE}{dP}$ of the voltage-power curve determines the degree of stability. I should like to point out that such a criterion does not take into consideration the mechanical transients which are always coincident with an unstable condition, and it may, therefore, lead to erroneous conclusions. In the region where $\frac{dE}{dP}$ approaches infinity, $\frac{dP}{dt}$ approaches zero, because $\frac{dP}{d\theta}$ is limited by the mass of the synchronous machines. For this reason $\frac{dE}{dt}$ becomes very small and, in the case of large systems having heavy masses, is undoubtedly much less than the combined time constants of voltage regulators, exciters and generator fields, for a normal building up of load. The maximum load which may be carried under steady conditions is therefore considerably increased by the use of voltage regulators. This conclusion agrees in a general way with similar conclusions by the authors although in some cases apparently contradictory statements and data are introduced.

In particular, it would be expected that the tests reported at the bottom of the eleventh page should show nearly equal maximum loads for the two forms of excitation used, provided the load was built up by increments that were small as compared with the stored energy released during a small shift in phase of the synchronous motor. It is also probable that a load consisting of a large number of small synchronous units would cause the power transmitted over the line to change more slowly, giving more time for the regulator to function.

In a similar manner, voltage regulators on synchronous condensers located at intermediate points on a transmission line, by holding the voltage constant under a gradually increasing load, should permit a much greater power to be transmitted than the same line with the same total condenser capacity located at the receiver end only. The maximum power limit of such a system, as given by the authors appears to be entirely too low for a condition of steady loading. During transients, the maximum load that can be transmitted safely is considerably reduced but will still be much higher than a straight-away line for the same disturbance.

The use of synchronous condensers at intermediate points has been discussed a number of times, but the advantages apparently have not been fully appreciated. Condensers are usually installed for the purpose of voltage regulation and since the receiving end of the line is usually the only point where voltage regulation is needed, all of the condensers are located there. However, the real function of the condensers is to supply the reactive energy loss due to the flow of current through the line reactance. This loss is distributed practically uniformly over the length of the line and consequently a reduction in copper loss and a slight decrease in total condenser capacity may be effected by installing a portion of the condenser capacity at an intermediate point. Such an arrangement would tend to reduce short-circuit currents, particularly at the receiving end which is usually a point of high power concentration. Location of condensers at intermediate points should not prove unduly expensive or difficult because, in the majority of cases, switching stations and attendance will be required for line sectionalizing. Machines of suitable characteristics and equipped with a high-speed excitation system, or compensation, are of particular advantage for this application. It should be noted, however, that such features are made desirable principally by the conditions obtaining during transients and not for steady loading.

R. D. Evans: Probably the most interesting data submitted by Doherty and Dewey are the results of the calculations shown in Fig. 2 of their paper. This figure shows the "Maximum power which can be transmitted 250 mi. at 220,000 volts, shown as a function of the capacity of synchronous apparatus, and the number of transmission circuits."

The curves of Fig. 2 were presented for the purpose of showing the importance of the charging kv-a. of lines in reducing the power limit and they serve this purpose in an excellent manner. However, the important effects of the charging kv-a. in limiting the maximum power appear only when the synchronous capacity is small in comparison with charging kv-a. of the transmission line. This condition of operation would suggest that a lower transmission voltage would give higher actual power limits.

The condition in which the generating capacity is small per line is of relatively minor importance because the power to be transmitted per circuit at 220 kv., 250 mi., must be of the order of 75,000 to 125,000 kw. in order to be within the economical range at the present time. With this relation in mind, it is advantageous to compare the results shown in Fig. 2 for different kv-a. capacities of synchronous apparatus. In the first place, it will be noted that the characteristics of machines assumed by Doherty and Dewey are such that the rating of the machine cannot be developed because the power limit of the system is approximately two-thirds of the nominal capacity of the synchronous machines, that is, 100,000-kv-a. capacity on this line will show a power limit of approximately 70,000 kw. per circuit. If the characteristics of the terminal equipment are altered so that the reactance is approximately two-thirds, and the field current approximately three-halves of the values assumed, the power limit would be increased to approximately 100,000 kw. This condition would correspond to the curve given in the paper for 150,000 kv-a. in synchronous apparatus. Similarly, if a power limit of 150,000 kw. were to be obtained, the machines should have approximately somewhat less than two-thirds the reactance and more than three-halves of the excitation of the machines assumed by Doherty and Dewey. In other words, the power limit per circuit can be increased up to at least 125,000 kw. per circuit by the use of machines of suitable characteristics. The significance of this discussion is that the desired static limit may be obtained by merely modifying the authors' assumptions so as to employ machines of lower reactance and higher excitation. In the absence of alternatives, which are still in the development stages such as special regulator and compensator schemes, the use of machines of suitable characteristics is a practical solution available at the present time for producing quite marked increases in the stability of systems.

In view of the position taken by the authors, that static

limits are the only limits that are worthy of computation, it is interesting to compare the calculated static stability limits as given in Fig. 2 of the paper with the practical results of experience on an actual 220-kv. system. For a single-circuit, 250-mi. transmission system operated at 60 cycles, with approximately 200,000 kv-a. in synchronous apparatus at each end, the static limit is calculated to be about 115,000 kw. In the June issue of the *Electric Journal*, H. A. Barre states that the static limit of the Edison System was reached under a particular emergency condition. For this condition, power was transmitted from 240 to 270 mi. over a single circuit at 220 kv., 50 cycles, with approximately 200,000 kv-a. in synchronous apparatus at each end, and the static limit was found under actual operating conditions to be 183,000 kw. One would expect that the static condition on the Edison system would correspond well with the other condition mentioned previously, the greater length of the 50-cycle system and the probably greater transformer impedance roughly compensating for the increased frequency upon which the calculations were based if the authors had assumed machine characteristics corresponding to those of the synchronous apparatus on the Big Creek system. What is the explanation of this discrepancy from 183,000 kw. on an actual system to 115,000 kw. as given in the calculated results? In the first place, the exact assumptions used by Doherty and Dewey are not stated, and it may be that the explanation lies in them. If such is the case, the Fig. 2 should be interpreted with care. A possible explanation may lie in the fact that probably synchronous motor load was assumed in the Doherty and Dewey calculations, whereas the actual system involves a certain amount of resistance load which would cause the power to fall off with drop in voltage. The influence of the load characteristics is not mentioned, so far as the writer can recall, at any point in the paper, and it may be that this factor is of importance in the particular case of the static limit on the Edison system and under certain conditions would undoubtedly be of great importance in other cases. The explanation of the discrepancy between the calculated maximum limit and the maximum limit obtained under actual operating conditions is, of course, very important. It is worth pointing out that actual static limits may be appreciably in excess of calculated limits which do not take into account all the factors affecting stability.

S. W. Copley: These two papers indicate that the methods of calculation used do not differ greatly fundamentally, but there is some difference between them in the assumptions made as to the values used for the characteristics of the terminal apparatus. This difference causes some important divergence in views as to the power-limit figures. Possibly Doherty and Dewey are too pessimistic in their assumptions with respect to the reactance of terminal apparatus, or they have not given enough credit to the action of voltage regulators in holding the system together. Both of these points warrant further investigation. Machines of lower reactance can be designed and a regulator which has higher speed characteristics is a possibility. There are certain drawbacks to the application of such machines and regulators, but if the limits of power transmission must be raised the disadvantages can without doubt be overcome.

C. L. Fortescue: Messrs. Doherty and Dewey have presented with clarity the characteristics of synchronous apparatus which are of importance in the problem of stability. In dealing with the stability of machines of this type, they have laid much stress on the fact that high power factor is detrimental to stability, as it involves low excitation or, what is the same thing, low internal voltage. While undoubtedly at times, transmission lines reach very low loads in which the excitation is correspondingly low, I do not know of a single case in which a system was thrown out of step by a sudden increase of load or a short circuit due to low excitation. I believe that the explanation which I shall give later will account for the fact that instability under such conditions is practically unknown.

While I believe we should keep such cases in mind as elements of the problem, I feel that the authors have over-emphasized their importance and may, therefore, produce a false impression in the minds of those who are not sufficiently familiar with the problem. A properly designed transmission system will make provision for the generators not to supply all of the charging current at light load, and, at heavy loads, the generator power factor will be normally lagging. Two transmission lines properly designed with the proper size of generating station and with proper provision at the receiver end and intermediate points to take care of the line reactive-volt-ampere requirements will always transmit more power than one line. I state this fact not because I believe the authors intended to convey the opposite impression but the emphasis they lay on certain features of generators and synchronous motors might easily convey the opposite idea to the minds of those who are not closely in touch with the problem.

I had felt encouraged when I read the statement made by the authors on the fourth page, column one, and in the first part of column two as to the importance of excitation, though I will take issue with them in regard to part of the statement by referring to a discussion on excitation in last Midwinter Convention by several of my colleagues in which the possibilities of high-speed excitation were discussed at some length and with considerable emphasis. Later on in their paper I was disappointed to find that the authors had reached the conclusion that high-speed excitation would not fit the bill but inherent regulation was what would be required. Again I must take issue with them in this matter and state that in my opinion they have reached an erroneous conclusion and their error is mainly due to their failure to perceive that the so-called static-stability problem is in reality one of transient stability.

I shall first show by means of a simple mechanical model that if generator and motor are provided with perfect regulators, no matter what their characteristics, they will furnish power up to the stability limit of the line itself. The model which I have in mind is quite simple and was devised by S. B. Griscom. If two sticks pivoted about one point are connected at the two ends by an extensible elastic string such that its linear extension is proportionate to its tension, and if torque be applied to one member the restraining torque on the other member will represent the power output of a line. The applied torque is the power input. The above applied to a line having no losses but having reactance and distributed capacity. This assumption involves no appreciable error in considering the actions that cause instability because the resistance of the line and generators has only a small effect on the stability problem.

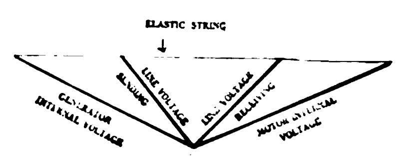


FIG. 3

One may picture one of these pivoted members attached rigidly to the shaft of a motor and the other to the shaft of a generator. The motor drives the generator at constant speed, using this device as a mechanical transmission. As the generator load increases, the elastic connection would be extended in such a way that the sine of the angle between the two members will increase in proportion to the load. If we keep on loading the generator, the angle between the two members will finally become a right angle, at which point the mechanical transmission system will have reached its maximum ability to transmit power and the system will become unstable.

Now the internal voltages of the generator and motor may be represented by two additional sticks (as shown in the accompany-

ing illustration) as extensions of the transmission line beyond this angle. The terminal voltages are kept constant; that is to say, the length of the original two pivoted sticks. As the angle is increased, the elastic line is kept straight by increasing the sticks representing the generator and motor internal voltages. Using this model, it can be shown that the torque at the generator will reach its maximum when the two members representing the terminal voltage of the transmission line are at an angle of 90 deg. with each other.

I have made no restrictions as to the characteristics of the generators and motors except in the matter of losses as in the case of the transmission line, but it is easy to show by means of the model that the rate at which the internal voltage must be increased with increase of load is very much influenced by the internal characteristics of the machines, and if we make the internal leakage impedance low, we shall not require to have as great a range of excitation.

Objection may be raised that ideal excitation systems do not exist and that commercial regulators are too slow. The explanation resides in the fact that the problem is, in reality, not one of static stability but one of transient stability. You must remember that instability involves a change in angular position and this means a change in angular position of the generator rotor and the motor rotor as well as of the line terminal voltage. The electrical angle and mechanical angle are, you might say, irrevocably tied together and to deliver power to a motor through a line at a given excitation requires that they must take up a definite angular position with reference to each other. In my paper, I have pointed out that the angular relation is a continuous function of the power and is therefore suitable for analytical work whereas the voltage at the terminals is a discontinuous function and is not suitable for analytical work.

The fact that the angular positions of the rotors must change with change of load introduces the natural period of the system into the problem of voltage regulation and this means also that sluggishness of the hydraulic or steam governor may have some advantages. If the load is increased, the motor slows down and so does the generator. In slowing down, the motor supplies part of the increased load by inertia. The generator supplies part of the increase in transmitted load by inertia at a slightly lower frequency, so that matters are improved from a stability point of view since, during this stage, only part of the increased load must be transmitted and also because it is transmitted at an appreciably lower frequency. While this is going on, the regulator has had time to get in its work and if the angular change is not too great, the voltage regulator will catch up before the angular displacement has reached the point where the system will pull apart at the increased value of load. Theoretically, this may be carried out close to the limit of stability of the line, providing the load increments are not so great as to cause large swings.

The authors have made no mention of the effect of the characteristics of the load and have merely touched on the improvement to be obtained by changing the generator characteristics, dismissing it with a statement that it will prove too costly. I wish to take exception to this statement and to say that such changes can be made with a small increase in cost over that of standard generators and the increase in the ability of the system to transmit power will more than counterbalance this added cost. Such generators are immediately available and, with specially designed high-speed exciters, will permit of operation of transmission lines with a high stability limit.

In regard to the problems of internally compensated machines, much progress has been made along these lines, but since it is still in the development stage, very little can be said about it at present. It is possible to compensate a generator completely and even to extend this compensation to cover the impedance of transformers so that the generator has the characteristics of the infinite system of which Mr. Doherty and Mr. Dewey speak in their paper; but there are grave questions to be considered in the application of such machines. The rapid retardation and acceleration, caused by short circuits, and the subsequent clearing of the lines may produce mechanical stresses of great magnitude. In all probability some limiting device will be needed to limit the amount of current that can be delivered above a certain value.

Regarding the matter of transients due to short circuits, I agree with the authors that experience has shown that in existing systems with suitable relay protection, short circuits do not constitute a serious problem in operation. However, they make the statement that experience is the best guide and that calculations are always made on the basis of conservative premises and are therefore too pessimistic. The transient condition under short circuit will undoubtedly be the factor which will determine the ultimate rating of a transmission line and it behooves us to avoid being so conservative that our results are pessimistic.

I believe that we can or will be able to compute, with a fair degree of approximation, the results of a short circuit either to ground or between phases if we are provided with proper data as to ground resistance and load characteristics. I am further willing to go on record that we shall be able to install apparatus that will enable us to approach within a reasonable distance of the effect of an infinite system, not only on a straight-away transmission but also for one using intermediate synchronous condensers so that, with the latter system, the stability will be determined by the weakest section.

The automatic voltage regulator is not a hopeless problem for it is assisted by the fact that it takes time for the system to change its angular position whereas the terminal voltage changes instantly. Moreover, the internal reactions are resisted by inherent flow of exciting current. Therefore, the voltage regulator has time to act before the system gets beyond control.

P. H. Thomas: Mr. Fortescue, with his usual skill, has developed generalized equations for showing the theoretical limits of stability in electric systems containing synchronous machines.

The most difficult and illusive part of the problem of stability is the determination of the numerical value of the parameters of stability in particular cases and especially for the pendulum action or the tendency to overswing when a change of load in a system or its equivalent requires a new position of equilibrium. The principles involved are well understood and at least one analytical and one electric analog method have been proposed. These, however, are merely methods of overcoming the mathematical difficulties of the solution and still leave untouched the difficulty of properly evaluating the factors of losses and damper currents.

As is well known, any damper current set up by an advance or retreat in the position of the rotor with regard to the revolving field of the stator will tend to reduce, temporarily, the forces driving the rotor toward its new position of equilibrium and similarly, if the rotor over-shoots, these damper currents tend to restrain the over-swing. If sufficiently powerful, these forces may render the swing of the rotor dead-beat. The conditions governing the effect of these damper currents, which will usually be of very low frequency, should be fully studied to see what can be done therewith to restrain the overswing.

These damper currents should be controlled by the resistance of the damper rather than its reactance, but subject to this limitation the damper resistance should apparently be as low as possible. The field winding, having by far the greatest weight of copper surrounding the field poles would naturally have the most effective damper action.

While Mr. Fortescue has given a definition of stability which is entirely logical, we shall ultimately need something further; viz: a standard test or criterion to be satisfied by any particular system to insure reasonable continuity of operation.

It is yet too soon to offer such a criterion for actual adoption, but ultimately something in the nature of an overload to be taken at a certain power factor, or a drop of voltage (taking account of both ends of the line) that must be sustained without falling out of step, will be required.

It is gratifying that much has been done to render the terminal apparatus more responsive to its duties—but still more is desirable and no doubt possible, on account of the dominating importance of the cost of the line as compared with the cost of regulating and exciting means.

R. E. Doherty: I agree with the general point of view expressed by Mr. Fortescue—namely, that the lack of any great amount of trouble from instability up to the present time should not be interpreted as evidence that such a thing is not possible with longer lines and greater power; that, in any study of the problem, all elements of the system, including generators, exciters, condensers, lines, etc., and not merely one element of it, should be considered; that the problem involves two fundamentally different "states" of operation—"transient" and "steady"—during which the operating characteristics of the apparatus are different. I also agree with the general exposition regarding the angle-power relations, only in so far as it gives a physical, qualitative picture of the phenomenon. I strongly endorse his appeal for reliable information regarding ground resistance and would add an appeal for recorded data and system experience during single-phase short circuits. And, finally, I endorse the view that the mathematical, or even graphical, determination of stability of such system networks as comprise our modern power systems, is quite beyond the range of practical possibility. For these cases an equivalent system from which the required values can be obtained by test becomes necessary—just as for the same reason, it is necessary to thus determine short-circuit currents in complicated networks.

Such methods are available; the equivalent system proposed by C. A. Nickle[6] affords a valuable means of studying the power oscillations during transients, and the scheme proposed by Spencer and Hazen[7] affords a means of testing steady state power limits with practical accuracy. The latter method assumes sine-wave relation between power and angle, and is, therefore, roughly correct for maximum power studies. Nickle's method, however, in its present state of development, assumes linear relation between power and angle, and is, therefore, limited in this particular application to a study of the behavior of the various components of the system during those transients which do not involve power swings beyond the point where the linear relation ceases to hold. However, there are many interesting and important phenomena bearing on stability which can thus be determined; and if a circuit element giving the sine-wave relation is found, the maximum power can also be determined. The company with which I am associated is now completing the development of both of these facilities. While, of course, further improvements are ahead, the present development provides a very helpful aid, and, in my opinion, is a significant step forward.

There are a few points in the paper with which, if I interpret them correctly, I do not agree. They are relatively unimportant with respect to the general problem to which I have referred above, but have importance only in numerical calculations. I refer to the author's statement that the steady-state limit depends upon the leakage impedance and not upon the synchronous impedance. Making due allowance for saturation, which, in effect, reduces the impedance, the steady-state, ultimate power limit at normal voltage is determined by synchronous impedance, not by the leakage or "transient" impedance. A steady-state, hand-controlled test, giving a family of voltage-power curves, (as in Fig. 3 of the paper by Mr. Dewey and myself), shows the same power maxima as determined by automatic regulator tests, and as calculated, using synchronous reactance. While it is possible with an automatic regulator, as it is not by hand control, to throw on suddenly loads equal to the ultimate maximum steady-state power, it is nevertheless not possible, according to our tests and conception of the problem to carry significantly more than that by using a regulator actuated by the alternator terminal voltage and operating on a shunt- or compound-wound exciter of quick response. This is discussed fully in our paper.

In discussing the group of papers by Mr. Fortescue and his colleagues at the Midwinter Convention in 1924, I stated power limits which "in the present state of engineering knowledge" I considered to be justified. I said: "We must neither gamble that a voltage regulator will be able to insert a supporting prop under an otherwise falling system, nor depend for stability during load transients upon possible momentary favorable conditions due to momentary and field transients." Now the intensive study and investigation of the past year and a half has shown what we did not then know—that, up to the ultimate maximum power value, as determined by tests under hand control, the regulator can be depended upon to insert "the supporting prop," but not beyond that limit. I understand the author's statement to be that the regulator makes it possible to carry a constant load significantly greater than the above maximum; with this I disagree.

I do agree with the author that the object sought with an excitation system is to obtain the same characteristics as would be afforded by a machine which would inherently maintain constant flux linkages—one in which the field and damper resistances were zero. To say the same result would be obtained by an exciter of quick response which holds the alternator field approximately constant is in all respects parallel to the statement that if the terminal voltages at both ends of a line were held approximately constant by a regulator (as they can be, even by hand control, with gradual increases of load) the ultimate maximum power would be that of the line alone, *i. e.*, all limitations in the generator would thus be compensated, which obviously is not true. Yet the two cases essentially involve the same elements. It can be shown[8] that, following a load change, the flux change of the alternator field, $\frac{d\phi}{d\,t}$, is not zero, but essentially negative, unless a series negative resistance is introduced in the alternator field circuit. A method for obtaining this is described in our paper. A shunt- or compound-wound exciter, of however quick response, does not have this characteristic. Fortunately, however, for any load up to the ultimate steady-state limit at normal voltage, the ordinary exciter and regulator usually suffice; and this steady-state limit cannot, so far as our study and tests show, be increased by speeding up the exciter magnetically.

R. J. C. Wood: The main reaction I get from these papers is a feeling that perhaps we are using the wrong term when we talk about instability. We are not, ourselves, putting up the money to build these big systems, and I think that anything which suggests unduly, a weak point in transmission should be avoided. I do not mean by that we are to conceal the truth in any way, but there is a psychological effect produced by the word "instability," which I do not think is produced when we talk about power limit.

What we are getting at is the power limit of a system. There are various things which limit that power; the current may be so great that the wire will fuse and fall in half, or it may be this "instability" that we are talking about.

If you go out to buy an automobile you take the automobile out and try it and you run it up a hill and the hill is of increasing steepness. After a time that car just lies down and quits.

6. Oscillograph solution of Electro-Mechanical Systems, by C. A. Nickle, JOUR. A. I. E. E., p. 1277, Dec. 1925.

7. The Artificial Representation of Power Systems, H. H. Spencer and H. L. Hazen, A. I. E. E. JOURNAL, January, 1925, page 24.

8. Exciter Instability, R. E. Doherty, A. I. E. E. TRANSACTIONS, 1922, page 767, eq. 30.

You have not an unstable automobile; you simply have reached the limit of its ability. Perhaps you kill the engine; perhaps you spin the hind wheels. That might be an illustration of the generators falling out of step.

It would be better if we could think and speak of this more in terms of power limit; everybody is familiar with the idea of a limit of endurance, both humanly speaking and as regards apparatus and machinery.

Roy Wilkins: I am employed by a company owning an interconnected system of upwards 8000 mi. of line 60-kv. and over, and with a total generating capacity of a little over 880,000 kv.-a. The connecting rotating load is about 2,000,000 h. p. At different times there have been tested 110-kv. lines up to 500 mi. in length in operation and carrying load, and loops as long as 350 mi.

I should like to point out certain road signs in the line of "don'ts" for people who, in the actual power industry, take up the study of power limits or instability as it has been called. First, don't worry about anything except the actual operating conditions. You will find trouble enough without running into any weird combinations which are impossible operating conditions. Second, don't expect to simplify the problem and still check the performance of a complete transmission system, because in a transmission system, every piece of connected apparatus has certain characteristics. These characteristics are all in their proper places, proper order and proper values. Any simplification means a certain amount of error.

At the present time, there is too little known about circuit-breaker operations, corona, WR_2, impedance, load character and load power factor, together with certain cases of trouble as grounds, etc. As a passing note, nobody, at the present time, knows exactly what "load power factor" is. I haven't been able to measure it in a year and a half. The final result will come from a mass of accumulated operating data just as in the past for the final solution the twenty-year old problem of a grounded-neutral system came not from brilliant mathematics or special studies, but from the final check and the actual operating procedure of a great number of operating systems.

F. G. Baum: If you will read the TRANSACTIONS of the Institute of twenty years ago you will find that the problem of stability was then one of very great importance and a great deal of work was done on it at that time. The reason for its importance was this. The Stanley Company made for operation on the first long transmission systems, an inductor type of generator which had no revolving coils of any kind. The generator had 100 per cent reactance. It was good for the conditions which then existed, since we had only air switches with which to open the circuit. If there was a short circuit, the voltage dropped to zero and you could open the circuit with the air switches.

Generators were actually advertised as being capable of being short-circuited without damage and only a few years ago many engineers were specifying that the short-circuit current should not be over so many times normal current.

We are now talking transmission-line stability again, and the generators are the main element in it. The transmission line will take care of itself if you will take care of the generators. The reason we are talking so much about instability is because we have flashovers, or expect them, and therefore want to be ready to take up and quickly replace the difficulty caused by the flashover. In other words, the trouble now is with flashovers, while twenty-five years ago it was that we didn't have any switches. At the time the Stanley generator was put out I was in charge of the operation of the Pacific Gas and Electric Company in which we had a number of these generators and the regulation was very poor. The voltage variation under normal operations was so bad that we couldn't operate lights at the same time as motors. Something had to be done so we applied to all the synchronous apparatus an excitation in proportion to the load. All the d-c. load current was taken around the exciters and the voltages built on the d-c. exciter in proportion to the load.

At that time I also worked out a regulating scheme for the a-c. generators which would build up the generator voltage in proportion to the drop in voltage due to the load, which as you know is practically $I \sin \theta$. I wasn't popular for proposing that because the generators were being sold because they had poor regulation, and I proposed to make them good.

For the last year and a half we have been making quite elaborate tests on power limits of transmission systems, and I agree with Mr. Wood that it is power limits and not instability which we are talking about. We don't get instability unless we have troubles outside of those that are expected and most of those come from flashovers. Stop flashovers and you won't get the instability.

The tests made have checked calculations very, very accurately. Early last Spring we calculated the power limit on the Pit River System as 185,000 kw., using a power-angle diagram, which you will find in the *Electrical World* in 1902. The limit of the Edison system under actual operation has been found to be 183,000 kw. and if you will allow for the increased length of line and decreased frequency the results check.

I want to express surprise at the suggestion made in Doherty-Dewey paper for the use of series capacity in the transmission line. You can do that in a radio system but to consider it seriously for a transmission line seems unreasonable.

The most important part of the transmission system today is the oil switch and relays. If we didn't have them today we couldn't operate our transmission systems. Any electric power system of high or low voltage and without proper relays, switches and fuses to eliminate defective line sections is inoperative. I think you will agree with that, so I say, work on the oil switches and relays. First work on the flashovers, and get rid of those so the switches won't have any more to do than necessary. Then when you get through with that, static stability will be the criterion of your power line and not transient stability.

A statement has been made with reference to the limitations of long-distance power transmission, which was quoted in a morning paper. The statement was that with the present apparatus (and present state of mind, especially) 300-mi. transmission is questionable of economic results.

I challenge that statement. I think it should never have been made. Any man who sets a limit at the present time on power transmission either does not understand the problem or perhaps he is purposely making the statement for some other reason.

I wrote a paper for this meeting which I didn't submit because certain developments afterward made it advisable to add other information. The first sentence reads: "The natural and approximately the economic load per circuit for load transmission is given by the equation $P = 2.5\ E^2$."

If 220 kv. will not do the work, we can go to 330 kv., or some other reasonable voltage, and if 330 kv. won't do it, we can go to 440 kv. When I say that I am saying it in view of the intense study made in the last two years on insulation, coupled with the results obtained on the present system of the Pacific Gas & Electric Company, operated at 220,000 volts. It is the most successful piece of work we have undertaken, and the power is transmitted about 300 mi.

To have a real natural transmission system, you must balance the magnetic energy all along the line with the electrostatic energy. To develop that you get this equation, $I = E \sqrt{\frac{C}{L}}$. I want to call your attention to the importance of this equation. I think that equation is more important than Ohm's law or any other in electrical engineering. It is a

fundamental equation. Nature tries to transmit power with the conditions given by that equation.

Now, if I want more current, I can do three things; Raise the voltage, lower the reactance or increase capacity. Most people will recognize that if you lower the reactance you will immediately get increased line capacity, but they do not appear to recognize that if you increase C you get the same results practically. I can reduce L to one-half and multiply the amount of power by $\sqrt{2}$; I can change C by doubling its value and also increase the power by $\sqrt{2}$.

Regarding line insulation, with the study we have been making in the last year and a half, I am satisfied that when we want the 330 kv. we can get it. We started this work early in 1924, not because of any troubles on our present 220-kv. transmission lines, but because we didn't want to be caught like we were in 1912 when we put in the 110-kv. lines, and later found troubles we didn't know anything about. We decided in 1924 that we would make a thorough study of insulation. The Westinghouse Company has supported that work on insulation, and the Pacific Gas and Electric Company is cooperating in the long-line tests and the practical tests which we find necessary.

So the first thing was to decide how to get at the matter of the mechanism of flashovers. I decided, after several years of study, taking probably thousands of flashovers and arriving at no mental picture of what was happening, that we had to get a reliable picture of what actually was happening whenever we had a breakdown. To get that we decided that we should probably have to get at it from a d-c. standpoint, projecting the electrons through the air, and if possible taking their pictures on the way. They are fast-moving and don't pose very long.

The pictures we have taken will I believe give a mental picture of the insulation of the air such as we have not had and I believe the work done and being done will tell us the true story of line insulation.

R. E. Doherty: The extensive discussion indicates a keen interest in this important subject, and serves the very helpful purpose of focusing attention on those points which have not yet been generally agreed upon. The more they are discussed, the more they will be studied and the sooner will the various interested engineers agree upon the more important details. While perhaps there is not at this time *universal* agreement upon even the more fundamental aspects of the problem, there has been, I think, for the past two years general agreement on these fundamental aspects by those who have given the matter serious study. As I mentioned at the Midwinter Convention at Philadelphia, in 1924, the fundamental theory underlying the problem, and the equations arrived therefrom, are used by all informed engineers. Divergence of views enters only when assumptions are made regarding numerical values for a particular case. More specifically, disagreement centers, not about the transmission-line theory or the general equations of the system, but about faulty understanding regarding internal characteristics and constants of synchronous machines. Although different views regarding such machine characteristics apparently result in different estimates of maximum power which can be transmitted over a given system, I am not sure that this difference is as great as might be expected from the tone of the discussion. Messrs. Fortescue and Evans say that the calculated values in our paper are too low, but they do not indicate what these values should be. And I believe that in any definite proposed undertaking, their conclusions as to the practical feasibility of carrying out the given proposal, would not be significantly different from ours. Indeed, in more recent proposals where such parallel studies have been made, the conclusions have not been widely different. All of which indicates, of course, that the protracted discussion regarding certain alleged, weird behavior of synchronous machines is somewhat of a trifling character, and not of the importance which engineers not familiar with such details might be led to suspect.

I shall attempt to answer the questions raised regarding our paper, although most of them could have been answered by referring to statements in the paper. Mr. Thomas believes that it is not likely that the charging current of a long line will be a detriment under practical operating conditions. It may, indeed, be a great advantage provided the generating capacity at the end of the line is sufficiently large, as clearly shown in Fig. 2. But this is not a matter of opinion; the extent of its effect can be easily computed for any given case. It must not be concluded just because calculations made on the basis of constant terminal voltage show a larger power limit with the normal line capacitance than without it, that the same result would obtain with synchronous apparatus of a kv-a. capacity comparable with the load to be transmitted.

Mr. Griscom states that he does not understand why synchronous apparatus becomes inherently more powerful during transients. The reason is that, for the moment, the *transient* reactance, instead of the *synchronous* reactance, determines the power characteristic of the synchronous machines. The ratio of synchronous reactance to transient reactance in ordinary commercial synchronous machines is of the order of 5 to 1. It may be as low as 3 to 1, or as high as 10 to 1. In other words, in rough values the synchronous reactance is about 100 per cent, and the transient reactance about 20 per cent. Thus the machine in such a transient state is decisively stiffened up. Mr. Griscom's question would probably be removed by reading over the paper—under the heading "Transients."

He also questions whether the slope of the voltage-power curve determines the degree of stability. If the slope is zero at all values of power, it merely indicates that the voltage of the bus under consideration is not affected by any power change whatsoever, regardless of whether the synchronous machines constituting the infinite bus are of zero inertia or infinite inertia or any value between these extremes. Mr. Griscom's statement is correct that when $\frac{d\,E}{d\,P}$ approaches infinity, $\frac{d\,P}{d\,T}$ approaches O; but this is not, as Mr. Griscom states, because $\frac{d\,P}{d\,\Theta}$ is limited by the mass of the synchronous machines, but because at that moment the electrical characteristics are such that the power is not changing, although the angle Θ may be changing.

I wish to add a word about this 183,000-kw. story as related by both Mr. Evans and Mr. Baum, and which Mr. Dewey has answered. When the engineers of the country are eagerly waiting for every additional fact of operating experience bearing on this subject, it seems unfortunate, indeed, that when some real data do become available, their meaning should be so completely misunderstood or misinterpreted. When the sending end wattmeter reads 183,000 kw. and the receiving-end meter reads 135,000 kw., should we say or imply that 183,000 kw. is *transmitted over* the line? And I think that neither Mr. Evans nor Mr. Baum would, after serious thought, adduce that test (which our calculations check) as evidence that our calculated values are much too low. In Mr. Evans' published work, he calculates, as most every one does, the receiver-end, not the sending-end, power.

Mr. Evans raises two other points: One is that the maximum power can be increased by reducing the reactance of the generator; the other, that Fig. 2 might be misleading. As to the one, the authors heartily agree, as presumably every one else does. Nobody would question that. The question is *how* will you decrease the reactance. Mr. Evans is referred back to the paper to the heading "Design," where this matter is fully discussed. The generator capacities given are based on present-day practise—synchronous reactance approximately 100 per cent. Nothing

would be gained by cutting the ratings to, say, one-half, thus reducing the per cent reactance to 50 per cent. That would not increase the maximum power. The question is how would one alter the design of a machine of given magnetic dimensions in order to lower the synchronous reactance, and to what extent could it be thus lowered. There could not be much disagreement among informed designing engineers on that point. After that is done, any further reduction must be obtained by increasing the active volume of the machine, or by adding more machines. Thus, as Mr. Evans says, and as the paper clearly points out, "quite marked increases in the stability" can be obtained in these ways, but there are perfectly obvious reasons, as the paper also points out, why this process cannot be extended far enough to satisfactorily solve the problem.

The other point raised by Mr. Evans is well founded. The authors acknowledge that the title of Fig. 2 should be more specific, and will revise it accordingly. The illustration refers to a 250-mi. straight-away line with synchronous-motor load.

Mr. Fortescue does not know of "a single case in which a system was thrown out of step by a sudden increase in load, or short circuit due to low excitation." There have been such cases, nevertheless. The September 1919 trouble of the Commonwealth Edison Company, described by Dr. Steinmetz in the 1920 TRANSACTIONS, is one notable example among others.

The authors naturally agree that if an additional line with duplicate sending and receiving apparatus be installed, the maximum power will be increased. Two power *systems* will obviously carry more than one. But that is not the point. Fig. 2 merely shows the relation between generating capacity, number of lines and maximum power. To say, as Mr. Fortescue does, that two "properly designed" systems with "proper size generating stations," etc., etc., will always carry more than one, would hardly bear close scrutiny where costs are regarded; because "proper size" for maximum power may be prohibitive in cost.

It does not require a mechanical model to prove the platitude that if "the terminal voltages are kept constant," the power limit will be the limit of the line itself. But to the authors' knowledge the "perfect regulator" to hold this condition does not exist. When it shall exist, or else some other method than synchronous operation is utilized, it will be time enough to talk seriously about the limit of the line alone. I have discussed this problem of regulation in my comments on Mr. Fortescue's paper.

Mr. Fortescue also bespeaks the gain from changing the generator characteristics. Such changed generators, he avers, will permit of operation with a "high stability limit," but he doesn't say how high. And the whole point, if there is any, depends upon *how high*. He, like Mr. Evans, is referred to the paper under the heading "Design."

They also mention that the authors have not discussed the effect of load characteristics. Loads which are functions of the voltage, such as lights and certain classes of converters feeding a constant voltage d-c. bus, are inherently stable. These have a maximum power, but that is not the limit of stability. Indeed, there is no stability limit with a plain impedance load. The shaft load of induction and synchronous motors is independent of voltage, and for these, the maximum power limit and stability limit coincide. Thus, a composite load would have greater stability than a pure shaft load of the same amount.

H. H. Dewey: In closing, I shall take up some of the points that have been brought up in the discussion of the paper by Mr. Doherty and myself.

Mr. Thomas in his discussion brought out a point in regard to the relation of the cost of the terminal apparatus to the cost of the line, pointing out that the line cost was very high per kilowatt. It might run to $125.00 per kilowatt, whereas the terminal apparatus, generators and motors, would be very much less than that, perhaps $8.00 or $10.00 per kilowatt, and that since the terminal apparatus was an important factor in the power limit of the completed system, the place to work to extend our power limits was on the synchronous apparatus. I agree with that thoroughly, and we can do considerable along that line.

Mr. Evans and Mr. Fortescue spoke of the possibilities of synchronous-apparatus improvement as a thing about which we were unduly pessimistic in our paper, that is, the question of what could be done to increase the power limit of terminal apparatus. Our paper did not stress that point for the reason that it seemed obvious. In presenting the curve given, showing the breakdown of a given generator and a given motor, it is quite apparent that the power limit is determined by the size of the generator. If we had a generator of double the size, or a motor of double the size, we would get double the power. In line with Mr. Thomas' suggestion then, since we can put on generating apparatus for $8.00 or $10.00 per kilowatt, we can obviously increase the size of the generator until we strike an economic balance between the size of the generator and the capacity of the line.

Now, the size of a generator is determined by its characteristics. We would fool ourselves if we tried to take a 10,000-kilowatt generator and cut its reactance in half, change its field, style, etc., and still call it a 10,000-kilowatt generator. It wouldn't be a ten thousand any more; it would be fifteen or twenty, and it would cost more money to build it. That is an obvious thing that we did not stress in our paper. Since generating and receiving apparatus is a large factor in limiting the power that can be transmitted over a system, everything possible should undoubtedly be done to improve their characteristics.

The paper tried to cover the essential points in determining what a given set-up would give. There was a point that Mr. Evans brought up and Mr. Fortescue also, in their discussion, in regard to the effect of charging current of transmission lines. They took issue with Mr. Doherty and myself in stating that charging current was an actual detriment. They evidently did not read our discussion of that point very carefully.

With given apparatus, with a given generator, with a given receiving-motor load, and a given voltage, at each end of the line, which we always have, charging current *is* an absolute detriment. We reduce the amount of power which can actually be transferred from the generator to the receiver end, no matter what the relation of charging current of the line to the generator. The charging current of the line on a high-voltage system will actually reduce the amount of power you can transfer from the generators to the motors, because it reduces the excitation of the generators and motors.

Mr. Evans brought out a point in which he indicated that our calculations on a 250-mi. line were in error in that it was considerably less than the value that had already been obtained in practise by the Southern California Edison Company. He stated that our calculations showed the limit to be 115,000 kw. whereas they obtained 183,000 kw. The calculation is 120,000 kw., not 115,000 as read from the curve by Mr. Evans. We have made a calculation of the Southern California Edison System based upon data furnished by Mr. Barre which showed 183,000 kw. Our check calculations, made in the same manner as our calculations in the paper, came within 5 per cent or thereabouts of the same results.

The big difference in these values comes in this respect: The 120,000 kw. shown in the paper was receiving load. The 183,000 kw. obtained in actual practise on the Southern California Edison Company's system was at the generating end. At the time they had 183,000 kw. input they had 135,000 kw. output. Thus, we have an error of only 120,000 kw. to 135,000 kw. and there is a difference of 20 per cent in frequency, that is, 50 instead of 60 cycles, which brings it to almost exactly the same thing.

Mr. Wood spoke of the term that has been quite often used to describe "power limit;" that is, "instability," and sounded a warning against its use. I agree with him thoroughly on that. It was for that reason that the title of our paper was made Power Limit. Power limit is something that is perfectly harmless,

and I agree that the use of the word instability is likely to cause concern where concern is not necessary.

Mr. Fortescue's discussion was quite lengthy and very helpful. He took issue with some parts of our paper. Some of these points I did not quite digest. Some of them made me rather think that he was saying the same thing we were saying only in different words, particularly as he laid very great stress on the effect of voltage regulators. I agree with him thoroughly that the regulator is a very important thing, and is so much more important than we originally thought that it makes a great deal of difference in the ultimate capacity of the transmission system.

We have very few real things to worry about. I agree with Mr. Wilkins that the final solution of this problem is going to come in the data that we get from actual operation, but so far the data of actual operation, where we have been able to obtain data, have checked so closely with our present methods of calculation that we feel we are in a position where it will be possible to predict what will happen to any given system. The more complicated the system, the more difficult it is to calculate, and when we get such complications, we must resort to some scheme such as Mr. Nickle has described[9], just as we reach the limit of the possibility of calculating short-circuit current on a network such as described by Mr. Wilkins with 880,000 kw. of generating capacity and thousands of miles of interconnected transmission line. That would be a hopeless case to calculate the short-circuit current, but we have calculating machines that arrive at these values very closely. We can likewise use the Nickle calculator, or some other device to arrive at our stability problem. We are not worrying about the question of stability or power limits; we know pretty closely how to calculate them, and it is very essential that we do so, as the amount of power that can be carried over a given line greatly influences the cost of delivered power.

C. L. Fortescue: In regard to Mr. Thomas' discussion, he emphasizes the effect of damping factors. In our calculations we try to work in the effect of the damping factor as much as possible, but Mr. Thomas remarks that if you increase the damping factor sufficiently the machine will be critically damped. We know that in practise this condition is never met. We have records of power swings and they are as far as we know never critically damped.

As regards Mr. Doherty's discussion I think we are substantially in agreement. I think an explanation of the differences in view might be somewhat as follows:

Two investigators have approached this problem from somewhat different angles, and while there is no disagreement in the fundamentals of the problem, there is a little apparent disagreement in what might be termed derived ideas.

The problem of stability involves so many factors, the speed of the exciters, the speed of the regulators, the inherent tendency of the machines to correct themselves, etc., that it is quite excusable that there should be a slight difference of opinion.

Now, I think you might say that Messrs. Doherty and Dewey and myself agree on what should be. We probably agree pretty well on what actually is, but we disagree somewhat in regard to what may be or might be, Messrs. Dewey and Doherty putting the "might be" a little closer to the "is," and I myself putting the "might be" a little closer to the "should be."

I hope that the result of our investigations will finally bring us both to an agreement on the "might be" and that the "might be" will finally come closer to the "should be" than Messrs. Doherty and Dewey place it at present. That is my hope. I am quite open-minded about this.

The final decision about this particular question will undoubtedly come about from actual work in the field and in the laboratory. We shall, of course, make calculations and analyze these results and there is no doubt at all that we shall finally come to a substantial agreément. In that day I hope we will be very close to the "should be."

9. "Oscillographic Solution of Electromechanical Systems," by C. A. Nickle, Jour. A. I. E. E., December 1925, p. 1277.

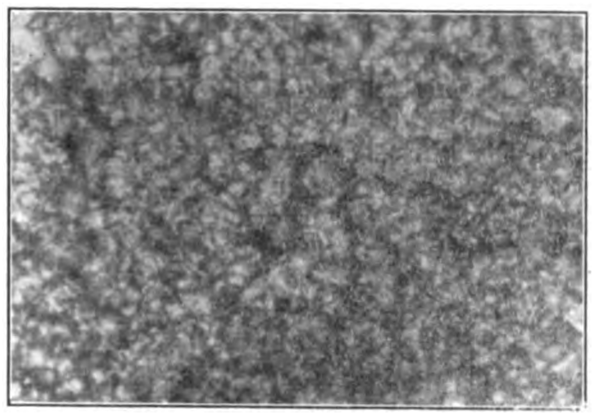
ILLUMINATION ITEMS

By the Lighting and Illumination Committee

INTERESTING ASPECTS OF THE INSIDE FROST LAMP[1]

For some twenty years or more the advantages of frosting an incandescent lamp on the inside of the bulb have been appreciated by illuminating engineers but until recently no satisfactory method had been devised whereby this frost may be applied to the *inside* of the lamp without at the same time greatly weakening the structure of the bulb.

An inside frost is etched into the glass and this etching process causes minute cracks or splits to appear just underneath the surface of the glass. These cracks weaken the strength of the glass in practically the same way as does the scratch made by the hard point of a glass cutter. Moreover they spread easily and cause premature failure just as does a crack in a plate-glass window or in a steel-truss member. It is a well-known fact, however, that if a round hole is drilled at the end of the crack or split in the latter cases the window will be less likely to become entirely broken and the steel supporting member will withstand a greater weight. In like manner, when the inside frosted lamp is subjected to the proper treatment, the entire area of the inside surface will become etched in such a manner as to round out the bottoms of these cracks. The effect in this action is to restore the strength of the bulb to its former value, and the inside frost thus becomes a thing of

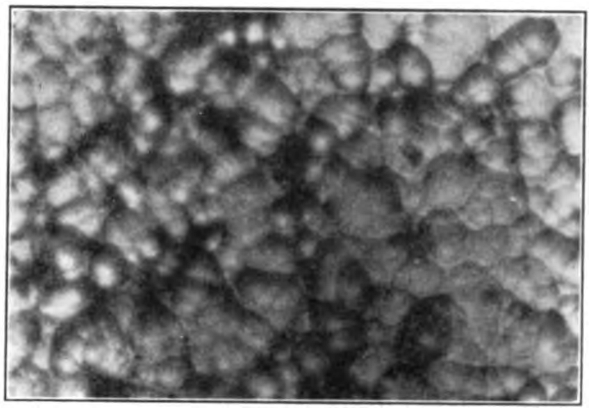


MICROGRAPH SHOWING INSIDE FROSTED SURFACE OF WEAK BULB

1. Marvin Pipkin, Chemist, National Lamp Works of General Electric Co., Nela Park, Cleveland, Ohio.

practical importance instead of theoretical conjecture. The accompanying micrographs show the frosted surface before and after this strengthening action takes place.

The diffusion of the light by the inside frost is obtained by prismatic refraction with comparatively little loss. In fact, the inside frost allows an even greater



Inside Frosted Surface Treated to Restore Strength

portion of the light to pass through than does a similar frost on the outside of the lamp. This is due to the fact that the multiple internal reflections are not so numerous in the inside frosted lamp because the rough, interior surface does not reflect any considerable portion of the light back and forth inside the lamp, as is the case with the outside frosted lamp. Moreover, the relative absorption of the inside frost does not increase so rapidly with the life of the lamp as do other diffusing media. The relative degrees of absorption of the various diffusing media are shown in the following table for new lamps as well as for lamps which have burned for approximately 800 hours.

TABLE NO. I

	Approximate Initial Absorption in per cent of Clear Bulb Light Output	Absorption After Burning in per cent of Clear Bulb Light Output
Inside Frost per cent..	1- 2	1- 5
Sand Frost (Outside) per cent.........	5–10	10–20
Spray Frost (Outside) per cent.........	5–10	10–20
White Mazda (Sprayed) per cent ..	10–15	15–30
Opal Glass...........	10–20	15–30

The light absorption by the inside frost is of little importance when the material reduction in the glare over that from a clear bulb lamp is considered. Other advantages of the inside frost such as the smooth exterior surface of the bulb and the resulting ease with which it may be cleaned, were mentioned in the July issue of the Journal.

When unlighted, the new bulb appears to be a light gray with the property of blending in a harmonious manner with the color of the background that is entirely lacking in the other types of bulb finish. The color of the background is diffused within the lamp, itself, giving it a faint corresponding tint. Because the inside frosted bulb will blend harmoniously with its background, it is hoped that its use will eliminate the necessity of supplying tinted bulbs where the unlighted appearance of the lamp has been an important factor and where the cold white appearance of the outside frosted or coated lamps has been objectionable.

CHAPTERS ON LIGHT

To most of us, the high school physics courses of today are removed somewhat from our general trend of thought. Nevertheless, let us consider them for the moment. They are essentially the same as they were some years ago—fair enough, perhaps, in some branches of physics since Archemedies' principle, Charles' and Boyles' laws, Newton's laws of motion and the like, are fundamental truths which will never change as far as we are concerned. But what about these chapters in the physics texts which deal with light—that vision-giving wave motion by means of which we are able to see what goes on about us?

Unfortunately, the majority of high school physics texts treat the subject of light in a rather dry and scientific manner which quite frequently presents no direct appeal to the average high school student. Realizing this, the Illuminating Engineering Society has prepared a booklet, "Chapters on Light," which is recommended for inclusion in physics text books. The preparation of this booklet has been sponsored by several of the most prominent illuminating engineers of the country and it is therefore up-to-date in every detail. Furthermore, the presentation of the subject matter is such that the average high school student will be directly interested in the practical applications of lighting and illumination to every-day life, and he is, therefore, much interested in the laboratory experiments which will really be of some practical benefit to him.

"Chapters on Light" will make an excellent addition to present text books and may be used in part as a substitute for present material. It is hoped that this booklet will be used more extensively in high school physics courses as it will undoubtedly tend to increase the students' interest in correct lighting and its application.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

A. I. E. E. Nominations

The National Nominating Committee of the Institute met at Institute headquarters, New York, December 3, and selected a complete official ticket of candidates for the Institute offices that will become vacant August 1, 1926.

The committee consists of fifteen members, one selected by the executive committee of each of the ten Geographical Districts, and the remaining five elected by the Board of Directors from its own membership.

Those present were: H. P. Cramer, Portland Ore.; W. P. Dobson, Toronto, Ontario; Gano Dunn, New York, N. Y.; G. Faccioli, Pittsfield, Mass.; M. M. Fowler, Chicago, Ill.; J. E. Kearns, Chicago, Ill.; M. M. Koch, Denver, Colo.; E. B. Merriam, Schenectady, N. Y.; L. F. Morehouse, New York, N. Y.; A. G. Pierce, Cleveland, Ohio; T. C. Ruhling, Kansas City, Mo.; A. M. Schoen, Atlanta, Ga.; Harold B. Smith, Worcester, Mass.; N. W. Storer, Pittsburgh, Pa.; H. S. Warren, New York, N. Y. (representing Pacific District); and National Secretary F. L. Hutchinson. Mr. Gano Dunn was unanimously elected chairman of the committee.

The following is a list of the official candidates:

FOR PRESIDENT

Cummings C. Chesney, Manager and Chief Engineer, General Electric Company, Pittsfield, Mass.

FOR VICE-PRESIDENTS

NORTH EASTERN DISTRICT: H. M. Hobart, Consulting Engineer, General Electric Company, Schenectady, N. Y.

NEW YORK DISTRICT: George L. Knight, Mechanical Engineer, Brooklyn Edison Company, Brooklyn, N. Y.

GREAT LAKES DISTRICT: B. G. Jamieson, Engineer of Inside Plant, Commonwealth Edison Company, Chicago, Ill.

SOUTH WEST DISTRICT: A. E. Bettis, Vice-President, Kansas City Power & Light Company, Kansas City, Mo.

NORTH WEST DISTRICT: H. H. Schoolfield, Chief Engineer, Pacific Power & Light Company, Portland, Ore.

FOR MANAGERS

F. J. Chesterman, Chief Engineer, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

H. C. Don Carlos, Operating Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

I. E. Moultrop, Asst. Supt., Construction Bureau, Edison Electric Illuminating Company of Boston, Boston, Mass.

FOR TREASURER

George A. Hamilton, Electrical Engineer, Elizabeth, N. J.

The constitution and by-laws of the Institute provide that the nominations made by the National Nominating Committee shall be published in the January issue of the Institute JOURNAL; and provision is made for independent nominations as indicated below:

CONSTITUTION

SEC. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the National Secretary when and as provided in the By-Laws; such petitions for the nomination of Vice-Presidents shall be signed only by members within the District concerned.

BY-LAWS

SEC. 22. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the Secretary of the National Nominating Committee not later than February 15 of each year, to be placed before that Committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the National Nominating Committee in accordance with Article VI of the Constitution and sent by the National Secretary to all qualified voters during the first week in March of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

F. L. HUTCHINSON,
Secretary
National Nominating Committee

Cummings C. Chesney

Mr. Chesney, official nominee for the office of President of the Institute, was born in Selingsgrove, Pa., October 28, 1863, and was graduated from the Pennsylvania State College in 1885. After teaching mathematics and chemistry for three years he became associated with Mr. William Stanley's laboratory at Great Barrington, Mass., and was one of the original incorporators of the Stanley Electric Manufacturing Company, of Pittsfield, Mass., which developed the well-known S K C polyphase system (Stanley-Kelly-Chesney). Mr. Chesney was vice-president and chief engineer of the Stanley Company from 1904 to 1906, and in the latter year he became chief engineer and manager of the Pittsfield Works of the General Electric Company, which had acquired the Stanley Company. Mr. Chesney has served as Manager and Vice-President of the A. I. E. E., and also upon various committees. He is also a member of various other scientific and engineering organizations. The Edison Medal was awarded to Mr. Chesney in 1921 "for early developments in alternating-current transmission."

Plans for the Midwinter Convention

FEBRUARY 8-11, 1926

A variety of excellent papers will be presented at the Midwinter Convention which will be held in the Engineering Societies Building, 33 West 39th Street, New York, February 8-11, 1926. The entertainment and social features as well as the inspections will be thoroughly enjoyable.

Among the technical subjects to be discussed are transmission stability, protective and control systems, bus and structural construction, electrical machinery, measurements, insulation and dielectric absorption, electromagnetism and electrophysics, communication and sound reproduction, and furnace-resistor design. The list of papers given below shows in detail the topics to be presented.

In the social part of the program there will be an informal smoker on Tuesday evening, February 9, at the Hotel Astor. Some very interesting entertainers will add to the pleasure of this evening.

The dinner-dance on Wednesday evening promises to be even better than the dinner-dances of the past few years which always have been most heartily enjoyed. This event will be held at the Hotel Astor and a Paul Whiteman orchestra will furnish the music. This fortunate combination is an absolute guarantee of an excellent dinner, fine music and very enjoyable dancing.

On Thursday evening an address will be given by a prominent speaker and all should take the opportunity of hearing him.

New York, of course, offers a limitless variety of possible inspection trips and the trips being arranged will be most instructive. Among the places to be visited will be the new Holland Tunnel (the vehicular tunnel under the Hudson River), Broadcasting Station W. E. A. F. of the American Telephone and Telegraph Company, the Edison Lighting Institute of the Edison Lamp Works, the Loening Airplane Factory, Kearny Power Station of the Public Service Electric and Gas Company, Hudson Avenue Station of the Brooklyn Edison Company, Hell Gate and Sherman Creek Stations of the United Electric Light and Power Company, the Bell Telephone Laboratories and a machine-switching central telephone office.

A live convention committee is perfecting plans to assure that all who attend the meeting will have a pleasurable and profitable time. The general committee appointed by President Pupin is as follows: H. A. Kidder, Chairman. H. H. Barnes, Jr., G. L. Knight, E. B. Meyer and L. F. Morehouse. Chairmen in charge of entertainment features are as follows: Smoker, G. W. Alder; Inspection Trips, H. Y. Hall; Dinner-Dance, J. B. Bassett, and Special Meeting, H. S. Sheppard.

Reduced Railroad Rates

A reduction in railroad fares is available to out-of-town visitors under the certificate plan. Under this plan each person requests a certificate when purchasing a one-way ticket to New York. Presentation of this certificate at convention headquarters will entitle the passenger to half-rate fare for the return trip by the same route provided 250 certificates are presented at the convention.

Members should advise their local ticket agents when purchasing tickets of their intention to attend the A. I. E. E. convention and should ask for certificates. Return tickets issued at the reduced rates are not acceptable on a few limited trains. Tickets must be purchased not more than a fixed number of days prior to the opening date of the meeting and return tickets must be used within a certain period after the closing date. Details relative to these dates, etc., can be obtained from ticket agents. Immediately on arrival in New York certificates should be presented to the endorsing officer at convention headquarters.

All Visitors Should Get Certificates

Everyone, whether he will use it or not, should get a certificate if his regular fare to New York is 67 cents or more, because all certificates presented will count toward the 250 required to give reduced fares to those coming long distances.

TENTATIVE PROGRAM OF MIDWINTER CONVENTION FEBRUARY 8-11, NEW YORK

Monday Morning

Registration
Committee Meetings

Monday Afternoon

Transmission Session

1. *An Investigation of Transmission-System Power Limits*, C. A. Nickle, General Electric Company, and F. L. Lawton, Quebec Development Company.

   Results of theoretical analysis, verified by miniature-system tests, of the power limits of transmission systems. Among the major conclusions are the following: (1) The criterion of stability for all conditions is the steady-state power limit, (2) the charging kv-a. exercises marked detrimental effects on stability, (3) the characteristics of synchronous terminal apparatus are of great importance, (4) improvements can be made by modifying present apparatus design, (5) automatic voltage regulators, suitable exciters and fast relays are essential, and (6) the mercury-arc rectifier as an adjunct in excitation circuits shows real advantages.

2. *Calculation of Steady-State Stability in Transmission Lines*, Edith Clarke, General Electric Company.

   Two simple methods of determining whether a proposed transmission system will or will not be stable for steady-state operation under the maximum proposed load, (1) by means of an equivalent circuit and (2) by means of a circle diagram. Examples are solved to illustrate the methods.

3. *Practical Aspects of System Stability*, Roy Wilkins, Pacific Gas and Electric Company.

   An account of field tests made on a 220-kv. transmission system to determine the behavior of the system under transient conditions. Among several important conclusions reached are: (1) Stability is inextricably entangled with system economics, (2) studies of artificial systems are not adequate, (3) only a certain part of a system's stored energy is available during trouble, (4) proper relay action is vital, and (5) operating distribution of exciting current is a major problem.

4. *Further Studies of Transmission Stability*, R. D. Evans and C. F. Wagner, Westinghouse Electric & Mfg. Company.

   This paper deals with the principal elements entering into the stability problem, such as the action of generators and exciters during disturbances, effect of dissymmetry produced by single-phase short circuits, simplification of load networks, and methods of combining these factors in determining electro-mechanical oscillations following disturbances. Results of calculations are compared with recent tests on the Pacific Gas and Electric Company system. Various methods of improving stability are discussed.

5. *Transmission Systems with Over-Compounded Voltages*, H. B. Dwight, Massachusetts Institute of Technology.

   A discussion of the advantages of causing the voltage at generating stations to be raised by automatic regulation at times of heavy load. Methods of calculation for the transmission line and transformers for over-compounded operation are given. Two methods are given (1) for over-compounded generator voltage and constant receiver voltage and (2) for over-compounded voltages at both generator and receiver.

Monday Evening

Dielectrics and Insulation

6. *Dielectric Absorption and Theories of Dielectric Behavior*, J. B. Whitehead, Johns Hopkins University.

   A review and comparison of all the theories of dielectric behavior and dielectric absorption which are found in existing literature. This is a report made on these subjects to the Division of Engineering and Industrial Research of the National Research Council. An exhaustive bibliography is included.

7. *Theory of Absorption in Solid Dielectrics*, V. Karapetoff, Cornell University.

   The purpose of this paper is to establish certain general relations between (a) the increase in electrical displacement in a solid dielectric and (b) time after the initial displacement which occurs almost instantly after applying a constant d-c. voltage.

The ultimate aim of the theory is to make it possible to correlate and mutually to check experimental data on absorption and dielectric loss and to predict these quantities where no test figures are available.

8. *Ionization Studies in Paper-Insulated Cables*, C. L. Dawes and P. L. Hoover, Harvard University.

Tests data are given in this paper which show the relations among voltage, power factor, watts, capacitance and temperature in impregnated-paper cables and in model cables. A new type of a-c bridge for measuring dielectric loss and power factor with great accuracy at very low power factors is described. Some new and interesting conclusions have been drawn from the results and theories formulated to account for the results.

Tuesday Morning

Protection, Control and Bus Construction

9. *Operating Performance of a Petersen Earth Coil-II*, J. M. Oliver and W. W. Eberhardt, Alabama Power Company.

A record of eleven months' operating experience with a Petersen earth coil installed on a 44,000-volt transmission system. A compilation of system troubles is given showing how often the coil functioned correctly or incorrectly. In 109 cases of insulator flashover the coil operated correctly in 94 cases.

10. *Theory of the Auto-Valve Lightning Arrester*, Joseph Slepian, Westinghouse Electric & Mfg. Company.

A discussion of the advantages of the valve-type arrester for protection of high-voltage power systems. The theory of the autovalve arrester is given including a discussion of the breakdown potential of very short gaps.

11. *Current-Limiting Reactors with Fire-Proof Insulation on the Conductor*, F. H. Kierstead, General Electric Company.

This paper describes tests made to determine the proper insulation to use to prevent flashovers of current-limiting reactors due to conducting objects accidentally lodged between the turns. The paper describes (a) short-circuit tests to determine the insulation necessary and (b) thermal tests to determine the fire-resisting characteristics of the insulation.

12. *Temperature Rise and Losses in Structural-Steel Members Exposed to the Fields from A-C. Conductors*, O. R. Schurig and H. P. Keuhni, General Electric Company.

Results of an experimental investigation to obtain practical data on the temperature rises and losses in various structural-steel members when exposed to the fields from a-c. conductors. Should be useful to designers in making estimates of temperature rise and avoiding construction in which heavy losses would occur. Data are given which will serve as a basis for designing copper sleeves to minimize heating and losses in iron members.

13. *Carrying Capacity of Sixty-Cycle Busses for Heavy Currents*, Titus G. LeClair, Commonwealth Edison Company.

This paper describes tests on grouped copper busses carrying very large phase currents. It shows how with very high currents the usual arrangement becomes quite inefficient on account of unequal distribution of current. Special arrangements of bus bars are suggested which have much greater current-carrying capacity. One arrangement shows a three-phase bus which carried 8500 amperes per phase with 30 deg. cent. rise.

14. *Supervisory Systems for Electric Power Apparatus*, Chester Lichtenberg, General Electric Company.

A general survey and description of the various types of supervisory systems for control and indication of remotely located electrical apparatus. The systems described are classed as follows, (1) selector, (2) distributor, (3) audible, (4) code-visual, (5) synchronous-relay-visual and (6) carrier-current. The principles and features of each system are discussed. Also the supervisory system is compared with the better known remote-control system. Telemetering also is covered.

Tuesday Afternoon

Two Parallel Sessions, A and B

(A) Electrical Machinery

15. *Experimental Determination of Losses in Alternators*, Edouard Roth, Societe Alsacienne de Constructions Mecaniques.

This paper presents some studies made to find accurate and simple methods of determining the losses in large electrical machines, particularly alternators. The studies were undertaken because it was felt that the separate-loss method when used for determining the efficiency of large machines does not give correct results.

16. *No-Load Copper Eddy-Current Losses*, Thomas Spooner, Westinghouse Electric & Mfg. Company.

This paper is an attempt to place on a firm theoretical foundation the calculation of no-load copper eddy-current losses. Test results are presented to show that the theoretical formulas developed are correct. Some of the consequences of this analysis are rather unexpected where the frequencies are sufficiently high to produce large skin effect. For instance laminating the copper may increase or decrease the losses depending on conditions.

17. *Mechanical Force Between Electric Circuits*, R. E. Doherty and R. H. Park, General Electric Company.

In this paper a general equation is developed for the mechanical forces exerted by electric circuits containing inductances which are functions both of position and of current. The equation is applicable to circuits involving saturated iron. The results are to be used in investigating the forces in synchronous machines under short-circuit conditions.

18. *Concluding Study of Ventilation of Turbo-Alternators*, C. J. Fechheimer and G. W. Penney, Westinghouse Electric and Mfg. Company.

An investigation by means of models of a method of ventilating turbo-alternators. Test results, the methods of determining the losses and the equations derived are given.

(B) Communication and Sound Reproduction

19. *The Development and Application of Loading of Telephone Circuits*, William Fondiller, Western Electric Company and Thomas Shaw, American Telephone & Telegraph Company.

A review of the art of loading telephone circuits as practised in the United States. Loading is discussed in relation to developments during the last 14 years pertaining to (1) phantom group loading, (2) loading for repeatered circuits, (3) incidental cables in open-wire lines, (4) crosstalk, (5) telegraphy over loaded telephone circuits, (6) loading for exchange-area cables and (7) submarine cables.

20. *Automatic Enciphering and Deciphering Systems.*, G. S. Vernam, American Telephone and Telegraph Company.

This paper describes a printing telegraph cipher system developed during the World War for use of the Signal Corps, U. S. Army. The system is so designed that the messages are in secret form from the time they leave the sender until they are deciphered automatically at the office of the addressee. If copied en route the messages cannot be deciphered by the copier even though he has full knowledge of the method used.

21. *Refraction of Short Radio Waves in the Upper Atmosphere*, W. R. G. Baker and C. W. Rice, both of General Electric Company.

Estimation of the most suitable wave lengths for night or day communication between any two points is made possible by the theory and calculations proposed in this paper. The paper shows first how the striking phenomena of short-wave radio transmission (below 60 meters) can be quantitatively accounted for by a simple electron-refraction theory. The paths taken by waves from an antenna to distant points on the earth's surface are calculated. Ideal signal-intensity curves are given which show how the transmitted energy is distributed over the earth's surface. Reflection at the surface also is considered.

22. *High-Quality Recording and Reproducing of Music and Speech*, J. P. Maxfield and H. C. Harrison, Bell Telephone Laboratories, Inc.

An analysis of the general problem of recording and reproducing sound with particular reference to the phonograph. A very definite design of mechanical parts is made possible by substituting in the analysis electrical analogs for mechanical parts and functions. The theory of electrical filters is applied to these analogs and is of great assistance in determining the desired mechanical wave-transmission system for high-quality recording and reproduction.

Tuesday Evening

Smoker

Wednesday Morning

Electrical Machinery

23. *Parameters of Heating Curves of Electrical Machinery*, V. Karapetoff, Cornell University.

In this paper it is pointed out that an electrical machine, for thermal purposes cannot be considered as a single body. In a rotating machine the stator consists of two metal bodies between which there may be a temperature difference and the same is true of the rotor; besides there is a mutual heat flow between stator and rotor. In a transformer three separate metal bodies at different temperatures may be distinguished.

24. *Rating of Electrical Machinery as Affected by Altitude*, C. J. Fechheimer, Westinghouse Electric & Mfg. Company.

It is known that an electrical machine carrying a given load becomes hotter at high altitude than it does at sea level. This paper proposes equations to show how the temperature increases with elevation. Also equations are given for the corollary case, namely, to show how the rating must be decreased at high altitude for the same temperature rise as normally occurs at sea level. The paper discusses the rules of the A. I. E. E. Standards on this point.

25. *Motor Band Losses*, Thomas Spooner, Westinghouse Electric & Mfg. Company.

This paper shows that railway-motor band losses are of appreciable magnitude, sometimes large enough to be detrimental to thS cooling of the motor. Band losses are shown to vary accordine to (a) the 1.7 power of the frequency and (b) the 1.35 to the 1.g power of the induction.

26. *Starting Characteristics of Polyphase Squirrel-Cage Induction Motors and Their Control*, H. M. Norman, Westinghouse Electric & Mfg. Company.

The characteristics of squirrel-cage induction motors during starting, stopping and reversing are discussed in this paper. Equations are given which allow a comparison to be made between loss and time of acceleration. These equations are useful in determining the best value of secondary resistance for a certain application. Short methods are given for determining time of acceleration and moment of inertia of rotors.

WEDNESDAY AFTERNOON

Inspection Trips

WEDNESDAY EVENING

Dinner-Dance, (Hotel Astor)

THURSDAY MORNING

ELECTROMAGNETISM AND PHYSICS

27. *Calculation of Magnetic Attraction*, Th. Lehmann, Consulting Engineer.

A description of a simple and practical way of surveying and appraising the magnetic force in an air gap by means of the theory of the potential function. The author decomposes the magnetic field into elemental tubes of magnetic force whose envelopes enclose spaces in which the magnetic density is constant.

28. *The Magnetic Hysteresis Curve*, Hans Lippelt, with Thomas E. Murray, Inc.

An analysis of the phenomena of hysteresis introducing the conception of a reactive component and a dissipative component of the counteractive force which acts when magnetic material is subjected to a magnetizing force. Equations and curves are developed which show how these components vary with variations of the magnetizing force.

29. *Properties of the Single Conductor*, Carl Hering, Consulting Electrical Engineer.

In this paper the properties of a unit length of single, straight conductor far removed from all other circuits are investigated in an endeavor to find whether such a unit is a basic, fundamental one on which deductions and a method of mathematical treatment could be based. A constant is deduced for the energy stored by a current in such a unit length, which seems to be one of the most fundamental, basic constants in electrodynamics, from which many useful deductions can be made. This energy corresponds to the $mv^2/2$ of moving masses. It is shown that what might be called "wattless flux" should be recognized, and that "self-inductance" is used in two senses which may sometimes lead to different results.

30. *Heaviside's Proof of His Expansion Theorem*, M. S. Vallarta, Massachusetts Institute of Technology.

Heaviside's proof of his Expansion Theorem found scattered in his "Electrical Papers" is reconstructed in this paper. It is based on his so-called "conjugate theorem" which establishes a relation between any two normal modes of oscillation of a dynamical system. The relations between Heaviside's, Carson's and Wagner's proofs are pointed out.

THURSDAY AFTERNOON

MEASUREMENTS, MACHINERY AND INDUSTRIAL

31. *A New Wave-Shape Factor and Meter*, L. A. Doggett, J. W. Heim and M. W. White, all of Pennsylvania State College.

A meter for determining wave-shape factor is described in this paper. This meter is claimed to have advantages over the method of analysis based on oscillograms. The advantages come under the following headings: (1) cost, (2) portability, (3) ease of experimental procedure (4) rapidity of obtaining results and (5) accuracy and consistency. The meter consists essentially of a star-connected circuit consisting of two voltmeters and a variable condenser.

32. *Practical Application of Vibration Instruments to Rotating Electrical Machines*, J. Ormondroyd, Westinghouse Electric & Mfg. Company.

The possibilities of using vibration instruments in testing rotating electrical apparatus are outlined in this paper. The advantages of vibration-type instruments for certain purposes and an outline of instruments adapted to the various uses are discussed.

33. *Use of High Frequency for Testing Insulation of Rotating Apparatus*, R. E. Ferris and J. L. Rylander, both of Westinghouse Electric and Mfg. Company.

This paper tells of the advantages of using high-frequency voltage for testing the insulation between the turns of coils or windings. By the use of high frequency, high voltages may be applied between turns. This method has been found useful as a shop method for checking defects in material and poor workmanship.

34. *The Cross-Field Theory of Alternating-Current Machines*, H. R. West, General Electric Company.

This paper shows how a general plan of analysis following the cross-field theory may be applied to a-c. motors to obtain simple and accurate numerical methods for routine calculations of performance characteristics. To explain the details and application of the method two examples are worked respectively for a single-phase induction motor and a repulsion motor.

35. *Rating of Heating Elements for Electric Furnaces*, A. D. Keene and G. E. Luke, both of Westinghouse Electric & Mfg. Company.

An experimental study of the effective heat produced by various arrangements of resistor heating elements such as used in electric ovens and furnaces. The effects of spacing, resistor shape, shielding, radiation and reflection are studied. The resultant data obtained should be useful in designing ovens and furnaces.

THURSDAY EVENING

Address by prominent speaker.

Five Regional Meetings Planned For Coming Year

The Regional Meeting idea has worked out so successfully in the Institute that three, and possibly five, of these meetings will be held during the year 1926. Meetings will be held in Cleveland, Niagara Falls, and Madison, Wis., during the first half of the year; and possibly in New York and Kansas City during the latter half.

Very fine programs are contemplated for all these meetings and technical papers of the highest quality will be presented. Authors of high-grade papers are realizing that their papers will be well received and ably discussed at the regional meetings. There are two advantages to presenting a paper at a regional meeting. The first results from the fact that papers are selected which will be of particular interest in the locality where the meeting is held, and therefore the audience will be responsive. The second advantage is that ample time is allowed for discussion. These papers are given the same treatment and publication rights as are papers for the so-called national conventions.

The plans for the contemplated meetings are given in the following paragraphs.

Cleveland Regional Meeting March 18 and 19

Sectionalized electrical drive and electrical refrigeration will be the principal technical topics discussed at the regional meeting which will be held under the Second District of the Institute at Cleveland on March 18 and 19. The social side of the meeting has been well planned and trips of inspection also will be made. The Hotel Cleveland will be headquarters.

The technical papers on sectionalized electrical drive will deal specifically with application to paper-making machines, but on account of the great possibilities of applying synchronized drives in other industries it is felt that these papers will attract to the meeting many engineers connected with rubber mills, textile

mills, wire mills, coal-handling, conveying, automobile production, etc. Three papers on this subject will be presented on March 18 by representatives of the three manufacturers who make equipment for this purpose. The authors will be H. W. Rogers of the General Electric Company, S. A. Staege of the Westinghouse Electric and Manufacturing Company, and R. N. Norris of the Harland Engineering Company.

A paper on Electrical Refrigeration will be presented on March 19 by C. F. Kettering, president of the General Motors Engineering Corporation. This will be followed by an address by Dr. Farley Osgood, Past-President of the Institute on The Human Side of Engineering.

Ample time for very full discussion will be allowed on all the papers presented at this meeting as the committee in charge has arranged the program with this object particularly in view.

A dinner will be held on the first evening at which two addresses will be delivered. These will probably be given by City Manager Hopkins of Cleveland and John Stanley, president of the Cleveland Railway. A number of inspection trips will be available, the main trip being one on the second evening to the Nela Park laboratories.

Arrangements for the meeting are being made by a competent general committee which is as follows: Chairman, A. M. MacCutcheon; Secretary, C. S. Ripley; A. G. Pierce, Vice-President of District No. 2; C. L. Dows, Ralph Higgins, A. F. E. Horn and Nathan Shute.

Madison Meeting in May

Rural electrification, interconnection between power systems, cooperative research relations between colleges and industries, and underground distribution developments will be featured on the program of the regional meeting to be held in Madison, Wis., early in May. Various other subjects also will be covered. This will probably be a two-day meeting. The officers of District No. 5 are progressing with further details of the plans.

Niagara Falls Meeting, May 26-28

A three-day meeting with a wide variety of technical topics will be held by District No. 1 at Niagara Falls, N. Y., May 26, 27 and 28. A number of important engineering subjects will be covered and a full program of social and entertainment features is contemplated.

The technical subjects will include methods of dielectric-loss measurements, transmission, power plants and a number of other topics.

Plans are being made for a special illumination of the Falls, a trip down the Gorge, visits to power plants, a dinner and entertaining addresses of general interest. Further details will be published in later issues.

Future Section Meetings

Boston

Latest Design and Practise in Power Plants, by Vern E. Alden, Consolidated Gas, Elec. Lt. & Pr. Co. Lorimer Hall, Tremont Temple. Joint meeting with A. S. M. E. January 14.

High-Tension Cable Testing, by F. M. Farmer, Electrical Testing Laboratories. Meeting to be held in the new 750,000-volt testing laboratory of the Simplex Wire & Cable Co., Boston, Mass. February 19.

Connecticut

Maintenance of Industrial Equipment. Hartford. January 19.

High-Voltage. New Haven. January 29.

Patents. Stamford. February 9.

Lehigh Valley

Research of Today, the Engineering of Tomorrow, by E. B. Craft, Bell Laboratories, Inc. Joint meeting with Engineers' Club, Lehigh University Branch and Lafayette College Branch. Easton, Pa. January 20.

St. Louis

Long-Distance Cable Communication for St. Louis, by H. H. Nance, American Tel. & Tel. Co. January 20.

New York

The next meeting of the New York Section of the A. I. E. E. will be held at 8:15 p.m., Friday, January 29, 1926, Auditorium, Engineering Societies Building, 33 West 39th Street, New York, and will be devoted to a subject of inherent interest to every engineer,—in fact to the general public itself,—"The Trend of the Electric Light and Power Industry." The meeting will be based on an analysis and discussion of the prize winning papers in the essay contest, conducted last Spring by Bonbright and Company.

The Meetings and Papers Committee has been successful in obtaining several very prominent speakers:

Robert M. Davis, Statistical Editor of the *Electrical World* and second prize winner in the contest will give a statistical analysis or survey of the field, including an analysis of the 1925 operating figures which will then be available.

H. P. Liversidge, Vice-President of the Philadelphia Electric Company, will discuss the engineering possibilities and probabilities in the industry's development.

John F. Gilchrist, Vice-President of the Commonwealth Edison Company, will discuss the commercial policies and probable developments.

H. V. Bozell, of Bonbright & Company, will cover the financial questions.

Other speakers of prominence will probably take part in the general discussion.

Directly preceding the meeting a second get-together dinner will be held at the Fraternity Club, and as accommodations are limited, members of the Section should make an early return of the dinner reservation cards which will accompany the regular notice.

New York Electrical Society to Discuss Long Distance Broadcasting

At a meeting of the New York Electrical Society to be held in the Auditorium, Engineering Societies Building, 33 West 39th St., New York, N. Y., at 8.15 p. m. on the evening of Wednesday, January 6th, 1926, Mr. S. M. Kintner, Manager of Research Dept., Westingthouse Elec. & Mfg. Co., will give an instructive talk on "Long Distance Radio Broadcasting." Short wave length broadcasting is in a very active stage of development and Mr. Kintner is particularly qualified to describe the most recent accomplishments. The talk will be accompanied by some unusually interesting and unique experiments and demonstrations. All interested in this meeting are cordially invited to be present as the guests of the Society.

Annual Meeting of American Society of Civil Engineers

The American Society of Civil Engineers will hold its seventy-third Annual Meeting beginning January 20, 1926, in the Engineering Societies Building, New York, N. Y. The general arrangement so popular in the past will be followed, with business sessions and honorary awards Wednesday morning; reports of the Society's committees Wednesday afternoon; meeting of the Technical Division throughout Thursday and an all-day excursion on Friday, the 22nd.

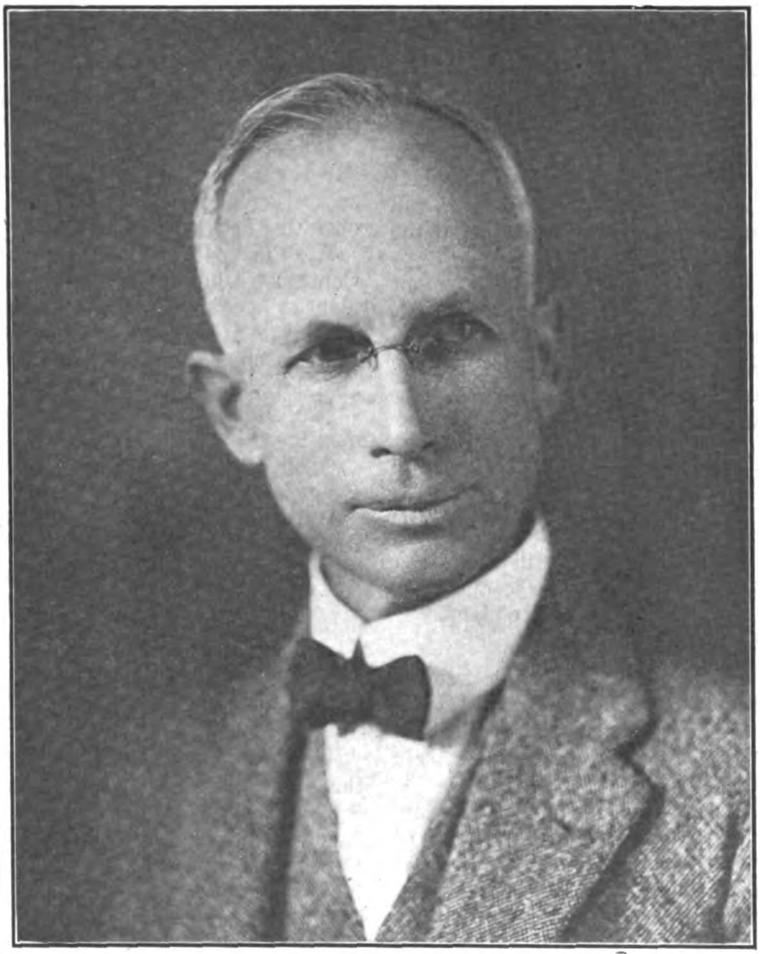
Beside the awards of Society prizes and medals, the Wednesday morning session will embrace the conferring of two honorary memberships—one upon William Barclay Parsons and the other upon Arthur N. Talbot.

A wide range of subjects will be considered in the technical sessions of Thursday, many of them of general as well as national importance.

Edison Medal Awarded Professor Harris J. Ryan

The Edison Medal for the year 1925 has been awarded by the Edison Medal Committee of the Institute to Dr. Harris J. Ryan, Professor of Electrical Engineering, Stanford University, California, "for his contributions to the science and the art of high-tension transmission of power."

Dr. Ryan was born in Powells Valley,, Pa., January 8, 1866 He studied at Baltimore City College 1879 to 1880; Lebannon. Valley 1880 to 1882, and received the degree of M. E. in Electrical Engineering from Cornell in 1887. In 1888 he became a member of the Western Engineering Company at Lincoln, Nebraska, and in 1889 Instructor in charge of the electrical machinery laboratory at Cornell. From 1890 to 1895 he served as Assistant Professor of electrical engineering in provisional charge of the department and from 1895 to 1905 was Professor in charge of the department of electrical engineering. In 1905 he accepted the same position at Stanford University which he holds today. In 1909 Professor Ryan became consulting engineer for the Los Angeles Aqueduct Power Development. During the war as a member of the Pacific Coast Section of the Submarine Group of the National Research Council he carried on valuable work and in 1918 and 1919 was in charge for the Research Council Supersonics Laboratory at Pasadena.



HARRIS J. RYAN

In the Chicago Exposition of 1893 Professor Ryan was a member of the Jury of Awards of the Department of Electricity and in 1904 was a delegate to the International Electrical Congress, St. Louis Exposition. He is a Fellow of the American Association for the Advancement of Science, member of the American Electrochemical Society, Institute of Radio Engineers, Society for Promotion of Engineering Education, American Physical Society and National Academy of Science. In 1887 he was elected an Associate of the A. I. E. E.; in 1895 was transferred to Member and in 1923 became a Fellow. He was a Director of the Institute from 1893 to 1896; Vice-President, 1896 to 1898; Honorary Vice-President representing the Institute at the Panama-Pacific International Exposition, San Francisco, 1915; President, 1923-24; and has served on the Edison Medal, Meetings and Papers, Electrophysics, Transmission and Distribution and Research Committees.

During Professor Ryan's twenty years at Stanford, he has been a pioneering leader in high-voltage transmission, upon the development of which largely depends the future growth of the Pacific Coast region. About three years ago the first 220,000-volt power lines were successfully put into commission by California companies, and Professor Ryan cooperated with the engineers in finding ways to cope with the insulator problems encountered, and it is on the solution of similar problems that his genius in the research field is expected to continue an outstanding advantage to science.

The Edison Medal was founded by the Edison Medal Association, composed of associates and friends of Mr. Thomas A. Edison, and is awarded annually by a committee consisting of twenty-four members of the American Institute of Electrical Engineers for "meritorious achievement in electrical science, electrical engineering, or the electrical arts."

The medal has previously been awarded Elihu Thomson, 1909; Frank J. Sprague 1910; George Westinghouse, 1911; William Stanley, 1912; Charles F. Brush, 1913; Alexander Graham Bell, 1914; Nikola Tesla, 1916; John J. Carty, 1917; Benjamin G. Lamme, 918; W. L. R. Emmet, 11919; Michael I. Pupin, 1920; Cummings C. Chesney, 1921; Robert A. Millikan, 1922; John W. Lieb, 1923; John White Howell, 1924.

First Convention of Radio Engineers

A convention of the Radio Engineers will be held in New York, January 18-19, 1926, when the Institute of Radio Engineers holds its Annual Meeting in the Engineering Societies Building, 33 West 39th Street. Important technical papers will be presented and discussed by engineers prominent in the profession; there will be organized trips of inspection to large radio factories and broadcasting stations, and the convention will close with a banquet at which many of the foremost radio engineers and executives of the country will deliver addresses on up-to-the-minute radio topics.

It is desired that every one identified with the Institute of Radio Engineers will attend one or more of the sessions, and guests are welcome. Chairman of the Convention Committee is R. H. Marriott.

A. I. E. E. Directors Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, December 11, 1925.

Officers present were: President M. I. Pupin, New York; Past-President Farley Osgood, Newark, N. J.; Vice-Presidents Harold B. Smith, Worcester, Mass.; A. G. Pierce, Cleveland; Managers H. M. Hobart, Schenectady; G. L. Knight, Brooklyn, N. Y.; H. P. Charlesworth, N. Y.; John B. Whitehead, Baltimore; E. B. Merriam, Schenectady; H. A. Kidder, New York; National Treasurer George A. Hamilton, Elizabeth, N. J., and

National Secretary F. L. Hutchinson, New York; also by invitation: Messrs. A. W. Berresford, J. Franklin Meyer and John B. Taylor.

The minutes of the meeting of the Directors held October 14, 1925, were approved.

Reports of meetings of the Board of Examiners held November 16, and December 7, 1925, were presented and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken on pending applications: 764 Students were ordered enrolled; 84 applicants were elected to the grade of Associate; 7 applicants were elected to the grade of Member; 1 applicant was transferred to the grade of Fellow; 37 applicants were transferred to the grade of Member.

The Board ratified the approval by the Finance Committee of monthly bills amounting to $18,391.51.

A request from the Executive Committee of the Great Lakes Geographical District, for authority to hold a regional meeting at Madison, Wisconsin, early in May 1926, was approved.

The organization of a Section at Sharon, Pa. was authorized in accordance with a petition from members in Sharon and vicinity.

The organization of a Student Branch at Stevens Institute of Technology, Hoboken, N. J., was authorized.

The Edison Medal Committee reported that the medal for the year 1925, has been awarded to Professor Harris J. Ryan, of Stanford University, Cal., "for his contributions to the science and the art of high-tension transmission of power."

Upon request of the Committee on Education, an appropriation of $600 was made, to apply to the cost of cooperating with the Society for the Promotion of Engineering Education, in an investigation relating to electrical engineering courses in colleges.

Mr. G. L. Knight was appointed a representative of the Institute, upon the Board of Trustees of the United Engineering Society, to succeed H. A. Lardner, whose term will expire in January and who is not eligible for re-appointment.

Professor W. I. Slichter was appointed to succeed himself as a Member of the Library Board of the United Engineering Society, for three years, beginning January 1, 1926.

Messrs. A. G. Pierce, of Cleveland and E. C. Stone, of Pittsburgh, were appointed Alternates, upon the Assembly of the American Engineering Council.

The report of Dr. A. E. Kennelly, who represented the Institute at the Fourth National Radio Conference, Washington, November 9-11, 1925, was presented and accepted with a vote of appreciation to Dr. Kennelly for his services.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Standards of the A. I. E. E.

At the meeting of the Board of Directors held December 11, 1925, the following Sections of Standards, as recommended by the Standards Committee, were adopted as Institute Standards.

No. 9—Standards for Induction Motors and Induction Machines in General.

No. 30—Standards for Wires and Cables.

No. 9 was referred to the Sectional Committee on Rating of Electrical Machinery, for consideration and report to the sponsor. No. 30 was referred to the Sectional Committee on Insulated Wires and Cables, for consideration and report to the sponsor, and then to be referred to the American Engineering Standards Committee for approval as an American Standard.

The following three Sections of the A. I. E. E. Standards were referred to the Sectional Committee on Rating of Electrical Machinery.

No. 5—Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.

No. 7—Standards for Alternators, Synchronous Motors and Synchronous Machines in General.

No. 10—Standards for Direct-Current and Alternating-Current Fractional Horse Power Motors.

The following resolutions were adopted:

RESOLVED

THAT in support of the plans and purposes of the A. E. S. C. in establishing American Standards, and recognizing the value and necessity of cooperative procedure in the field of electrical standardization, the Board of Directors of the American Institute of Electrical Engineers recommends to the A. E. S. C. that the A. E. S. C. set up an Electrical Advisory Committee of the A. E. S. C. constituted of representatives of at least the major interested groups, to advise the Main Committee on all questions relating to Electrical standards and to serve as a general coordinating committee in the electrical field within the scope of the Constitution, By-Laws and Rules of Procedure of the A. E. S. C.

RESOLVED FURTHER

THAT it is recommended that this Advisory Committee should have such constitution and functions as to be sufficiently elastic to permit the appointment of Special Committees of particularly qualified experts to pass upon specific questions in case any interested parties so requesting should submit to the A. E. S. C. reasonable evidence of the desirability of such action.

Corrections in Standards Pamphlets

Section 1. General Principles Upon Which Temperature Limits are Based in the Rating of Electrical Machinery and Apparatus.

In the reprint (September 1925) of Section 1 of the A. I. E. E. Standards the following fundamental statement should appear just below the title on page 5:

"THESE ARE NOT RULES FOR RATING OR TESTING"

"The limits of temperature and temperature rise given in the pamphlet are not limits for the rating or testing of electrical machinery. The pamphlet deals with the general considerations upon which rating limits are based. It is the introductory chapter to the Standards of the A. I. E. E."

Attention is also called to the corrections as noted on page 1359 of the December JOURNAL. Correct copies of both Sections 1 and 10 can be obtained by returning the incomplete pamphlets to H. E. Farrer, Secretary, Standards Committee, A. I. E. E., 33 West 39th St., New York, N. Y.

American Roadbuilders' Association in Convention January 11-14.

The Annual Convention and Road Show of the American Road Builders' Association will be held in Chicago, January 11-15, 1926. Sessions will be held for the discussion of varying problems in connection with traffic regulation, highway design and construction, with an innovation this year of a division of these meetings into two sections—one for the investigation of traffic and engineering problems contingent to the cause, and the other for points of interest on the side of construction. Men nationally representative for each subject on the program will address the meetings and these addresses will be followed by open, general discussion.

Dr. Parke Rexford Kolbe New President of Polytechnic Institute

An event of interest to engineers and chemists generally will take place at the Academy of Music, Brooklyn, N. Y., on January 13th, 1926, when Doctor Parke Rexford Kolbe will be installed as the new president of the Polytechnic Institute. Doctor Charles Alexander Richmond, president of Union College, will deliver the principal address of the evening; the presentation of the charter, seal and keys will be made by Charles E. Potts, of

the class of 1892, now chairman of the Board of Trustees of the Polytechnic Institute. Other speakers of the evening will be Doctor William H. Nichols, chairman of the Board of the General Chemical Company, and for many years chairman of the Corporation of the Polytechnic Institute; Doctor George S. Collins, senior member of the faculty, and Bancroft Gherardi, chief engineer of the American Telephone and Telegraph Company. Official delegates from colleges, universities and societies have been invited to attend and acceptances received indicate an attendance of a noteworthy number of prominent men from all parts of the country; among them Robert Lincoln Kelley, executive secretary of the Association of American Colleges; George B. Pegram, president of the Society for the Promotion of Engineering Education; W. E. Wickenden, director of Investigation for the Society for the Promotion of Engineering Education; H. Foster Bain, secretary of the American Institute of Mining and Metallurgical Engineers; Robert Ridgway, American Society of Civil Engineers; Elmer E. Brown, Chancellor, New York University; Charles C. Mierow, president of the Colorado College; General James G. Harbord, Kansas State Agricultural College, Col. R. C. Langdon, West Point; Arthur M. Greene, Jr., Engineering Foundation; Palmer C. Ricketts, Rensselaer Polytechnic Institute, and Allen Hazen, University of New Hampshire. A reception for the official delegates will be held at the conclusion of the academic exercises.

ENGINEERING FOUNDATION

PROFESSOR MARX SUCCEEDS PROFESSOR DERLETH, Jr.

Charles David Marx, professor emeritus of civil engineering, Leland Stanford, Jr., University, has been elected chairman of the Engineering Foundation Committee in charge of the Arch Dam Investigation. He succeeds Professor Derleth, Jr., of the University of California, who relinquishes the chairmanship because of ill health, but continues a member of the working committee.

The Southern California Edison Company is furnishing the services of its chief construction engineer, H. W. Dennis to be in charge of the building of the test dam, and also the services of other members of its organization essential to the accomplishment of this undertaking. Use of the property for the erection of the dam is contributed by the U. S. Department of Agriculture: The Portland Cement Association is also cooperating and Doctor J. A. Mathews, vice-president and metallurgist of the Crucible Steel Company of America is producing special metal for some of the instruments.

The Engineering Foundation contributes funds and services for the general purpose of the Committee, but unfortunately its resources will not yet permit it to do more. It invites all others interested to cooperate in providing the remainder of the $100,000 necessary to the completion of the dam.

AMERICAN ENGINEERING COUNCIL

AN APPEAL TO AID BILL FOR PROVIDING ADEQUATE SALARIES FOR FEDERAL JUDGES

BY EDWIN J. PRINDLE.

Chairman, Patents Committee

Americans having to do with engineering, science or the industries are pretty generally aware of the tremendous importance of keeping our patent system operating in a helpful and efficient manner. They realize that that system has been of primary importance in enabling our country to attain the foremost position among the nations in inventing, manufacturing and agriculture. When the Patent Office was going to pieces because of salaries insufficient to induce trained Patent Office Examiners to stay in the service, after a long and arduous campaign, the technical and scientific men and the manufacturers succeeded in sufficiently raising the Patent Office salaries to stem the tide of resignations, with the result that the Patent Office was saved from disintegration and has now made substantial progress toward an efficient condition.

But the granting of patents is only one branch of the operation of the patent system. The other branch is the adjudication of patents and their enforcement in proper cases. This latter function is performed exclusively by the federal courts and the efficient operation of those courts is of as much importance to the patent system as that of the Patent Office. The rise in the cost of living, and the depreciation of the purchasing power of the dollar have placed those in courts in a position where their efficiency is being impaired by causing many excellent judges to resign and by disturbing that peace of mind without which the best work is not likely to be done. Many of the judges are restive and waiting to see whether relief will not be given them, feeling that they will be forced to leave the bench if the present condition continues. Distress of the judges is particularly keen in the larger cities where the cost of living is highest. Here also it is more unjust that they should be asked to work for totally inadequate salaries because the compensation which they could receive in the private practise of law is correspondingly greater. The federal courts have jurisdiction over a wide variety of subjects—much wider than that of the courts of any of the States—so that the position is one of large responsibility, and requiring a high order of ability. Yet their salaries are so low that they are unable to live as befitting their station and the high dignity of their office, and to educate their children. They may not practise law, and have practically no opportunities for earning, outside of their salaries.

These conditions are probably more important to the welfare of our patent system than to any other branch of the law, because almost without exception, the federal judges when appointed, have had no contact whatever with patent law. It takes years of education and experience in trying and listening to the argument, and in deciding patent cases, to make a competent patent judge under these circumstances. When a federal judge who is efficient in patent law resigns, the process of education has to be gone through with by his successor, and the result necessarily is in such cases that the average ability brought to the decision of patent cases over a series of years is low. A few unwise decisions would cost not only the parties, but the country, many times the difference between present salaries and adequate ones.

The United States district judges receive but $7500 per annum and United States circuit judges only $8500. Comparison with the salaries paid in the State courts shows the gross unfairness of these salaries.

In New York City the Supreme Court judges receive $17,500, and the question is being considered of raising that salary. The judges of the New York Court of Appeals in Albany receive $13,750.

In New Jersey the judges of the Supreme Court receive $18,000.
In Pennsylvania they receive $17,500.
In Illinois they receive $15,000.
In Massachusetts they receive $12,000.
In Michigan they receive $10,000.

A bill having the approval of the federal judges has been introduced into Congress, known as the Reed Bill, which provides salaries for the circuit judges of $15,000 for the Second Circuit, comprising New York and Vermont; $14,000. for the next most populous circuits—Third, Seventh, Eighth and Ninth; and $13,000 for the remaining of the nine circuits.

The Bill provides salaries for the United States District judges of $10,000 with the provision that if the population in a district exceeds 2,000,000 the salaries shall be increased $500 for each 100,000 population in excess of that sum up to within $1000

of the circuit judges' salary. If the differential in favor of the salaries in the more populous districts should not be enacted, then the salaries for the district judges in general should be correspondingly raised.

While our federal judicial system is one of the three great branches of our government and is co-equal in importance with the legislature and the executive, yet its cost is truly insignificant. There are only 191 federal judges, and the cost per capita is now but one and one-half cents.

No matter how conscientious a judge may be, it is impossible for him to have as high an average of clear, penetrating thought in deciding the many intricate and important questions which come before him if his living and that of his family are inadequately provided for, as if his mind is reasonably free from financial care. The loss to the public through avoidable mistakes of failure to think clear through a problem under these conditions, must be vastly greater than the cost of proper salaries.

As Ex-Judge Edwin L. Garvin of Brooklyn has said:

> "The present salaries paid to United States judges are a disgrace to the American people."

Judge Garvin has just left the Federal Bench, being forced to do so by inability to live on his salary and the absolute impossibility of giving a college education to either of his children. Many of the federal judges are eking out their salaries by using the savings which they had provided for their old age. The American Engineering Council has adopted vigorous resolutions favoring the increase of the federal judiciary salaries, and last winter appeared, by Mr. L. W. Wallace, its Executive Secretary, the Chairman of its Patents Committee, and other representatives, before the Committees of Congress in favor of bills for that purpose. These efforts will be continued and reinforced at the present session of Congress.

Fair play and simple justice should make every American citizen interested in correcting this unjust and unwise condition. Every man and concern who is at all interested in patents and in preserving our patent system in an efficient condition should express himself to his Senator and Representatives as being strongly in favor of immediately passing the Reed Bill or some other bill for raising the salaries at least as high as that bill.

Let us be as effective in aiding the federal judges as we were in aiding the Patent Office. That can be done if every man will do his duty.

Industrial Cooperation With the War Department

Hearty endorsement of the War Department in its program for industrial preparedness and insurance against war was represented by the large audience which gathered in the Engineering Societies Building, New York, on the evening of December 4, at a meeting held under the auspices of the New York Sections of the A. I. E. E., A. S. C. E., A. I. M. E., A. S. M. E., American Chemical Society and Society of Automotive Engineers, and the Army Ordnance Association. Honorable Elbert H. Gary presided and the speakers of the evening were Dwight F. Davis, Secretary of War; Hanford MacNider, Assistant Secretary of War; General James G. Harbord, president of the Radio Corporation of America, and Major-General Charles P. Summerall, Commander of the Second Corps Area, U. S. Army. A telegram of commendation from President Coolidge also was read. Prior to the addresses, the colors of the 24th Regiment of Engineers were transferred, by an impressive ceremony, to the custody of the United Engineering Societies.

Secretary Davis first spoke of the many constructive peacetime accomplishments of the Army, including its activities in standardization, communication, navigation, power development, medicine, agriculture, mail, merchandising and aviation.

He then outlined the plans and the necessities for industrial preparedness for national defense. He said, in part, that the saving of time in swift and effective mobilization is the essence of all plans. Industrial preparedness means that demands of finance, power, labor, transportation and materials be intelligently analyzed and properly coordinated, that all resources may be marshalled against aggression. The combination of a weak and wealthy nation has never existed for any length of time. If present plans can render America safe for peace for one generation only they will accomplish more than any other plans in our history.

Two pictures of industry stand out in the planning: The one is the picture of industry as it operates in time of peace; the other, the picture as it looks in war. Industrial preparedness has as its purpose the planning of the transition from one picture to the other, with a minimum of dislocation and confusion both before and after war. Competent bodies have studied and are studying the general problems, with the cooperation of business and industrial concerns and of individuals, and courses of action are being formulated.

In general industrial preparedness is the contribution of business to the national peace. It is preparedness against war, not for war. But if war comes it will be a potent factor in winning peace through victory. Equality of obligation, mutuality of responsibility, the common defense of all by all is the democratic doctrine of a free republic. This is the spirit of industrial preparedness.

Assistant-Secretary MacNider emphasized the fact that for each combat soldier there should be seventeen people backing him up with material. With the help of experts and business executives plans have been formulated for swift mobilization. The supply organization must be built so that it can in a moment be stretched to a hundred times its peace-time size and function effectively. The nation's best insurance against war is not a great army but an expert nucleous.

General Harbord emphasized the need of sustaining interest and support for the work of national defense of which industrial preparedness is one part. To bring out the advantage of preparedness, he stated that if the present plan and organization had been in effect prior to the World War, besides greatly decreasing our losses in killed and wounded, for every hour by which the war was shortened one million dollars would have been saved.

Major-General Summerall, in the name of the Army, acknowledged all that industry is doing for the welfare of the military establishment and the country, and said that these efforts hearten and encourage that establishment beyond measure.

ADDRESS OF W. L. SAUNDERS, ACCEPTING THE 24TH ENGINEERS COLORS

Engineering Auditorium, December 4, 1925

Colonel Whitlock and men of the 24th Engineers:

On behalf of the Trustees of United Engineering Society I accept the custody of these colors of the 24th Engineers. They shall be carefully installed and exhibited in the halls of this building, there to remain as a permanent memorial.

Yours was the first regiment of its kind to be organized in the Army of the United States. Never before had the value and aid of the engineers in war been so fully recognized. You built and maintained shops, cement block plants, railways, pumping stations, lighting plants, buildings, hospitals, schools, camps, stables and many other things so important in modern warfare. To the men in the trenches you were what the laboratory is to the chemist. Through such work as you did the world war was brought to an end.

And as future generations look upon these colors, they shall see in them not a cold monument of stone raised to a gallant warrier, whose example one might seek to follow, but a living reminder that strength in war is no longer a human, but a material thing; that through machinery, industry and engineering a nation fully prepared in peace is likewise prepared for and insured against war.

Fuel and Power Meeting Held in Boston

Power problems in industrial plants were discussed at a meeting held in Boston, December 10 and 11, by the Affiliated Technical Societies of Boston of which the A. I. E. E. Section is a member. The papers presented were *Sources and Utilization of Coal*, by F. H. Daniels, Sanford-Riley Stoker Company; *Supply and Utilization of Fuel Oil*, by E. H. Peabody, Peabody Engineering Corp.; *Diesel Engines for New England Power Plants*, by J. F. Hecking, Worthington Pump and Machinery Corp.; *Possibilities of Obtaining Power from Public-Service Corporations*, by L. R. Nash, Stone & Webster, Inc.; *Power for Textile Mills*, by C. T. Main, Consulting Engineer; *Power for the Paper Industry*, by J. A. Warren, S. D. Warren Company; *The Utilization of Power in the Typical New England Plant*, by K. D. Hamilton, Geo. E. Keith Company; *The Advantages and Disadvantages of High-Pressure Steam in Industrial Plants*, by Joseph Pope, Stone & Webster, Inc.; *Utilization of Extraction Steam*, by E. A. Dickinson, General Electric Company; *The Supply of Industrial Power*, by W. H. Larkin, Jr., U.S. Rubber Company; *The Coal Situation*, by E. C. Hultman, Chairman of Special Commission (Mass.) on the Necessaries of Life; *Household Heating*, by H. R. Linn, American Radiator Company.

Sterling Fellowship for Research at Yale

The Sterling Fellowship has been established by a gift of one million dollars from the John W. Sterling Estate, "to stimulate scholarship and advanced research in fields of knowledge." While a Yale University fellowship, this is open to all approved colleges and universities both here and abroad,—men and women —whether graduate students, instructors or professors who desire to carry on studies and research under the direction of the Graduate Faculty of Yale University in affiliation therewith. Applications should be addressed to the Dean of the Graduate School, Yale University, New Haven, Connecticut, on blanks supplied by him. Junior prior to March 1 and Senior Fellowships by April 1.

Penn State Branch Holds Electrical Show

On November 7, the annual Alumni Homecoming Day, the Student Branch at the Pennsylvania State College presented an electrical show in the laboratories of the two Electrical Engineering Buildings. The exhibits which were designed and prepared by the members of the Branch proved of great interest to the thousands who visited the show.

The exhibits, of an educational nature, showed the work carried out in the Electrical Engineering Department of the College. Other exhibits traced the historical development of common electrical devices. Special lighting exhibits were featured at the night session. Numerous trick features constituted a less serious part of the show.

PERSONAL MENTION

G. W. Quentin has resigned from the American Blower Company in Pittsburgh to accept the position of promotion manager for the *Electrical World*.

F. L. Gilman has been elected Treasurer of the Western Electric Company to take effect January 1, 1926, and thereafter will be located at 195 Broadway.

Morris Keiser, formerly with the National Bureau of Standards, has joined the Research Department of the Marland Refining Company as Associate Electrical Engineer.

Harold J. McCreary, Inspection Methods Engineer of the Western Electric Company, has accepted a position as research engineer with the Automatic Electric Company of Chicago.

James R. Cravath, President of the Pioneer Electric Company of Richmond, Calif., has opened an office in the Call Building, San Francisco, as a consulting electrical and illuminating engineer.

Harry A. Yoe has resigned from the engineering department of the New York Central Railroad where he has been employed for ten years and has entered the firm of Schultze & Weaver of New York City.

Clifford G. Hillier, formerly manager of the Merchandising Sales Department of the Westinghouse Electric & Manufacturing Company, in their Boston office, has been appointed manager of the Receiver Section of the Radio Department of that Company, with headquarters in New York City.

Dr. E. R. Berry, assistant director of the Thomson Research Laboratory of the General Electric Company of Lynn, Mass., has been awarded the Grasselli Medal by the American Section of the Society of Chemical Industry, in honor of the paper presented by him describing a new achievement in applied chemistry.

Samuel W. Beach, Chief Radioman, U. S. S. Nevada, has recently written a book entitled, "The Great Cruise of 1925"—a history of the trip made by the United States Fleet to Australia, New Zealand and South Sea ports. It also contains speeches made by the Premiers and Governors-General of Australia and New Zealand upon the occasion of the fleet's visit to their respective countries.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Ezra Adelsberger, 1912 Cold Spring Ave., Milwaukee, Wis.
2.—F. E. Bell, U. G. I. Contracting Co., Box 371, Sioux City, Iowa.
3.—Geo. B. Coleman, P. O. Box 322, Dayton, Ohio.
4.—T. L. Davenport, 2530 May St., Cincinnati, Ohio.
5.—George E. Haines, 3538 W. Monroe St., Chicago, Ill.
6.—S. Larios, 143 Fourth St., Milwaukee, Wis.
7.—Willis E. Osborne, 312 West 4th St., Erie, Pa.
8.—Mary Shimanovsky, 24 Mt. Morris Park W, New York, N. Y.

Obituary

George I. Brown, an Associate of the Institute since 1908, died on November 1st, 1925. Mr. Brown was a Canadian by birth and received his education under private tutoring and at the University of Toronto, being employed by the Canadian Government during the years 1879 to 1892. Mr. Brown resided in this country for many years, in 1915 opening an office as consulting engineer in Red Bank, N. J.

David C. Rankin, Managing Director of the Commonwealth Power Equipment Company of Melbourne, Australia, died in that city after an illness of two years. Mr. Rankin was a native of Melbourne, being a graduate of Melbourne University, and coming to this country in 1919. He was in the employ of the Guarantee Battery Company of San Francisco as automotive instructor and the Ballantine Electrical Company of Chicago as plant superintendent and general manager, returning to Australia in July, 1923.

Allen A. Tirrell, inventor and consulting engineer of the

Westinghouse Electric & Manufacturing Company died recently. Mr. Tirrell was the inventor of the voltage regulator which bears his name, being employed for some years by the General Electric Company as a designing engineer—later going into business for himself as mechanical and electrical engineer in Pittsburgh.

George Harry Wirth, Associate of the Institute for the past five years, died at his home in Collingdale, Pennsylvania on November 6th. Mr. Wirth received his engineering education at Drexel Institute in Philadelphia; during the World War he served as a commissioned pilot instructor in the air Service of the United States Army. He was afterwards in the employ of Stone & Webster, in Philadelphia, later with the Right and Left Tool Holder Company and with the Edw. G. Budd Manufacturing Company as operator in charge of High Voltage Substations.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (Nov. 1-30, 1925)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

DYNAMIK, 2; DYNAMIK VON KÖRPERSYSTEMEN.

By Wilhelm Müller. Ber. u. Lpz., Walter de Gruyter & Co., 1925. 137 pp., 6 x 4 in., cloth. 1.25 mk.

Devoted to the methods for mathematically investigating the motion of structures composed of rigid elements. An attempt is made to condense the development of the subject as much as possible and to arrange the whole systematically. The analytic methods used are grouped in general around d'Alembert's principle.

ELEKTROMASCHINENBAU.

By P. B. Arthur Linker. Ber., Julius Springer, 1925. 304 pp., diagrs., 9 x 6 in., boards. 24-gm.

A textbook on the design of continuous-current dynamos and motors, transformers, induction motors, synchronous dynamos and motors, converters and alternating-current commutator motors. The book follows the course given in the Hannover Technical High School.

The author shows how the design of electrical machinery may be based on the intelligent use of the elements and basic laws of theoretical electricity, and how it may be used also to deepen by use the student's knowledge of theory. At the same time, many devices to lessen the purely clerical items of design are shown.

FOUNDATIONS OF BRIDGES AND BUILDINGS.

By Henry S. Jacoby and Roland P. Davis. N. Y., McGraw-Hill Book Co., 1925. 665 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

Treats of piles and pile driving, cofferdams, caissons, piers, abutments, spread foundations and underpinning. Intended to present American practice on the entire subject of foundations in a systematic manner. Includes a useful, classified bibliography of selected articles.

The new edition has been revised and amplified.

FOUR-FIGURE MATHEMATICAL TABLES.

By G. W. C. Kaye and T. H. Laby. Lond., & N. Y., Longmans, Green & Co., 1925. 26 pp., 10 x 6 in., paper. $.40.

A convenient collection of the mathematical functions usually tabulated in four-figure tables, printed in clear type. Logarithms, anti-logarithms, reciprocals, squares, natural and logarithmic sines, cosines and tangents, degrees to radians, powers, roots and reciprocals are included.

HISTORY OF ARITHMETIC.

By Louis Charles Karpinski. Chic. & N. Y., Rand McNally & Co., 1925. 200 pp., illus., facsims., 8 x 5 in., cloth. $2.00.

A brief account, intended primarily for teachers of arithmetic in elementary schools. Gives particular attention to the material of arithmetic which is still taught in those schools. It also pays particular attention to early American textbooks and to the popular English treatises from which they were derived. Bibliographies accompany each chapter and there are many illustrations from early books.

INTERMEDIATE LIGHT.

By R. A. Houstoun. Lond. & N. Y., Longmans, Green & Co., 1925, 228 pp., illus., diagrs., 8 x 5 in., cloth. $1.75.

A brief elementary textbook intended for use by students in secondary schools and the first years of college.

MAKING, SHAPING AND TREATING OF STEEL. 4th edition.

By J. M. Camp and C. B. Francis. Pittsburgh, Pa., Carnegie Steel Co., 1925. 1142 pp., illus., diagrs., tables, 8 x 5 in., fabrikoid. $7.50. [Payment should accompany order. Money orders and checks to be made payable to Carnegie Steel Co. Orders and inquiries should be addressed to Carnegie Steel Co., Bureau of Technical Instruction, Carnegie Bldg., Pittsburgh, Pa.]

This book is intended primarily for use as a text-book in the schools conducted by constituent companies of the United States Steel Corporation for employees without a technical education. It is also admirably adapted to the needs of every one, wishing an accurate account of standard practice in the American steel and iron industry.

Beginning with a survey of those principles of physics and chemistry which are useful to the metallurgist, the authors take up refractories, iron ores, fuels, fluxes, describing their varieties, properties and uses. The manufacture of pig iron, wrought iron and steel are then discussed. Section two is devoted to the shaping of steel by rolling and forging. Section three treats of the constitution, heat treatment and composition of steel. Section four describes the manufacture of wire, sheets, pipe and tubes.

No other book approaches this in its fulness of detail on current practise in American iron and steel works. It is a complete account of the industry, from the ore to the semi-finished product, prepared by men in intimate contact with current practice.

MECHANICAL INVESTIGATIONS OF LEONARDO DA VINCI.

By Ivor B. Hart. Chic., Open Court Pub. Co., 1925. 240 pp., illus., facsims., port., 9 x 6 in., cloth. $4.00.

The author's primary purpose was to make a detailed study of the nature and value of Leonardo's contribution to the study of aeronautics, but as the study of flight is linked with that of mechanics, the whole field of his work in mechanics has been surveyed.

After an introductory chapter on the characteristics of

Leonardo's manuscripts, there is a discussion of the state of mechanical science in the fifteenth century, of the scientific influences that bore upon Leonardo and of the sources of information available to him. This is followed by an account of his work in mechanics and as a pioneer of aviation. The book concludes with a complete translation of his Codex on the Flight of Birds and other Matters from the manuscript in the Library of Turin.

MECHANISM OF THE CAR.

By Arthur W. Judge. Lond., Chapman & Hall, 1925. (Motor manuals, v. 3.) 175 pp., illus., 8 x 5 in., cloth. 4s.

A non-technical exposition of the basic principles, illustrated by examples from current automobile practice. Covers the chassis, transmission, gears, etc. While adapted to use by owners and mechanics, it also will interest the engineer.

OIL ENGINE POWER PLANT HANDBOOK.

By Staff of Oil Engine Power. N. Y., Oil Engine Power, 1925. 192 pp., illus., diagrs., 11 x 8 in., fabrikoid. $3.00.

The work is a combination of catalog information on the products of various manufacturers of oil engines and accessories, with a series of articles by various engineers. These articles treat of such matters as lubrication, operation and maintenance, valve-setting, installation and similar topics, and are written from a practical viewpoint.

OSCILLOGRAPHS. . . .

By J. T. Irwin. N. Y., Isaac Pitman & Sons, 1925. 164 pp., illus., diagrs., 7 x 5 in., cloth. $2.25.

After a chapter on the fundamental principles involved, the author describes the various types of oscillographs and the methods of damping. Much space is given to the cathode-ray oscillograph. The book is apparently the first in English devoted to the subject and is, the author remarks, to a great extent original.

PHOTO-ELECTRICITY. . . .

By H. Stanley Allen. 2d edition. Lond. & N. Y., Longmans, Green & Co., 1925. (Monographs on physics). 320 pp., 9 x 6 in., cloth. $6.50.

A very complete exposition of our theoretical knowledge of photo-electric phenomena and of the practical applications of photo-electric cells. The new edition incorporates the results of the investigations during the past decade and includes a valuable bibliography of all the relevant papers published between 1913 and 1924.

PRINCIPLES OF ELECTRIC POWER TRANSMISSION AND DISTRIBUTION.

By L. F. Woodruff. N. Y., John Wiley & Sons, 1925. 340 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

A work based on instruction given to senior and graduate students at the Massachusetts Institute of Technology. Its aim is to call attention to the fundamental scientific principles involved in power transmission and the methods by which they are made applicable to practical engineering problems; and at the same time to impart as much information as is feasible about present practise in electric power transmission.

PROTEUS, OR THE FUTURE OF INTELLIGENCE.

By Vernon Lee. N. Y., E. P. Dutton & Co., 1925. (To-day and to-morrow series.) 63 pp., 6 x 4 in., cloth. $1.00.

In this very interesting little volume Vernon Lee discusses intelligence; what it is, when it originated, and how it influences us in the realms of art, religion, morals and economics and in our personal lives and outlooks.

THEORY OF MEASUREMENTS.

By Lucius Tuttle and John Satterly. Lond. & N. Y., Longmans, Green & Co., 1925. 333 pp., diagrs., 9 x 6 in., cloth. $4.50.

This textbook is intended for use in connection with courses in physics or mathematics. It emphasizes general considerations of measurement, theory of errors, general methods of procedure, quantitative accuracy, adjustment of observations, and similar topics that are usually merely mentioned in a laboratory manual, but that need laboratory work and drill as much as measurements of individual quantities. It is also adapted for use as a reference book.

The work represents a course given in the University of Toronto.

TREATISE ON THE LAW OF PUBLIC UTILITIES.

By Oscar L. Pond. 3rd edition. Indianapolis, Bobbs-Merrill Co., 1925. 1065 pp., 10 x 7 in., buckram. $10.00.

An endeavor to give a full, impartial exposition of the law of municipal public utilities. The book is based on the decisions of the courts and the various commissions, so that it is authoritative and practical. The new edition contains an extended study of motor vehicle transportation and a chapter on the subject of appeals.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Frogleg Windings for Multipolar D-C. Generators and Motors, by G. M. Albrecht, Allis Chalmers Co. A dinner preceded the lecture. November 20. Attendance 54.

Boston

Business Meeting. November 23. Attendance 8.

Chicago

Rectifiers, by L. T. Robinson, General Electric Co. Joint with Western Society of Engineers. November 23. Attendance 260.

Cincinnati

Transmission Problems, by C. L. Fortescue, Westinghouse Elec. & Mfg. Co. An illustrated lecture on the "Klydonograph" was also given. November 10. Attendance 142.

Connecticut

Distribution at Increased Voltages, by J. E. King, Connecticut Light and Power Co. December 9. Attendance 125.

Cleveland

Inspection trip to the plant of the Otis Steel Company. October 22. Attendance 300.

Denver

Some Epoch-Making Scientific Advances within the Last One Hundred Years, by B. F. Howard, The Mountain States Telephone and Telegraph Co. November 20. Attendance 33.

Erie

The Metric System, by Howard Richard, Secretary of the Metric Association. A buffet luncheon was served. November 17. Attendance 65.

Fort Wayne

Transformers and Reactors in Radio, by R. H. Chadwick, General Electric Co. Motion pictures on the action of radio receiving tubes were shown. November 12. Attendance 40.

Ithaca

The Power System of Alabama, by F. G. Switzer and J. G. Tarboux. November 20. Attendance 50.

Lehigh Valley

Automatic Stations and Their Remote Supervision, by Chester Lichtenberg, General Electric Co. October 30. Attendance 50.

Power—Electrical and Personal, by Farley Osgood, Consulting engineer and Past-President of the A. I. E. E.;

Developments in Control of Mine Equipment, by H. D. James, Westinghouse Electric & Mfg. Co., and

Business Engineering, by J. H. Pierce, Buck Run Coal Company. The three above addresses were given November 13 and an inspection trip was made to the Lansford Coal Company and the Lehigh Coal and Navigation Company November 14. Attendance 200.

Los Angeles

Automatic Substations and Power Conversion for Railway Purposes, by L. J. Turley, Los Angeles Railway Co., December 1. Attendance 118.

Lynn

Dream Pictures, by Branson DeCou. This was in the form of a musical travelog, illustrated with masterpieces of art and photography. November 23. Attendance 580.

Industrial Heating by Electricity, by N. R. Stansel, General Electric Co. Illustrated with slides. December 2. Attendance 100.

Madison

Natural Electricity and Lightning Protection, J. Slepian, Westinghouse Elec. & Mfg. Co. November 27. Attendance 80.

Mexico

Substations, by L. M. Speirs, Mexican Light & Power Co. November 5. Attendance 34.

Milwaukee

The History of Cooperation Among Engineers, by W. M. White, Allis Chalmers Mfg. Co.

Activities of A. I. E. E. in Great Lakes District, by Professor Edward Bennett, University of Wisconsin. A film, entitled "Milwaukee Electrically" was shown. Dinner meeting. November 23. Attendance 75.

Minnesota

Some Contemporary Advances in Radio Communication, by Professor C. M. Jansky, University of Minnesota. November 30. Attendance 100.

Niagara Frontier

Radio Development, by C. W. Horn, Westinghouse Electric & Mfg. Co. November 6. Attendance 35.

Some Fundamental Properties of the Electron, by Professor V. Karapetoff, Cornell University. December 7. Attendance 123.

Pittsfield

Certain Researches and Hobbies, by Dr. W. R. Whitney, General Electric Co. November 17. Attendance 280.

Round-table discussion on fundamental considerations of power limits of transmission systems with special reference to stability. Mr. R. E. Doherty, General Electric Co., led the discussion by abstracting his paper "Fundamental Considerations of Power Limits of Transmission Systems." December 8. Attendance 60.

Portland

Public-Service Management, by F. T. Griffith, Portland Electric Power Co. A motion picture, entitled "Modern Pioneers" was shown. November 18. Attendance 165.

Providence

The Quest of the Unknown, by Professor H. B. Smith, Worcester Polytechnic Institute. December 2. Attendance 50.

Rochester

Automatic Train Control. This illustrated lecture was written by W. H. Reichard, General Railway Signal Co., but presented by one of his assistants. November 6. Attendance 50.

Saskatchewan

Advances of Physical Science from the Electrical Viewpoint, by Dr. E. L. Harrington, University of Saskatchewan. November 27. Attendance 65.

Schenectady

Smoker. October 23. Attendance 350.

The Quest of the Unknown, by Professor H. B. Smith, Worcester Polytechnic Institute. Illustrated with slides. November 13. Attendance 310.

Springfield

Electric Propulsion of Ships, by W. E. Thau, Westinghouse Elec. & Mfg. Co. Illustrated with slides. November 23. Attendance 56.

Toledo

Police, Fire and Traffic Signal Systems, by Tyler Green, Chief City Electrician. After the lecture an inspection trip to an engine house was made. November 18. Attendance 35.

Toronto

Electric Steam Generators, by C. E. Sisson, Canadian General Electric Co. November 13. Attendance 63.

Watthour Meters, Demand Meters and Kv-a. Meters, by E. G. Ratz, Canadian Westinghouse Co. Illustrated with slides, and

Recent Developments in Relays, by L. N. Crichton, Westinghouse Elec. & Mfg. Co. November 27. Attendance 100.

Utah

Switchboards and Switches, by S. W. Mauger, General Electric Co. Illustrated with slides and moving pictures. October 21. Attendance 44.

Carrier-Current Communication, by R. E. Pierce, Utah Power & Light Co., and

Temperature and Motor Endurance, by Leo Brandenberger, Electrical Engineer. Illustrated with moving picture. December 2. Attendance 46.

Vancouver

Radio, by Dr. H. Vickers, University of British Columbia. Illustrated with slides. December 1. Attendance 61.

Washington

Municipal Electrical Regulation, by A. R. Small, National Fire Protection Association. December 8. Attendance 112.

Worcester

Transmission of Pictures over Wires, by R. D. Parker, American Telephone and Telegraph Co. Illustrated with slides. November 19. Attendance 75.

BRANCH MEETINGS

Alabama Polytechnic Institute

A motion picture, entitled "White Coal," was shown. November 18. Attendance 38.

The Tunnel under the Hudson River, by Mr. Earnest;

The Development of the Steam Locomotive, by Mr. Stain. Mr. Allen gave a talk on his work with the Westinghouse Company. Joint meeting with A. S. M. E. December 2. Attendance 21.

Armour Institute of Technology

Smoker. November 18. Attendance 72.

Wired Wireless, by R. U. Hagen, Illinois Bell Telephone Co. Illustrated. December 3. Attendance 59.

University of Alabama

Talks on membership in the A. I. E. E. were given by F. R. Maxwell, Jr., C. E. Rankin and E. H. Pritchett. Moving pictures, entitled "Back of the Button (Electrical)" and "How Uneeda Biscuits Are Made," were shown. November 16. Attendance 14.

Brooklyn Polytechnic Institute

Radio Meters and Their Application, by Mr. Banks, Jewell Electric Instrument Co., and

Transmission of Motion Pictures by Radio, by Joseph Heller, student. November 24. Attendance 50.

Inspection trip to the new Swedish liner "Gripsholm." December 5. Attendance 50.

University of California

Business Meeting. The following officers were elected: Faculty Advisor, T. C. McFacland; Chairman, E. A. Fenander; Vice-Chairman, E. L. Ramer; Secretary, C. F. Dalziel; Treasurer, G. B. Kenline. November 24. Attendance 25.

University of Cincinnati

Miami Fort Power Plant, by J. R. Hartman, Columbia Gas and Electric Co. Illustrated with slides. November 12. Attendance 75.

Power Transmission, by Professor A. M. Wilson, University of Cincinnati. November 19. Attendance 70.

Clarkson College of Technology

A talk on his experiences while working with the General Electric Company was given by Edward Augustine. November 17. Attendance 21.

Clemson Agricultural College

Past, Present and Future of Industrial Accident Prevention, by J. A. Davis:

The Economics of Safety, by F. A. Burley;

Safety Work at the Plants of the Southern Manganese Corporation, and Federal Phosphorous Company, by F. J. Fishburne, and

Current Events, by J. R. Smith. November 5. Attendance 22.

University of Colorado

Officials of the Public Service Company from Denver and Boulder explained the Doherty Training Course offered by the Public Service Company for college graduates. After the meeting the visitors inspected the electrical engineering laboratories of the University of Colorado. November 18. Attendance 60.

Super Power, by H. M. Webber, student, and

Resuscitation from Electric Shocks, by Dr. Gillespie. Demonstrated. December 2. Attendance 55.

University of Denver

The Wave Propagation of High Frequency, by Stewart Ellis, and

A Year's Progress in Lighting, by Earl Reed. November 12. Attendance 15.

A New Departure in Electrical Education, by C. A. Conner, and

Electric Shovels, by O. C. Hawley. December 4. Attendance 21.

Drexel Institute

Recent Progress on the Delaware River Bridge, by Mr. Chase, A. S. C. E. Joint meeting with A. S. M. E. and A. S. C. E. December 4. Attendance 250.

University of Florida

The Development of Steam Turbines, by Mr. Carey, Western Electric Co., and

Heat Insulation, by Mr. Dean. Illustrated with slides. November 16. Attendance 20.

The Action and Development of the Bell Telephone, by Colonel R. L. Boyd, Southern Bell Telephone and Telegraph System. Illustrated with moving pictures. Joint meeting with Benton Engineering Society. December 7. Attendance 50.

Georgia School of Technology

Telephotography, by D. M. Therral, The Southern Bell Telephone Co. Illustrated with slides and photographs. November 24. Attendace 60.

University of Idaho

Experiences in Shops at Schenectady, by Professor Bailey. November 17. Attendance 15.

University of Iowa

Railless Electrical Vehicles, by F. A. Kulas, and

Manufacturing Insulated Copper Wire, by M. C. Little. November 18. Attendance 45.

The St. Lawrence Water Way, by R. H. Lird;

Rural Electrification, by E. F. Miller, and

Electric Locomotive Drives, by D. A. Shaw. November 25. Attendance 48.

Water, by N. C. Grover, United States Geological Survey. Joint meeting with A. S. M. E. and A. S. C. E. December 4. Attendance 53.

Alternating-Current Railways, by J. C. Risius, and

Wilson Dam, by G. Smith. December 9. Attendance 47.

Kansas State College

Summer Work with the Kansas Gas and Electric Company, by A. L. Brady. November 26. Attendance 76.

University of Kansas

Economics in Engineering, by Professor John Ise. December 3. Attendance 59.

Annual Banquet. December 10. Attendance 173.

University of Kentucky

Business Meeting. The following officers were elected: President, J. W. Weingartner; Secretary, C. E. Albert. October 7.

University of Maine

Business Meeting. The following officers were elected: Chairman, S. B. Coleman; Vice-Chairman, R. A. Parkman; Secretary, H. S. McPhee; Treasurer, R. M. Noyes. November 24. Attendance 9.

Massachusetts Institute of Technology

Uses of Vacuum Tubes, by O. M. Hovgaard, student. November 27. Attendance 21.

Inspection trip to plant of the General Electric Company at Lynn. December 2. Attendance 5.

Michigan State College

Business Meeting. November 17. Attendance 17.

A film, entitled "White Coal," was shown. November 24. Attendance 80.

School of Engineering of Milwaukee

Lightning Arresters, by R. N. Selleg, Westinghouse Electric & Mfg. Co. October 31. Attendance 56.

Business Meeting. The following officers were elected: Chairman, S. A. Moore; Vice-Chairman, Carl Herr; Secretary, B. J. Chromy; Treasurer, W. G. Peck. November 19. Attendance 25.

Missouri School of Mines and Metallurgy

Loud Speakers, by Dryden Hodges. December 4. Attendance 14.

University of Missouri

Talks were given by students on their Summer experiences working for various companies. October 19. Attendance 17.

Bell Telephone Laboratory of New York City, by Professor Grandy. A film on the manufacture of storage batteries was shown. November 2. Attendance 34.

Electrification of Railways—History and Development of Rapid Transit, by Professor Johnson. November 16. Attendance 21.

Montana State College

A moving picture, entitled "The King of the Rails." was shown. November 16. Attendance 162.

The Transmutation of Mercury into Gold. This lecture was read by B. A. Shaw, and

Hydrogen as a Cooling Medium for Electrical Machinery. Read by John Chamberlain. December 7. Attendance 159.

University of Nevada

Transformers, by W. C. Smith, General Electric Co. Illustrated with slides and a model transformer. November 18. Attendance 48.

College of the City of New York

Railway Signals, by James Wilson, student. November 19. Attendance 17.

Inspection trip to the Electrical Testing Laboratories. November 30. Attendance 14.

A report on the test of a 150-kw. alternator was given by Daniel Schneeweis and James Wilson. December 10. Attendance 13.

North Carolina State College

The Life and Work of the Late J. B Duke, and

Report of Committee on Production and Application of Light, by E. W. Chadwick. November 3. Attendance 36.

Methods of Resuscitation, by Captain Gordon, Red Cross Life Saving Corps. November 17. Attendance 45.

University of North Carolina

Hydrogen-Cooled Generators, by W. E. Wortman, student. November 19. Attendance 20.

University of North Dakota

Sightseeing in a Large Manufacturing Plant, by Professor D. R. Jenkins;

A New Theory of Light, by Elmer Johnston, student, and

Permalloy, by Helmer Gronhovd, student. November 16. Attendance 30.

The Vacuum Tube, by Karl Rudser, student, and

Muscle Shoals, by Merton Peterson, student. November 30. Attendance 15.

Northeastern University

Business Meeting. The following officers were elected: Chairman, F. W. Morley; Vice-Chairman, E. O. Alden; Assistant Secretary-Treasurer, L. C. Tyack. November 27. Attendance 21.

University of Notre Dame

Short-Wave Propagation, by Frank Castro, and

Heating as Your Job, by Mr. Strawbridge, Indiana and Michigan Elec. Co. November 2. Attendance 31.

A Comparison of Electrically Driven Centrifugal Oil Pumps with Steam-Driven Reciprocating Pumps, by M. B. Daly, and

The Milky Way, by Rev. Emil de Wulf. Illustrated. November 16. Attendance 26.

Ohio Northern University

Business Meeting. December 10. Attendance 15.

Ohio State University

Arc Welding, by E. K. Lincoln, Lincoln Electric Co. November 20. Attendance 180.

Oklahoma Agricultural and Mechanical College

Rural Electrification, by Earl Miller, student. Illustrated. November 18. Attendance 19.

University of Oklahoma

A Brake Test on a 0.000,001-H. p. Motor, by Prof. O. W. Walter;

Local Engineering, by Bruce Spence;

Electric Meters, by Floyd Williams, and

High-Line Maintenance, by Ralph Tyler. November 19. Attendance 32.

Pennsylvania State College

Business Meeting. October 28. Attendance 40.

A film, entitled "The Queen of the Waves," was shown. Professor L. A. Doggett gave a talk in which he described the electrical installations of the U. S. S. New Mexico, the U. S. S

Saratoga and other battleships. He also gave an explanation of the action of the gyro-compass and its installations. November 18. Attendance 100.

Canal Zone, by G. J. Cartwright;

Bell Telephone Laboratories, by D. A. McMaster;

New York Edison Company, by J. E. Hogan, and

Westinghouse Elec. & Mfg. Company, by Professor H. I. Tarpley. These talks dealt with recent Summer experiences of some of the members. December 9. Attendance 52.

University of Pittsburgh

Pittsburgh Railways Problems, by G. A. Culbertson, student;

Purification of Circuit-Breaker Oils, by R. L. Johnson; student and

Recent Developments in Palestine, by A. Abulafia, student. November 6. Attendance 29.

Machine-Switching Telephones, by S. H. King, student. November 13. Attendance 26.

The Klydonograph, by E. H. Powell; student;

The Manufacture of Steel Pipe, by D. P. Mitchell, student, and

Harnessing the Tides of the Bay of Fundy, by N. Watkins, student. November 20. Attendance 25.

Purdue University

The Use of Electrical Analogies in Solving Mechanical Problems, by J. A. Long, American Tel. & Tel. Co., and

Telephone Apparatus in the Purdue Telephone Laboratory, by E. B. King, Indiana Bell Telephone Co. October 26. Attendance 40.

Improving Consumer Substations, by A. W. Miller, student, and

Transformer Design and Operation, by A. M. Wiggins, student. November 10. Attendance 80.

The Electric Railway and Its Relation to Industry, by Professor D. D. Ewing, and

Swordfishing, by Professor J. L. Bray. December 1. Attendance 100.

Rensselaer Polytechnic Institute

Work with the New York Edison Company, by Fred Van Olinda;

Work with the United Electric Light and Power Company, by Louis M. Dowell;

Work with Kingston Public Utilities Company, by Luke Holton;

Work with the New Haven Power and Light Company, by Paul Escholtz;

Work with the General Electric Company, at Springfield, by Leslie Hochgraf;

New Methods of Making Transmission-Line Surveys, by Dr. Wm. L. Robb;

New Alloy for Spark-Plug Points, by Dr. M. A. Hunter;

Physics and the Theory of Relativity, by Dr. R. A. Patterson and

Making an Interference Survey by Radio, by Dr. W. J. Williams. November 10. Attendance 106.

Rhode Island State College

The Life and Work of Oliver Heaviside, and

The Einstein Theory of Relativity, by Professor Anderson. November 20. Attendance 27.

The Melrose Substation, by J. Lamb. December 4. Attendance 18.

Rose Polytechnic Institute

Principles of Street Lighting, by G. F. Mudgett, Westinghouse Elec. & Mfg. Co. November 11. Attendance 41.

High-Frequency Waves, by D. R. Werner. December 2. Attendance 43.

South Dakota State School of Mines

Telephone Engineering, by Fred Spain. November 16. Attendance 16.

Swarthmore College

Engineering as a Profession, by A. Prescott Willis. December 10. Attendance 50.

Syracuse University

Business Meeting. The following officers were elected: President, K. N. Cook; Secretary, R. H. Watkins; Treasurer, G. R. Brownell. September 23. Attendance 20.

Commercial Research Engineering, by W. E. Mueller. September 30. Attendance 19.

High-Tension Cables, by E. L. Dunlap. October 7. Attendance 18.

Automobile Braking Systems, by G. R. Brownell. October 14. Attendance 17.

The Dufour High-Frequency Oscillograph, by L. F. Busse. October 21. Attendance 19.

Piezo Crystals and Piezo Electricity, by B. C. Carpenter. October 28. Attendance 19.

The Klydonograph and Its Application to Surge Investigation, by K. N. Cook. November 4. Attendance 20.

Carrier Telephony on High-Voltage Lines, by C. N. Coombe. November 11. Attendance 20.

Street-Railway Power and Line Distribution, by E. R. Fitzgerald. November 18. Attendance 20.

Texas Agricultural and Mechanical College

High-Voltage Transmission Lines, by D. M. Davis, student, and

Power-Plant Design, by R. M. Kennedy, student. November 20. Attendance 83.

Virginia Military Institute

A New Departure in Engineering Education, by Cadet S. A. Carson;

Losses in Iron under the Action of Superposed A-C. and D-C. Excitations, by Cadet L. Metcalfe, and

Electricity as Applied to Medicine, by Cadet R. L. Yeager. December 7. Attendance 21.

Virginia Polytechnic Institute

The New Orthophonic Victrola, by A. R. Green;

New Courses Offered by the University of Pennsylvania, by Mr. Keller, and

The Corn Products Refining Plant, by H. E. Broyles. November 18. Attendance 25.

The Wireless, by Professor Haynes. December 2. Attendance 35.

University of Virginia

A film, entitled "Speeding Up Our Deep-Sea Cables," was shown. November 16. Attendance 23.

University of Washington

The Development of the Submarine Cable, by M. T. Crawford, Puget Sound Power and Light Co. Illustrated with slides. November 4. Attendance 27.

West Virginia University

What Mental Tests Will Do in Industries, by W. L. Nuhfer;

Dipping and Baking Railway-Motor Armatures, by W. F. Davis;

Babbitt Metal, by G. R. Latham;

Advantages of Highway Lighting, by W. A. Williams;

Steam Geysers and Electrical Development, by E. A. Berry;

A Thermostat, by S. McGowan, and

Highway Lighting, by C. W. Moore. November 23. Attendance 28.

Business Meeting. November 30. Attendance 28.

University of Wisconsin

The Value of Non-Professional Subjects to the Engineer, by Professor Edward Bennett;

Accuracy in Engineering Work, by Professor C. M. Jansky, and

The Value of Membership in the Student Branch and National A. I. E. E., by Professor J. T. Rood. November 10. Attendance 140.

Worcester Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, O. H. Brewster; Vice-Chairman, D. A. Calder; Secretary, R. A. Beth; Treasurer, J. F. Wood; Counselor, H. A. Maxfield. November 19. Attendance 21.

My Travels in Mohammedan Countries, by Professor H. B. Smith. December 8. Attendance 60.

University of Wyoming

Business Meeting. The following officers were elected: Chairman, Everett Murray; Vice-Chairman, James Yates; Secretary-Treasurer, Virgil Shinbur; Faculty Advisor, G. H. Sechrist. November 19. Attendance 9.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
63 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL DESIGNER, who has had experience on oil switches. Salary $200-$250 a month. Location, Chicago. R-7818-R-7-C.

DESIGNER, for manufacturing purposes of such equipment as air break switches, gang operated disconnect switches, bus supports, etc. Experience in simple station operation, design of substations, etc., does not qualify a man for this position. Experience in the actual design and manufacture of the class of equipment described essential. Location, Pennsylvania. R-8118-C.

SALES ENGINEER, technical graduate, for manufacturer of storage batteries. Opportunity. Apply by letter stating age, education and experience. Location, Georgia. R-8208-C.

ELECTRICAL ENGINEER, experienced in developing small electrical machines and devices. Knowledge of spot welding and heat resistance units desirable. Apply by letter stating experience, age, education and salary desired. Location, Middlewest. R-8243-C.

SALES ENGINEER, for manufacturer of electrical heating and control appliances. Apply by letter. Location, San Francisco. R-8257-C-S.

DESIGNING ENGINEER, 30-35, with electrical crane and hoist experience. Apply by letter. Salary $3000 a year. Location, Pennsylvania. R-8205-C.

MEN AVAILABLE

EXECUTIVE, 43, married, thoroughly competent to take charge of offices, plant or factory. Many years' actual experience in organization, personnel management, valuation and appraisal, installations and supervision, office management, correspondent and special confidential investigations. Available at once. Location, New York or New Jersey. C-521.

ENGINEERING EXECUTIVE, position desired with growing company in commercial or engineering capacity, preferably as department head, or assistant to general executive. At present assistant to chief engineer company manufacturing heavy machinery. Ten years' experience since graduation from Rensselaer Polytechnic Institute in design, manufacture heavy machinery, design, manufacture electrical equipment, appraisal of physical property of public service corporations, maintenance of shop equipment, and power plant operation. Authority on application of industrial electrical equipment. Available because of closing of plant with which connected for past seven years. A-280.

PLANT ENGINEER, age 33, technical education, broad experience in the design, construction and maintenance of industrial plants. Specialty oil refineries. New York license. Available immediately. B-9376.

ENGINEER-SCIENTIST, 30, married, educated at M. I. T., three years in chemistry, three years in mathematical physics, graduating in mechanical engineering. Employed as technical report writer for research laboratory of G. E. and as industrial physicist and designer by Corning Glass Works. Executive experience and broad training in commercial subjects. Employed. B-9930.

ENGINEERING EXECUTIVE, nine years' experience, mainly with one large power company in station operation, distribution lines, substation construction, transmission line construction, distribution engineering, commercial work including power sales. Now district superintendent charge distribution entire district, also entire charge local offices reporting to district office. Graduate electrical engineer, G. E. test course training. Wants place as assistant to chief engineer, or general manager electric power company, or in consulting engineering firm. Married, 32. C-650.

ENGINEERING EXECUTIVE, 44, married, considerable experience selection, installation, operation wide variety electrical and mechanical equipment. G. E. test, sales engineering, steel mill superintendent. Successful record building efficient operating organization. Effective in practical analysis and presentation of industrial problems. Refer present employer. Available January first. Location anywhere. C-615.

ELECTRICAL ENGINEER, 30, technical graduate, desires position as assistant engineer or executive. Eighteen months G. E. test, four years assistant foreman on installation, testing and development work. Will not consider a place that has no chance for advancement. Location, greater New York City. Available on two weeks' notice to present employer. C-702.

ELECTRICAL ENGINEER, college graduate with five years' experience in power house and substation design, as well as construction, desires responsible position with public utility or engineering firm, offering opportunity. Available on reasonable notice. C-692.

ELECTRICAL ENGINEER, research, designing and executive practice, particularly in gasoline-electric traction problems, fully acquainted with theory and practice of electrical, electro-physical and mechanical problems and shop practice, desires responsible permanent position. At present chief and consulting engineer. Available in short time. Pittsburgh or East preferred. C-693.

GRADUATE OF THE UNIVERISTY OF PENNSYLVANIA in industrial management, four years' experience in electrical construction, drafting and machine design in executive capacity. Age 26. Available January 15, 1926. C-694.

ELECTRO-PHYSICIST AND RADIO ENGINEER, age 40, married, former professor in Russian technical colleges; publications and inventions in x-rays, positive rays, radio, measuring instruments, agricultural applications. Two years' industrial experience in radio receivers and parts in United States. Employed in testing laboratory of radio concern. Desires research, radio engineering, or testing position. Available on one week's notice. B-371.

ELECTRICAL AND VALUATION ENGINEER, 32, single, good working knowledge Spanish. Ten years' practical experience installation, operation of steam, hydro-electric plants, electric mining, industrial and public utility equipment, including two years General Electric Company's tests, two years with Public Service Commission of New York State. Now specializing in inventories, appraisals, property reports, investigations, classified accounting systems for public utilities, mining and industrial corporations. Salary $300 per month. B-9636.

ELECTRICAL AND MECHANICAL ENGINEER, 45, married, with very wide experience in dredging, construction and executive work, desires a permanent position with public utility, or consulting, or construction firm. Willing to go anywhere. Perfect knowledge of modern languages. Available end of January or earlier. C-720.

ELECTRICAL ENGINEER, 25, single, Columbia graduate 1925, extensive training of six years with ability to use his hands and his head; ten years' electrical and mechanical shop experience, seven months' experience in test department of large power company, desires a position with a manufacturing company where there is an opportunity for advancement. Wishes to specialize in electric relays and control devices and would be most interested in this work. Available on two weeks' notice. Location, anywhere. C-237.

TECHNICAL GRADUATE, desires position with established radio manufacturing concern, domestic or foreign. Present position with U. S. Government on care, upkeep, and maintenance of radio direction finding stations. C-723.

PROFESSOR, electrical engineering, would consider making a change. Ten years' of teaching experience. Well acquainted with industrial requirements through design, application and construction experience. Desires professorship in an institution where research is encouraged. B-7083.

STUDENT ENGINEER, age 22, single, seventeen months on G. E. test, desires position in power plant, preferably in connection with generation and transmission. Available on two weeks' notice. Location, New England, or Eastern New York. C-731.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED DECEMBER 11, 1925

AGENS, HERBERT M., Asst. to Electrical Engineer, The Foundation Co., 120 Liberty St., New York, N. Y.

ARMERO, JOSE P., Electrical Engineer, Operating Dept., Alabama Power Co., Birmingham, Ala.

BARBER, HARRY ORVAL, Supt., Snoqualmie Falls Generating Sta., Puget Sound Power & Light Co., Snoqualmie, Wash.

BATES, L. W., Engineer in charge of Automatic Substations, Appalachian Power Co., Bluefield, W. Va.

BOOTHE, EUGENE F., Electrician, Marshall Electric Co., 3225A Locust St., St. Louis, Mo.

BUSCH, HUGO WILLIAM, Designing & Maintaining of Test Equipment, Ware Radio Corp., 543 West 42nd St., New York, N. Y.

CARVER, DELMONT WILSON, Charge of Meter Dept., Brevard County Power Co., Melbourne, Fla.

CASSELL, WALLACE LEWIS, Instructor, Elec. Engg. Dept., University of Colorado, Boulder, Colo.

CAYLOR, RALPH A., Service Manager, The E. H. Walker Co., 210-212 N. Erie St., Toledo, Ohio.

CHRISTIE, SOREN L., Jr., Electrical Engineer, Elec. Heating Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

CLANCEY, JOSEPH A., Jr., Production Manager, Gray Electro Chemical Laboratory, Inc., 9-11 W. 20th St., Bayonne, N. J.

*CONNOLLY, ROBERT COTTMAN, Asst. Electrical Engineer, Western Sugar Refinery, San Francisco, Calif.

CONOLEY, ALEXANDER GORMAN, Division Line Inspector, American Tel. & Tel. Co., 928 Hurt Bldg., Atlanta, Ga.

*CORCORAN, HARRY ROBERT, Sales Engineer, Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio.

*CRANKALL, RICHARD JOHN, Technical Writer, Engg. Dept., National Lamp Works, General Electric Co., Nela Park, Cleveland, Ohio.

CULLINAN, CORNELIUS, Construction Superintendent, Public Service Production Corp., 15 E. Park St., Newark, N. J.

DANCE, HERBERT ERNEST, Asst. Consulting Engineer, Lecturer, Elec. Engg. Dept., Birkenhead Technical School, Birkenhead, Eng.

DAVIS, ROWLAND FENNER, Engineer, O. & E. Dept., American Tel. & Tel. Co., 195 Broadway, New York; res., Brooklyn, N. Y.

DEAN, SAMUEL MILLS, Engineer, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

DEARLOVE, TOM CARLTON, Electrical Engineering, 19 Homewood Ave., Toronto, Ontario, Can.

*De VEYHER, CONSTANTIN, Fieldman, Transmission Engg. Dept., So. California Telephone Co., 433 S. Olive St., Los Angeles, Calif.

DIGGINS, GEORGE J., Jr., Asst. Engineer, Railway Electrification, Gibbs & Hill, Pennsylvania Sta., New York, N. Y.

DRUSHEL, RAYMOND WENDELL, Division Operator, The Ohio Public Service Co., Alliance, Ohio.

ECKERSLEY, JAMES, Foreman, Meter Dept., Toronto Hydro-Electric System, 225 Yonge St., Toronto, Ont., Can.

ELBERTY, ROBERT S., Jr., Engineer, American Laundry Machinery Co., Norwood; res., Cincinnati, Ohio.

*FANAFF, PAUL ANDREW, Electrical Work, 628 Ogden Ave., Toledo, Ohio.

FLEMING, WILLIAM RAYMOND, Electrical Switchboard Operator, Commonwealth Edison Co., Fisk Street Station, Chicago, Ill.

GARDNER, JOHN H., Jr., Captain, U. S. A., Fort Hayes, Columbus, Ohio.

GETTESS, GEORGE HAROLD, Engineer, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

GLAZIER, FORREST SMOOT, Sales Engineer, W. A. Ramsay, Ltd., 74 S. Queen St., Honolulu, T. H.

GRISWOLD, RALPH G., Instructor, Elec. Engg. Dept., Purdue University, West Lafayette, Ind.

HARDY, ROBERT S., Asst. General Manager, Niagara Lockport & Ontario Power Co., 608 Lafayette Bldg., Buffalo, N. Y.

*HOFFMAN, HENRY JULIUS, Student Engineer, General Electric Co., Erie, Pa.

HORN, HENRY GEORGE, Designing Engineer, General Electric Co., Pittsfield, Mass.

*HOWERTH, DWIGHT GOLDWIN, Asst. to Statistician, Adirondack Power & Light Corp., Clinton St., Schenectady, N. Y.

HUBBARD, McCOY, Asst. Engineer, Southern Utilities Co., West Palm Beach, Fla.

HUBINGER, JOSEPH EDWARD, Jr., Construction Dept., Mississippi River Power Co., Keokuk, Iowa; for mail Warsaw, Ill.

ISAAC, ARCHIBALD CHARLES THOMPSON, Mechanical Engineer, General Electric Co., Pittsfield, Mass.

JOHNSTON, ROBERT FOSTER, Estimator, General Electric Co., 120 Broadway, New York, N. Y.

KOLDOFF, ANTHONY GEORGE, Cabling Engineer, Western Electric Co., Inc., 24th St., & Cicero Ave., Cicero; res., Elmhurst, Ill.

KOPATZKE, GEORGE A., Service Manager, Wagner Electric Corp., 501 Broadway, Milwaukee, Wis.

*KWONG, FREDERICK KIMMING, Chief Engineer, Toi-shan Electric Light & Power Co., Ltd., 97 Wing Lok St., Hongkong, China.

LARSON, NILS GERON, Electrical Drafting, The International Paper Co., 100 E. 42nd St., New York, N. Y.

LEROY, EVERETT ROOSEVELT, Engineering Assistant, New York Telephone Co., 104 Broad St., New York, N. Y.

LOCHNER, BJORN R., Draftsman, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

LOSINSKY, JACOB, Control Engineer, Volhov Hydro-Electric Power Plant Works, A. S. E. A., Ludvika, Sweden.

MARSH, HALLOCK SNYDER, Service Clerk, Radio Corp. of America, 925 Fort St., Honolulu, T. H.

MILTON, ROBERT McCARLEY, Electrical Inspector, U. S. Engineer's Office, Wilson Dam, Florence, Ala.

*McNAIR, J. W., Engr. Assistant, United Electric Light & Power Co., 56 Cooper Square, New York, N. Y.

McNALLY, CLAUDE, Electrical Instructor & Engineer, Academy High School, Erie, Pa.

MILLER, WILLIAM G., Electrical Engineer, Designing Dept., Electric Bond & Share Co., 71 Broadway, New York, N. Y.

NUTTALL, BRANSON, Switchboard Engineer, Messrs. Ferguson Pailin Ltd., Higher Openshaw, Manchester, Eng.

PARRY, EDWARD M., 202 Howard St., Passaic Park, N. J.

PALMER, HARLAN B., Instructor, Elec. Engg. Dept., University of Colorado, 810 14th St., Boulder, Colo.

PETTERSEN, HERBERT CHRISTIAN, Draftsman, Inside Plant Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

PULLEN, JOHN THOMAS, Jr., Asst. Engineer, Southern Utilities Co., West Palm Beach, Fla.

PYLE, MARK, Engineer, Puget Sound Power & Light Co., Eastern Dist., Wenatchee, Wash.

QUINN, JOSEPH JOHN, Estimating Engineer, Engg. Dept., Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.

*RICHARDS, KENNETH WEATHERBY, Cadet Engineer, Public Service Electric & Gas Co., Newark, N. J.

ROBINSON, TREVOR ARMSTRONG, Draughtsman, Northern States Power Co., 76 W. 3rd St., St. Paul, Minn.

ROITBURD, BERNARD, 2905 Grand Concourse, Bronx, New York, N. Y.

ROTE, OAKLEIGH C., Student Engineer, General Electric Co., Schenectady, N. Y.

RUDERSHAUSEN, FRANZ JOSEF, Laboratory Assistant, Chile Exploration Co., Chuquicamata, Chile, So. Amer.

RUMP, SIGURD, Yarmouthville, Maine.

SALERNO, MARCUS JOSEPH, 515 W. 111th St., New York, N. Y.

SANDSTROM, PER N., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SAYRE, EARL ROLAND, Sales Engineer, Hart & Hegeman Co., 623 W. Jackson Blvd., Chicago, Ill.

SCHENCK, IRVING PRIESTLEY, Electrical Engineer, Day & Zimmerman, 1600 Walnut St., Philadelphia, Pa.; for mail, Plainfield, N. J.

SCLAVOUNOS, LAMPROS P., Manager, Member, Board of Directors, The Egyptian Radio Co., Cheriff Pacha Street 16, Alexandria, Egypt.

SCOTT, ARTHUR H., Engineer, General Electric Co., Pittsfield, Mass.

SIMPSON, WALTER LA VERN, Electrical Engineer, Canadian & General Finance Co., 357 Bay St., Toronto, Ont., Can.

SIVIAN, LEON J., Research Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SOCOLOFSKY, PAUL, Student, Industrial Elec. Engg. Dept., Pratt Institute, 254 Clermont Ave., Brooklyn, N. Y.

STAROSSELSKY, DMITRY V., Inspector, Electrical Construction Bureau, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn, N. Y.

STEWART, PHILIP BRUCE, Supt. of Transmission, Union Gas & Electric Co., 4th & Plum Sts., Cincinnati, Ohio.

SUMMERS, CHARNELLE H., Jr., Asst. Distribution Engineer, Southern Utilities Co., West Palm Beach, Fla.

TAYLOR, PAUL B., Instructor, Engineering School, Drexel Institute, Philadelphia, Pa.

THOMAS, WINTHROP ATHERTON, Asst. Engineer, Elec. Engg. Dept., New York Edison Co., 124 E. 15th St., New York, N. Y.

*THOMASON, FREDERICK LAYTON, Engineer, Murrie & Co., 45 E. 17th St., New York; res., Brooklyn, N. Y.

THOMPSON, SUMNER MATELL, Electrical Inspector, Bureau of Power & Light, City of Los Angeles, 120 E. 4th St., Los Angeles, Calif.

WILKINSON, GEORGE DAVID, Division Traffic Inspector, Western Union Telegraph Co., 24 Walker St., New York, N. Y.

*WOOD, A. ROYAL, Ass't Supervisor, The Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.

Total 82

*Formerly Enrolled Students

ASSOCIATES REELECTED DECEMBER 11, 1925

ASHLEY, ALLEN, Special Representative, Condit Electrical Mfg. Corp., 152 W. 42nd St., New York, N. Y.

TUCKER, ALLAN WINTHROP, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., West New York, N. J.

MEMBERS ELECTED DECEMBER 11, 1925

BOLIS, PIETRO, Chief Engineer, Transformer Factory, Compagnia Generale di Elettricita, Via Borgognone, 40, Milan, Italy.

DOW, JAY L., Telephone Engineer, Bell Tel. Laboratories, Inc., 463 West St., New York, N. Y.

DREESE, ERWIN ERNEST, Chief Engineer, Lincoln Electric Co., Cleveland, Ohio.

PERSHAD, BALA, Supt., Telephone Dept., H. E. H., The Nizam's Government, Hyderabad, Deccan, India.

RUTH, CONANT W., President, C. W. Ruth Engineering Co., 8 S. Dearborn St., Chicago, Ill.

SCUDDER, FREDERICK J., Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

van MEETEREN, WILLIAM, General Manager, Siemens-Mexico, S. A., Puente de Alvarado, 91-99, Mexico, D. F., Mex.

TRANSFERRED TO GRADE OF FELLOW DECEMBER 11, 1925

PANNELL, ERNEST V., Technical Advisor to the British Aluminum Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER DECEMBER 11, 1925

BAILEY, EDGAR L., Electrical Engi eer, Detroit, Mich.

BARTON, ROBERT C., Engineer on Construction Methods, Pacific Tel. & Tel. Co., San Francisco, Calif.

BROWN, HARRY F., Assistant Electrical Engineer, N. Y., N. H. & H. R. R. Co., New Haven, Conn.

CAMP, C. R., Head Draftsman, Commonwealth Edison Co., Chicago, Ill.

CANNADY, N. E., State Electrical Engineer, Raleigh, N. C.

CODDING, HENRY W., Assistant Engineer, Elec. Engg. Dept., Public Service Production Co., Newark, N. J.

COLEY, WALTER R., Plant Superintendent, Leeds & Northrup Co., Philadelphia, Pa.

CROTHERS, HAROLD M., Professor of Electrical Engineering, South Dakota State College, Brookings, S. D.

D'ALTON, F. K., Assistant Laboratory Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

DANA, ALAN S., Research Engineer, Kerite Insulated Wire & Cable Co., Seymour, Conn.

DAVIS, LEE I., Test Engineer, Otis Elevator Co., Yonkers, N. Y.

DuBOIS, DELAFIELD, Electrical Research Engineer, Safety Insulated Wire & Cable Co., Bayonne, N. J.

FINCH, FLOYD R., Electrical Engineer, General Electric Co., Pittsfield, Mass.

GAGE, DAVID H., Foreign Wire Relations Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York, N. Y.

GEORGE, F. R., Engineer of Operation, Pacific Gas & Electric Co., San Francisco, Calif.

HALL, HERBERT S., Electrical Engineer on Valuation, Murrie & Co., New York, N. Y.

HYER, RAYMOND G., Superintendent Design & Construction, Westchester Lighting Co., Yonkers, N. Y.

JOLLYMAN, JOSIAH P., Chief, Div. of Hydroelectric & Transmission Engineering, Pacific Gas & Electric Co., San Francisco, Calif.

KRUG, FREDERICK, Superintendent of Power Production, Porto Rico Railway, Light & Power Co., San Juan, P. R.

MACK, CARL T., Attorney at Law, Patent Causes, Washington, D. C.

MAC LAREN, MALCOLM, Professor of Electrical Engineering, Princeton University, Princeton, N. J.

McCABE, GORDON B., Technical Engineer Operating Dept., Detroit Edison Co., Detroit, Mich.

METZENHEIM, HENRY H., Instructor in Electricity & Mathematics, Newark Technical School, Newark, N. J.

MICHETTI, O. D., Lieut. Commander, Engineering, Argentine Navy, Quincy, Mass.

PAXTON, E. B., Engineer, General Engineering Dept., General Electric Co., Schenectady, N. Y.

REID, MEREDITH W., Electrical Engineer, General Engineering & Management Corp. New York, N. Y.

RUSSELL, ROY E., Estimator, Frank J. York, Co., Detroit, Mich.

SMITH, LOUIS G., Assistant to General Superintendent, Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

SNYDER, EDWARD B., Manager, Sales & Engineering, Hi-Tension Ins. Div., Ohio Brass Co., Mansfield, Ohio.

SPOONER, HENRY W., Engineer, The Foundation Co., New York, N. Y.

STEMLER, EDWARD J., Chief Operator, Interborough Rapid Transit Co., New York, N. Y.

TALBOT, EMMETT D., Engineer, Bell Telephone Laboratories, New York, N. Y.

TOUR, GREGORY I., Assistant Engineer, Stone & Webster, Inc., Boston, Mass.

TRUEBLOOD, HOWARD M., Engineer, Dept of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

van NIEUKERKEN, J. M., Assistant Engineer, Cleveland Union Terminals Co., Cleveland, Ohio.

VINET, EUGENE, Assistant to Vice-President in charge of Engineering, Middle West Utilities Co., Chicago, Ill.

WOOD, E. M., Assistant Engineer, Hydro-Electric Power Commission, Toronto, Ont.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held December 7, 1925, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

BETTIS, ALEXANDER E., Vice-President, Kansas City Power & Light Co., Kansas City, Mo.

CURTIS, HARVEY L., Senior Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

DANN, WALTER M., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.

HOBART, K. E., Superintendent Overhead Lines, Commonwealth Edison Co., Chicago, Ill.

PRINCE, DAVID C., Research Engineer, General Electric Co., Schenectady, N. Y.

TO Grade of Member

CAMPBELL, THADDEUS C., Telephone Engineer, Systems Development Dept., Bell Telephone Laboratories, New York.

EWENS, W. SYDNEY, District Manager, Alfred Collyer & Co., Toronto, Ont.

HAZELTINE, HAROLD L., Engineer of Insulation, Sterling Varnish Co., Pittsburgh, Pa.

JOHNSON, EDWARD J., Member of Technical Staff, Bell Telephone Laboratories, New York

MEYER, A. A., Assistant General Superintendent Detroit Edison Co., Detroit, Mich.

NOSS, MARSENA A., Chief Engineer, International Telepost Co., New York.

ROBINSON, BLIGHT S., Engineer, R. W. Cramer & Co., Inc., New York.

SHEPARD, ROBERT B., Electrical Engineer, Underwriters' Laboratories, New York

SILSBEE, FRANCIS B., Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

SMITH, EVERETT H., Supervising Equipment Design Engineer, Bell Telephone Laboratories, New York.

SNIDER, GEORGE E., Chief Electrical Engineer, Ohio Public Service Co., Cleveland, O.

STEVENS, ALEXANDER C., Electrical Engineer, General Electric Co., Schenectady, N. Y.

WEIGHT, JOHN W., Head, Industrial Truck and Locomotive Dept., Electric Storage Battery Co., New York.

WILKINS, ROY, Assistant Engineer, Dept. of Hydro-Elec. & Transmission Engg., Pacific Gas & Electric Co., San Francisco, Calif.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1926.

Abe, T., Japanese Government Railways, New York, N. Y.

Adam, A. O., Jr., Bell Telephone Laboratories, Inc., New York, N. Y.

Adkins, A. H., Electric Storage Battery Co., Washington, D. C.

Ahrens, J. H., Henry & Wright Mfg. Co., Hartford, Conn.

Ahrling, G. A., Murrie & Co., Inc., New York, N. Y.

Aikins, N. B., New England Tel. & Tel. Co., Portland, Me.

Alexander, G. H. W., Bell Telephone Laboratories, Inc., New York, N. Y.

Alexander, R., Jr., Murrie & Co., New York, N. Y.

Allen, J. P., New York Telephone Co., New York, N. Y.

Allen, L. M., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.

Allison, D. C., General Electric S. A., Mexico D. F., Mex.

Andem, K. S., Public Service Production Co., Newark, N. J.

Anderson, A. S., New Orleans Public Service, Inc., New Orleans, La.

Anderson, E. W. N., Virginia Northern Power Co., Warrenton, Va.

Arnold, O. B., General Electric Co., Schenectady, N. Y.

Auer, G., Automatic Electric, Inc., Chicago, Ill.

Baer, H. J., Metropolitan Edison Co., Reading, Pa.

Baily, F. A. A., Canadian Marconi Co., Montreal, P. Q., Can.

Barber, H. W., Jr., General Electric Co., Lynn, Mass.

Barley, T. T., Public Service Electric & Gas Co., Orange, N. J.

Barringer, F. D., Pratt Institute, Brooklyn, N. Y.

Bartheld, L. P., Bell Telephone Laboratories, Inc., New York, N. Y.

Bartholomew, H. G., New York Telephone Co., New York, N. Y.

Batt, L. T., Public Service Electric & Gas Co., Newark, N. J.

Baumgarten, A. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Baxandall, F. M., Commonwealth Power Corp. of Michigan, Jackson, Mich.
Baxter, L. H., Hydro-Elec. Pr. Commission of Ontario, Toronto, Ont., Can.
Bayers, C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Bedl, H. S., Public Service Co. of No. Illinois, Chicago, Ill.
Beller, C. J., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Bergen, P. V., Bronx Gas & Electric Co., Bronx, New York, N. Y.
Best, A. O., Ignition & Repair Service Station, Owensmouth, Calif.
Bitterli, J. A., Commonwealth Edison Co., Chicago, Ill.
Bixby, O. M., New York Central Railroad, New York, N. Y.
Blocklin, H. G., Bell Telephone Laboratories, Inc., New York, N. Y.
Blumstein, G., Pullman Car Co., Long Island City, N. Y.
Bobb, L. C., Pennsylvania Power & Light Co., Sunbury, Pa.
Bolstad, A. L., Western Electric Co., Seattle, Wash.
Borge, W. P., Illinois Power & Light Co., Chicago, Ill.
Brandt, C. H., Chas. B. Hawley & Co., Washington, D. C.
Brazier, W., The Canadian Crocker-Wheeler Co., Ltd., St. Catherines, Ont., Can.
Brown, H. H., Iowa Electric Co., Cedar Rapids, Ia.
Brown, L. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Brown, N. H., Consolidated Steam Specialty Co., Milwaukee, Wis.
Bruce, E., Bell Telephone Laboratories, Inc., New York, N. Y.
Bruhn, H. D., Bell Telephone Laboratories, Inc., New York, N. Y.
Buckner, L. O., American Trona Corp., New York, N. Y.
Bugge, A. F. C., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Bump, R. L., General Electric Co., Bridgeport, Conn.
Burkhart, W. G., Commonwealth Edison Co., Chicago, Ill.
Burnett, N. O., N. Y. & Queens Electric Light & Power Co., Flushing, N. Y.
Burns, A. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Burrier, E. R., (Member), Hudson Coal Co., Scranton, Pa.
Bushman, A. K., (Member), General Electric Co., Chicago, Ill.
Busteed, J. R., American Tel. & Tel. Co., New York, N. Y.
Byrne, J. A., Troy Gas Co., North Troy, N. Y.
Callow, C. A., Utah Power & Light Co., Grace, Idaho
Camp, G. B., Arctic Dairy Products Co., Detroit, Mich.
Campbell, A. H., Madras Hotel, Portland, Ore.
Caradonna, V., New York Edison Co., New York, N. Y.
Carlson, E., Jr., Stone & Webster, Inc., Boston, Mass.
Carr, C. C., Bell Telephone Laboratories, Inc., New York, N. Y. (Applicant for re-election)
Caskin, J. M., Danvers Electric Light Dept., Danvers, Mass.
Caywood, R. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Cedillo, J. (Member), Mexican Railway Co., Maltrata, Vera Cruz., Mex.
Chandler, M., Commonwealth Power Co., Jackson, Mich.
Chapin, R. L., Crocker McElwain Co., Holyoke, Mass.
Churchill, T. C., Bell Telephone Co. of Canada, Toronto, Ont., Can.
Clark, H. H., Ohio Public Co., Lorain, Ohio
Clark, R. F., Edison Elec. Illuminating Co. of Boston, Boston, Mass.
Clark, S. W., Consulting Engineer, Mexico, D. F., Mex.
Clarke, H. A., Meter Dept., City of Norwich, Norwich, Conn.
Clarke, P., So. New England Telephone Co., New Haven, Conn.
Clifford, C. J., U. S. Coast & Geodetic Survey, Washington, D. C.
Cole, C. C., Duquesne Light Co., Pittsburgh, Pa.
Coley, J., New York Edison Co., New York, N. Y.
Combs, C. R., Omar-Schaefer Electric Co., Detroit, Mich.
Contino, N., Public Service Electric & Gas Co., Irvington, N. J.
Conway, J. T., Murrie & Co., New York, N. Y.
Cook, John W., A. T. & S. F. R. R. Co., Topeka, Kans.
Coram, R. E., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Corby, E., General Electric Co., Bridgeport, Conn.
Cook, H. S., Cia. Cubana de Electricidad, Inc., Sancti-Spiritus, Cuba
Coultrip, R. L., Fausteel Products Co., Inc., N. Chicago, Ill.
Crabtree, T. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Crosby, R. A., Los Angeles Gas & Electric Corp., Los Angeles, Calif.
Dahl, H. A., Bell Telephone Laboratories, Inc., New York, N. Y.
Dahl, J. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Daley, J. J., Murrie & Co., New York, N. Y.
Davis, C. F., Jr., General Electric Co., Schenectady, N. Y.
Davis, J. A., Automatic Electric Co., Chicago, Ill.
Day, J. F., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Daymude, E. L., Puget Sound Power & Light Co., Portland, Ore.
Dean, H. C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
de Bernard, E., Compania Cubana de Electricidad, Inc., Matanzas, Cuba
Degner, L. A., Industrial Controller Co., Milwaukee, Wis.
De Graw, H., Louis Kalisher, Inc., Brooklyn, N. Y.
de Savoye, L. A., Brooklyn Edison Co., Brooklyn, N. Y.
Dewey, G. H., General Electric Co., Schenectady, N. Y.
Dickinson, A. G., Consolidated Mining & Smelting Co., Trail, B. C., Can.
Dietz, H. W., Auto Specialties Co., Inc., Elkhart, Ind.
Dittwe, G. R., Pacific Gas & Electric Co., San Francisco, Calif.
Dolarea, O. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Dowling, R. C., Wisconsin Telephone Co., Milwaukee, Wis.
Downing, W. C., Jr., Yale University, New Haven, Conn.
Dreyer, W. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Dugger, P. K., Chief Engineer, Farmville, Va.
Dunn, B. J., Victor X-Ray Corp. of Texas, Dallas, Texas
Ebert, H., Canadian General Electric Co., Toronto, Ont., Can.
Ehrke, L. F., Westinghouse Lamp Co., Bloomfield, N. J.
Ellis, F. A., University of Toronto, Toronto, Ont., Can.
Ensor, J. S., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Erwin, E. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Essig, C. H., Pacific Gas & Electric Co., San Francisco, Calif.
Etkin, H. A., General Electric Co., West Philadelphia, Pa.
Everett, W. J., Cia. Cubana de Electricidad, Inc., Cienfuegos, Cuba
Farnham, C., Schweitzer & Conrad, Inc., Los Angeles, Calif.
Fidler, I., Stehli Silks Corp., New York, N. Y.
Finkelstein, L. M., International Harvester Co., Chicago, Ill.
Finkenstein, A., General Electric Co., New Haven, Conn.
Fitz-Gerald, M. C., Pacific Tel. & Tel. Co., San Francisco, Calif.
Fitzgerald, W. F., Chicago Surface Lines, Chicago, Ill.
Floyd, R. E., Pacific Power & Light Co., Lewiston, Idaho
Flynn, J. A., Interborough Rapid Transit Co., New York, N. Y.
Forbes, L. N., No. Indiana Gas & Electric Co., Hammond, Ind.
Ford, W. F., Union Gas & Electric Co., Cincinnati, Ohio
Freedman, E. A., New York Central Railroad Co., New York, N. Y.
French, B. V., American Bosch Magneto Corp., Springfield, Mass.
Fruchtman, M., Metropolitan Electric Co., Long Island City, N. Y.
Gallup, W. G., Lake Shore Electric Railway, Bay Village, Ohio
Gamboa, C. F., Cia. Cubana de Electricidad, Inc., Station Clara, Cuba
Gannon, J. T., Brooklyn Edison Co., Brooklyn, N. Y.
Gerard, H., Public Service Co. of No. Illinois, Kankakee, Ill.
Gerhart, P. L., Electrical Testing Laboratories, New York, N. Y.
Geymer, H. H., Armour Institute of Technology, Chicago, Ill.
Giersch, O. L., General Electric Co., Schenectady, N. Y.
Gilchrist, J. M., Empire Gas & Electric Co., Auburn, N. Y.
Gillen, G., Pennsylvania Power & Light Co., Hauto, Pa.
Girault, M., General Electric S. A., Mexico D. F., Mex.
Goddard, E. J., Pennsylvania Railroad, Long Island City, N. Y.
Godfrey, H. L., Howson & Howson, Philadelphia, Pa.
Goldsworthy, T. H., Portland Electric Power Co., Portland, Ore.
Goodwin, S., Brooklyn Edison Co., Brooklyn, N. Y.
Graham, A., Postal Tel. & Commercial Cable Co., New York, N. Y.
Graham, R. C., Bartholomew & Montgomery, Vancouver, B. C.
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Gray, E. V., Pratt Institute, Brooklyn, N. Y.
Gray, F. R., Murrie Engineering Co., New York, N. Y.
Gray, R. H., Foreman Electrician, City of Los Angeles, Los Angeles, Calif.
Greene, O. W., Jr., General Electric Co., Pittsfield, Mass.
Greenwald, R. C., Murrie & Co., Inc., New York, N. Y.
Greer, L., General Electric Co., Lynn, Mass.
Griffin, G. A., Union Gas & Electric Co., Cincinnati, Ohio
Gruenberg, A. R., with W. T. Swoyer Co., Johnson City, Tenn.
Gussett, N. B., San Antonio Public Service Co., San Antonio, Texas
Gustafson, H. M., General Electric Co., Seattle, Wash.
Hadley, P. T., General Electric Co., Schenectady, N. Y.
Halloran, D., New York & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.
Halpin, L. C., A. P. & L. Corp., Glens Falls, N. Y.
Hamilton, W. R., West Penn Power Co., Pittsburgh, Pa.
Hamke, J. C., Aluminum Co. of America, Niagara Falls, N. Y.
Harris, H. R., Detroit Edison Co., Connors Creek Plant, Detroit, Mich.

Harrison, C. A., Public Service Co. of Colorado, Denver, Colo.
Hart, W. J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Hatch, P. M., The Connecticut Co., New London, Conn.
Hausman, S. I. R., Nelson Co., Newark, N. J.
Haw, C. H., New York Edison Co., New York, N. Y.
Hazlett, H. M., U. S. Bureau of Reclamation, Rupert, Idaho
Hearding, W. S., Brooklyn Edison Co., Brooklyn, N. Y.
Helpbringer, J. N., (Fellow), Staten Island Edison Co., Staten Island, N. Y.
Hendrickson, O. F., Pratt Institute, Brooklyn, N. Y.
Herbers, H. H. W., New York Edison Co., Astoria, N. Y.
Herrick, G. H., The Ideal Electric & Mfg. Co., Mansfield, Ohio
Hershey, P. J., Western Electric Co., New York, N. Y.
Herskind, C. C., General Electric Co., Schenectady, N. Y.
Hibbeler, A. F., Commonwealth Edison Co., Chicago, Ill.
Hicks, F. T., U. S. Patent Office, Washington, D. C.
Hill, A. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Hirsch, C. J., Electrical Engineer, 452 Riverside Drive, New York, N. Y.
Hoffman, N. W., The Milwaukee Elec. Ry. & Light Co., Milwaukee, Wis.
Holborn, F., Hazeltine Corp. Laboratories, Stevens Inst., Hoboken, N. J.
Hooks, J. H., E. L. Phillips & Co., New York, N. Y.
Hotchkiss, F. H., Western Electric Co., New York, N. Y.
Hubbell, F. J., Western Electric Co., Inc., New York, N. Y.
Huggins, L. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hunt, L. A., Smith Robinson & Co., Ltd., Vancouver, B. C.
Huseby, G. E., Western Electric Co., Chicago, Ill.
Hussey, E. O., Alabama Power Co., Tuscaloosa, Ala.
Inman, E. J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Jacocks, T. B., General Electric Co., Schenectady, N. Y.
Jarvie, J., Kansas City So. Railway Co., Meavener, Okla.
Jatlow, J. L., Conner Crouse Corp., New York, N. Y.
Jeffery, A. G., Bell Telephone Laboratories, Inc., New York, N. Y.
Jewett, U. M., Eastern Connecticut Power Co., Norwich, Conn.
Jimenez, R., General Electric Co., Schenectady, N. Y.
Jockers, F. E., Greenpoint Electric Equipment Co., Brooklyn, N. Y.
Johannessen, V. L., Western Electric Co., Chicago, Ill.
Johnson, R. E., Railroad Commission of Wisconsin, Madison, Wis.
Johnson, V. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Johnston, D. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Johnstone, H. H., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Joslin, G. B., Bell Telephone Laboratories, Inc., New York, N. Y.
Kahn, J., Otis Elevator Co., Yonkers, N. Y.
Kaplan, S., General Electric Co., Pittsfield, Mass.
Karsten, E. J., United Light & Power Co., Davenport, Ia.
Keckler, C. W., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Keeton, T. E., Cia. Cubana de Electricidad, Inc., Cienfuegos, Cuba
Kemp, M. V., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Keoughan, L. M., Duquesne Light Co., Pittsburgh, Pa.
Kepp, K., Puget Sound Power & Light Co., Seattle, Wash.
Kershner, V. H., Oklahoma Gas & Electric Co., Muskogee, Okla.
Kietzmann, E. H., Beloit Water, Gas & Electric Co., Beloit, Wis.
King, C. W., Union Gas & Electric Co., Cincinnati, Ohio
Kinney, A. A., Murrie & Co., New York, N. Y.
Kirchner, B. J., Western Electric Co., Inc., New York, N. Y.
Kirk, D., Ware Radio Corp., New York, N. Y.
Kissell, A. L., School of Engg. of Milwaukee, Milwaukee, Wis.
Koch, E. L., Kellogg Switchboard & Supply Co., Chicago, Ill.
Kooistra, L. F., Babcock & Wilcox Co., Bayonne, N. J.
Kopp, O. H., (Member), Bell Telephone Laboratories, Inc., New York, N. Y. (Applicant for re-election)
Kristan, P., Jr., Brooklyn Manhattan Transit Co., Brooklyn, N. Y.
Krupy, A. J., Commonwealth Edison Co., Chicago, Ill.
Kuelling, V. A., Marko Storage Battery Co., Brooklyn, N. Y.
Kunef, C. T., Fort Humphreys, Va.
Kurtz, E. K., Edison Electric Co., Lancaster, Pa.
La Forge, C., Murrie Engineering Co., New York, N. Y.
Lamb, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Landau, M., Bureau of Pr. & Lt., City of Los Angeles, Los Angeles, Calif.
Langman, J. D., Langman Electric & Mach. Co., Portland, Ore.
Langworthy, R. S., United Electric Light & Power Co., New York, N. Y.
Larner, R. A., Texas Power & Light Co., Dallas, Texas
Lawthers, S. M., Union Switch & Signal Co., Swissvale, Pa.
Ley, H. S., East Penn Electric Co., Pottsville, Pa.
Lindvall, I., Adirondack Power & Light Corp., Schenectady, N. Y.
Litchfield, H. S., Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
Little, F. G., Home Tel. & Tel. Co. of Pasadena, Pasadena, Calif.
Locher, L. L., General Electric Co., Schenectady, N. Y.
Long, G. A., Jr., General Electric Co., Schenectady, N. Y.
Ludlow, M. O., Pacific Gas & Electric Co., Antioch, Calif.
Lundius, E. R., Bell Telephone Laboratories, Inc., New York, N. Y.
MacLaren, R. P., Bell Telephone Laboratories, Inc., New York, N. Y.
Mader, C. E., Lewis Institute, Chicago, Ill.
Maloney, J. I., Bell Telephone Co. of Pa., Philadelphia, Pa.
Mallett, M. B., General Electric Co., Pittsfield, Mass.
Maltby, C. W., So. California Tel. Co., Los Angeles, Calif.
Margiotts, G., New York Edison Co., New York, N. Y.
Marousek, G., W. A. Wieboldt & Co., Chicago, Ill.
Marsteller, G. F., C. H. Tenney & Co., Boston, Mass. (Applicant for re-election)
Martin, J. J., Wagner Electric Corp., Chicago, Ill.
Martin, T. G., (Fellow), Automatic Electric Co., Inc., Chicago, Ill.
Martin, W. H., General Electric Co., Schenectady, N. Y.
Marting, H. E., (Member), Bell Telephone Laboratories, Inc., New York, N. Y. (Applicant for re-election)
Mason, M. A., Los Angeles Gas & Electric Corp., Los Angeles, Calif.
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Oliver, C. N., New Orleans Public Service Co., Inc., New Orleans, La.
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Yates, James O., Univ. of Wyo.
Yim, Henry Y., Marquette University
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Young, John E., Drexel Inst.
Young, L. L., Purdue University
Zornik, Anton, Carnegie Tech.

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Motors.—Bulletin 137, 12 pp. Describes Wagner wound-rotor, slip-ring, polyphase motors. Wagner Electric Corporation, St. Louis, Mo.

Circuit Breakers.—Bulletin 9000, 12 pp. Describes Pacific multi-break oil circuit breakers. Pacific Electric & Manufacturing Company, 5815 Third Street, San Francisco, Cal.

Transformers.—Bulletin 2050, 4 pp. Describes Pittsburgh polyphase transformers, and discusses the importance of low exciting current and its value in the operation of transformers. Pittsburgh Transformer Company, Columbus & Preble Avenues, Pittsburgh, Pa.

Outdoor Substations.—The December 15 issue of the "Delta-Star Monthly," published by the Delta Star Electric Company, 2400 Block Fulton Street, Chicago, contains an interesting description of a standard outdoor substation construction for voltages up to 132 kv.

Electrical Drives for Power Plant Auxiliaries.—Bulletin 7381, 24 pp. Describes the advantages of motor driven power plant auxiliaries, including pumps, fans and blowers, coal handling equipment, pulverized fuel equipment, etc. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Illuminating and Wiring Equipment.—Catalog 24, 182 pp. Describes Benjamin electrical products, which include reflector-sockets, outdoor lighting fixtures, store and office lighting equipment, industrial signals, wiring devices, etc., Benjamin Electric Manufacturing Company, 120 So. Sangamon Street, Chicago, Ill.

Block Signals On a Steam Railway.—Bulletin 146, 100 pp., entitled "Alternating Current Signals on the Southern." The installation described covers 667 continuous miles of double track and presents a good example of the applicability of this type of signal system on a steam railroad where average track conditions prevail. General Railway Signal Company, Rochester, N. Y.

General Electric Catalog No. 6001 B.—Supersedes all previous catalogs issued by the company, except those dealing with railway, mine and industrial supplies and merchandise products. This complete catalog is issued every two years. The book is two inches thick and contains more than 1100 pages, the illustrations total more than 3200. The catalog is thumb-indexed into sixteen sections, as follows: Generation, wire and cable, distribution transformers, arresters, voltage regulators, switchboards and accessories, meters and instruments, motors, motor applications, industrial control, railway, lighting, industrial heating, miscellaneous and indexes.

NOTES OF INDUSTRY

Union Electric Manufacturing Company, Milwaukee, Wis., manufacturers of electric motor control equipment, announce the opening of a New York office in the Hudson Terminal Building, 30 Church Street, under the direction of A. J. Heidt.

Simplex Wire & Cable Company, Boston, Mass., has opened a branch office in the Lew Building, St. Augustine, Fla., in order to better care for the steadily increasing volume of business in this state. F. H. Pettee, who has represented the company in Florida for a number of years will be manager of the new office.

The Gray Instrument Company, 64 W. Johnson St., Germantown, Philadelphia, has been organized by J. G. Gray, formerly president of Queen & Company, Inc., and Queen-Gray Company. The new company will continue the manufacture of the line of electrical measuring and scientific instruments made for many years by the above named companies.

The J. G. White Engineering Corporation, New York, which has a contract with the Firestone Plantations Company to construct a harbor, breakwater, wharves, roads, etc., for the Government of Liberia at Monrovia, West Africa, recently sent a construction organization via England on the steamship President Roosevelt. Plant, tools, equipment and all necessary supplies also went forward on the same day, via the steamship West Humhaw, sailing direct to Monrovia.

Electrification of Chilean Mines.—The Andes Copper Company and the Chilean Exploration Company, both of Chile, have placed with the Westinghouse Electric & Manufacturing Company, orders totalling twenty-three industrial electric locomotives for the purpose of inaugurating the electrification of the haulage systems of these two mining properties. The complete electrification eventually will require some fifty additional 70-ton locomotives. The electric power for the haulage system at the Chile Exploration Company is generated by steam turbines and oil fired boilers located at the seacoast seventy-five miles away, and transmitted to the mining property at 110,000 volts.

General Electric Company Secures Manufacturing Site in St. Louis.—Gerard Swope, President of the General Electric Company, has announced that the company has definitely decided to purchase a site for a manufacturing establishment in the City of St. Louis. The tracts of real estate selected contain in the aggregate about 155 acres, of which all but 11 acres are within the city limits of St. Louis; the balance lies just beyond the city limits in St. Louis County. The property in general lies between the Belt Line of the Terminal Railroad Association and Goodfellow Avenue. It also has a frontage on Bircher Avenue.

Increase in Foreign Trade During 1925.—The Director of the Bureau of Foreign and Domestic Commerce reports that the export trade of the United States during 1925 continued its steady advance, exceeding by more than 7% its value in 1924. The total value of our exports for the year is in the neighborhood of $4,900,000,000, the largest figure since 1920. British exports of domestic products were slightly less than in 1924, and French exports also showed a decline. Those of Germany increased about 6%.

Exports of electrical machinery, in contrast with the normal increase in recent years, have been stationary. The increase of recent years in exports of copper was continued during 1925.

Buffalo General Electric Company Expands.—The rapidly increasing load supplied by the Niagara system, and the necessity of maintaining a proper balance in the supply of steam and hydro-power have made it necessary to add a 60,000 kw. turbine to the equipment of the River Station of the Buffalo General Electric Company. The construction schedule calls for the new unit to be in operation early in the fall of 1926. The River Station at present includes three 20,000 kw. and one 35,000 kw. turbine generators. These, as well as the new unit now to be added, are of General Electric manufacture.

Western Electric Creates New Company.—The electrical supply business carried on by the Western Electric Company has been set apart from the telephone manufacturing business and incorporated under the name of Graybar Electric Company. The Western Electric Company has been both the manufacturing company of the Bell System and a distributor of electrical supplies. Both of these lines of business require specialized organization and specialized management. The rapid expansion of the supply department made an entirely separate corporate identity even more necessary.

The new company is capitalized at $15,000,000, all owned by the Western Electric Company. The officers are as follows: Charles G. DuBois, president of the Western Electric Company, is chairman of the Board; Albert L. Salt, president; Frank A. Ketcham, George E. Cullinan, Leo M. Dunn and Howard A. Halligan, vice-presidents; Richard H. Gregory, comptroller.

JOURNAL OF THE A·I·E·E·

FEBRUARY 1926

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33 WEST 39TH ST· NEW YORK CITY

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Some Notable Electrical Engineering Features in and near New York

Open to A. I. E. E. Members and Guests at Midwinter Convention

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OF THE
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Engineers and Engineering, December, 1925

Motorbus as an Adjunct to the Street Railway, by R. H. Horton

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV | FEBRUARY, 1926 | Number 2

The Invisible Service of Science

Service of Science reminds us first of the visible service of science, which one can see in every nook and corner of our daily life. But there is an invisible service of science which has a purely intellectual, esthetic, and spiritual value. This is the service to which I wish to call attention. In this connection it is well to point out at this very outset that during the last three hundred years, since the pilgrim fathers landed at Plymouth rock, science has revealed three distinct physical realities. The first physical reality was revealed through the science of matter in motion; the second, through the science of electricity in motion; and the third, through the science of energy in motion. Each one of these contributes a service which is not visible in every nook and corner of our daily life; but it has an intellectual as well as an esthetic and spiritual value.

1. The Science of Matter in Motion

The first physical reality revealed by the science of matter in motion announced its approach three hundred years ago, when Galileo discovered the concept of acceleration and its relation to the moving force. A hundred years later Newton finished the work which Galileo had commenced; he placed the crowning dome upon the beautiful intellectual structure the foundation of which had been laid by Galileo. The Galileo-Newton science of matter in motion, the science of dynamics, is this intellectual structure. It revealed the first physical reality which is our earliest scientific knowledge of the material unvierse. Nothing exhibits the beauty of this reality so well as the motion of the planets around the sun. Here we have a cosmic system of bodies, in whch each part moves along a definite path with a precision unattainable in any mechanism constructed by the hand of man. And yet the only guiding force in this perfect order is the gravitational action of matter, operating according to laws of childlike simplicity. Michelangelo, we know, rendered immortal service to the intellectual as well as to the esthetic and spiritual activity of the human soul, when he impressed his genius upon that magnificent edifice on the Vatican Hill, St. Peter's basilica in Rome. Newton, the Michelangelo of the science of dynamics, rendered to mankind a similar, but immeasurably greater service when through his science he gave a new meaning to the most sublime edifice known to man, to the starry vault of heaven.

2. Science of Electricity in Motion

The second physical reality revealed itself through the science of electricity in motion. Among those who laid the foundation to this physical reality Faraday must be mentioned first. He discovered the meaning of acceleration in electrical motions; he is the Galileo of the Electrical science. But who is its Newton? Sixty years ago Maxwell spoke like a prophet when he made the startling announcement that radiation of light and heat is a manifestation of moving electricity. The prophecy came true and Maxwell rose to the lofty position of a Newton of electrical science. Its achievements during the last sixty years are the fruits of our efforts to find a complete interpretation of Maxwell's prophecy. The greatest among them is the discovery that the origin of all radiation is in the motions of the tiny electrons which are, as far as we know today, the immutable primordial building stones of the material universe. Atoms have been revealed to us as complex structures, made up of positive and negative electrons, the unchangeable granules of that subtle substance which we call electricity. Everything that moves and has its being in this boundless universe seems to be deriving its breath of existence from the electrical forces which have their origin in the tiny electrons. The combined activities of these infinitely small but infinitely numerous workers is the activity of that stupendous unit, called the universe. The book of Genesis, composed by a Moses of modern science, would probably start as follows:

In the beginning God said: Let electricity move, and the embryo of the universe began to form.

If the contemplation of this physical reality does not uplift the soul of man and stimulate its intellectual and esthetic as well as its spiritual activity then St. Paul was in error when he said: "We all with open face beholding the glory of the Lord are changed into the same image from glory to glory . . . . ."

3. The Science of Radient Energy in Motion

These two physical realities prepared the human mind for a third physical reality which is being revealed to us through the motion of cosmic, that is of radiant, energy. The concept of energy is a comparatively new concept, and its full meaning dawned upon us less than a hundred years ago. Today we know that the background of every physical phenomenon is a transformation of some form of energy. We also know that

*Address delivered on January 8th before the Pittsburgh Section of the A. I. E. E.

the total energy content in the universe is constant, but that its radiated parts are wandering through space, as if in search of new opportunities for benevolent service. Each visible star radiates its energy to other stars, and our little terrestrial globe would be a sad and barren abode if it did not float in the life-giving energy stream of solar radiation.

This radiation proceeds from countless tiny electronic centers, each one of them attending strictly to its own activity and paying no attention to the activity of its neighbors. It is, therefore, a chaotic activity of an immense number of essentially autonomous workers. Hence solar radiation is a most chaotic swarm of countless energy units, and yet their service on earth shows that beautiful order which is the fairest adornment of our terrestrial globe. Just watch the clouds of the summer sky, moving, like Milton's heavenly host, in stately procession, and carrying relief to the thirsty continent. Remember, then, that the power behind this gigantic labor of beautifully ordered service is the chaotic energy stream of solar radiation. Here is a transformation of a chaos into a cosmos, a revelation of a new physical reality, which gives a concrete meaning to the belief of ancient Greece, that the creation of the world is a transformation of a chaos into a cosmos. A new science is rising in the background of this physical reality. Its foundation was laid a hundred years ago by that great savant, Sadi Carnot, who is its Galileo. But who is its Newton? Not only has he not yet appeared but the science has not yet received its appropriate name. I call it, for want of a better name, The Science of Coordination.

Carnot told us how the chaotic molecular activity, called heat, can be transformed into orderly service by interposing a heat engine in the path of heat in its passage from a higher to a lower temperature. The engine is a guide, a coordinator, of the chaotic heat energy. Similarly a galvanic cell is a coordinator of chemical activity which is chaotic when unguided. The caloric engine and the galvanic cell are coordinators invented by man. Their guiding operation is performed in accordance with the designing intelligence of man who has a definite purpose in view. But what is the coordinator which transforms the chaotic solar energy, absorbed by the leaf of a plant, into a coordinated service which manifests itself in the orderly growth of the plant? Each organic cell as a whole and all of its miscroscopic and ultra microscopic components feed, grow, and divide in an orderly way; they transform chemical activity, which is chaotic when unguided, into orderly work and service. Is there a guiding coordinator attached to each one of these tiny organic units, and, if there is, does it operate in accordance with some intelligent design and purpose as is the case in the caloric engine and the galvanic cell? What function, if any, does the recently revealed radiation of marvellous penetrability play in the physico-chemical processes of the organic cells? One cannot resist the temptation of asking this question, because it suggests the possibility of finding a new relationship between some new cosmic processes going on near the very boundaries of our stellar system and the tiny living cells on earth. Some future Newton will answer all these questions; in the meantime the contemplation of the physical reality of which these questions are a part cannot fail to furnish that intellectual, esthetic, and spiritual exhilaration which is the noblest service of science to the human soul.

M. I. PUPIN.

Some Leaders of the A. I. E. E.

Dugald C. Jackson, the twenty-third president of the A. I. E. E., was born at Kennett Square, Pa., February 13, 1865. He was graduated from Pennsylvania State College in 1885 with the degree of B. S., receiving the degree of C. E. from the same college in the year 1888. Following graduation, Mr. Jackson devoted two years to post graduate work in electrical engineering at Cornell University, serving as instructor in physics in 1887.

For two years he was vice-president and engineer of the Western Engineering Company, at Lincoln, Neb., and throughout the years 1889-1890 served as assistant chief engineer with the Sprague Electric Railway and Motor Company, at New York. Following this, for one year, he was chief engineer of the central district of the Edison General Electric Company.

In the year 1891, Mr. Jackson became a member of the faculty of the University of Wisconsin. During the sixteen years of his engagement there the department of Electrical Engineering of the University was developed.

Since the year 1907 Professor Jackson has been at the head of the Department of Electrical Engineering at Massachusetts Institute of Technology. He was senior member of the firm of D. C. and W. B. Jackson, consulting engineers, for twenty years, during which time the company was actively identified with many of the noteworthy electrical projects of the country. At the time the British telephone systems were taken over by the British Government, he served it as consulting engineer.

In the World War, Professor Jackson served overseas as Lieut.-Colonel of Engineers, rendering distinguished service to the American Expeditionary Forces.

Professor Jackson was a member of the Jury of Electrical Awards at the World's Columbian Exposition, Chicago, 1893, and at the Pan-American Exposition, Buffalo, 1901. He is a Chevalier of the Legion of Honor, France; was president of the A. I. E. E. throughout the term 1910-11; president of the Society for Promotion of Engineering Education, 1905-06, and a member of various other American and foreign technical and scientific societies.

He is the inventor of a number of electrical devices as well as author of many technical papers and books.

Cipher Printing Telegraph Systems

For Secret Wire and Radio Telegraphic Communications

BY G. S. VERNAM[1]

Associate, A. I. E. E.

Synopsis.—*This paper describes a printing telegraph cipher system developed during the World War for the use of the Signal Corps, U. S. Army. This system is so designed that the messages are in secret form from the time they leave the sender until they are deciphered automatically at the office of the addressee. If copied while en route, the messages cannot be deciphered by an enemy, even though he has full knowledge of the methods and apparatus used. The operation of the equipment is described, as well as the method of using it for sending messages by wire, mail or radio.*

The paper also discusses the practical impossibility of preventing the copying of messages, as by wire tapping, and the relative advantages of various codes and ciphers as regards speed, accuracy and the secrecy of their messages.

* * * * *

Introduction

The purpose of this paper is to discuss briefly certain methods for obtaining secrecy in connection with messages sent by wire or radio telegraphy, and to describe in particular printing telegraph cipher systems that were developed for this purpose during the World War.

The desirability of obtaining secrecy in telegraphic communications and the possible advantages of a system that would be capable of sending messages in such form as to be entirely secret, and which at the same time, would be more rapid and accurate than the codes and ciphers ordinarily used, were brought out in conversations with officers of the Signal Corps, U. S. Army. These discussions made it evident to the engineers of the Bell System that it would be very helpful if the well-known automatic features of the printing telegraph art could be made available for enciphering and deciphering telegraph messages, and could at the same time be made practical for use under service conditions.

The engineers recognized that printing telegraphs[2] were rapid and accurate, but were not secret except to the extent that their signals could not be read from a telegraph sounder. With the general requirements for secrecy systems in mind, studies were made of printing telegraph systems to determine how their messages could be made secret. The result of this work was the development of a cipher system that is capable of rendering messages entirely secret, is rapid and accurate, and is practical to use.

This "Cipher Printing Telegraph System" was called to the attention of the Signal Corps. The Signal Corps became very much interested, tested the secrecy of communications handled by the system and tried it out between New York and Washington. This trial proved that the system could be successfully used to send messages secretly and at a speed many times faster than by methods previously in use.[3]

Each message is automatically enciphered at the sending station and deciphered in the same manner at the receiving station. The method of ciphering will be described later in this paper and is such that under certain conditions of use, the messages are rendered entirely secret, and are impossible to analyze without the key, even if it is assumed that the enemy can capture a machine, learn its method of operation in all details, and intercept a large number of messages.

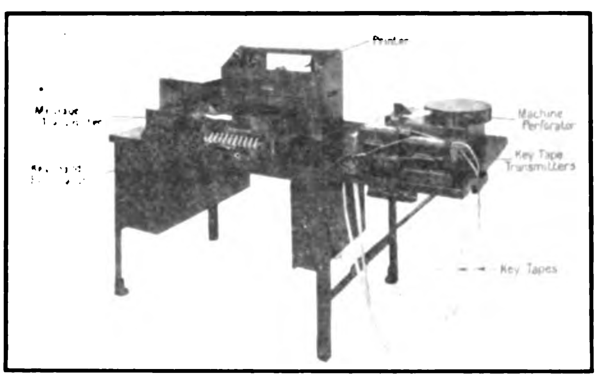

Fig. 1—Cipher Printing Telegraph Machine

Flexibility of System

This method of ciphering can be used with machines of various types. The electrically-driven machine shown in Fig. 1 was developed during the war particularly for the Signal Corps, U. S. Army. In order to save time in production, standard printing telegraph parts were used wherever possible with the result that this machine has the appearance of a "start-stop" printing telegraph set with some additional units mounted on a shelf at the right end of the table. This type of cipher set is particularly suitable for handling large amounts of traffic at high speed.

1. Engineer, Dept. Development and Research, Am. Tel. & Tel. Co.

2. See John H. Bell, "Printing Telegraph Systems," Trans. A. I. E. E. for 1920, Vol. XXXIX, Part 1, p. 167, and A. H. Reiber, 'Printing Telegraph Systems Applied to Message Traffic Handling," Trans. A. I. E. E. for 1922, Vol. XLI. p. 39.

To be presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926.

3. Note: See page 140, "Report of the Chief Signal Officer to the Secretary of War" for the year ending June 30, 1919.

If something smaller in size and portable is required, the machine shown in Fig. 2 may be used. This machine is light and strictly portable as no electric current is required for its operation. It is slower than the large machine and requires a knowledge of the standard "Baudot" printer code (see Fig. 8) on the part of the operator, but its messages are equally secret.

These machines are considered suitable for general use by government departments, business concerns,

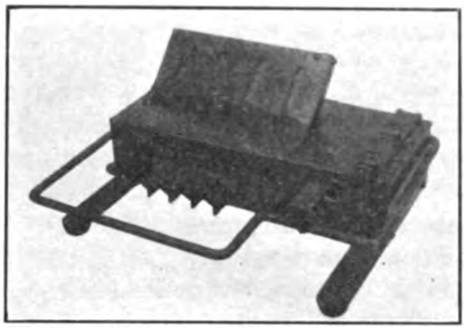

FIG. 2—PORTABLE CIPHER MACHINE

etc., for handling confidential messages rapidly and secretly. The method of using them can be varied to suit conditions and so as to make unauthorized decipherment as difficult as may be necessary up to the point where it becomes impossible even for an expert cryptanalyst.

If an appreciable demand exists for machines of special sizes or having particular operating features for special uses, these can be built to employ the same secrecy principle. For example, the functions of ciphering and transmitting over a telegraph circuit can be combined in one machine, if desired, so that, at the sending station, messages can be simultaneously enciphered and transmitted over the telegraph circuit, and so that, at the receiving station, messages can be received, deciphered automatically and printed directly in plain text; thus avoiding the slight delay caused by separately enciphering and deciphering each message.

RUIYW TGCZG PIETY RJGUA ELKEJ EZIAO
ISCFE LCXHF CONEC XELVY DXJBT WFEJM
HLGDL DDPYD TPGVQ EZAYI LXSZX

FIG. 3—SAMPLE CIPHER MESSAGE IN PRINTED FORM

This method is particularly suitable for cases where the cipher equipment can be directly connected to a telegraph line or to a radio transmitter and receiver and can be operated by the same personnel.

If the cipher messages are to be turned over to a telegraph or cable company to transmit, they should be in written or printed form. For this purpose, the cipher machine can be arranged to print the cipher messages in groups of five letters each, spaced to form "words." Fig. 3 is a copy of such a message shown exactly as it was prepared by the cipher set. Such messages can be printed by the machine directly on the telegram blank with the address and signature in plain English, and if desired, a carbon copy can be made at the same time for record purposes.

PREVENTING ACCESS TO MESSAGES

There appear to be two general methods for securing secrecy in connection with communications, namely, (1) by preventing or at least attempting to prevent access to the messages or to the lines of communication and, in the case of telegraphic communications by rendering the lines incapable of being tapped, and (2) by the use of codes and ciphers with key systems known only to the proper parties.

As regards wire tapping, sensitive alarm devices arranged to operate on small changes in the electrical constants of the line circuit, are unsuccessful as a means of preventing unauthorized parties from obtaining access to the circuit. The electrical condition of a long telegraph circuit is continually changing as a result of variation in temperature and other weather conditions. This fact limits the useful sensitivity of any such alarm devices, whereas by using vacuum tube amplifiers, a record of the signals passing over a circuit can be obtained without appreciably disturbing the line circuit and even without actual contact with the wire.

Telegraph systems have been invented, that will operate successfully on very small line currents, and which use coils and condensers to suppress the harmonics in the signal impulses, or in other words to avoid sudden changes in current value. The currents induced in neighboring circuits by such a system would be small, so that it would be rather difficult, if ordinary methods are used, to obtain a record of the signals by their inductive effect. This can be readily done, however, if modern vacuum tube amplifying equipment is used. It is also obvious that a record can be easily obtained if the wire is tapped.

Many attempts have been made to obtain secrecy during the actual transmission of telegraph messages by making them unintelligible. In one system of this sort, successive signal impulses are sent alternately over two line wires by means of a rotary switch which puts the sending key in connection first with one wire and then with the other at each movement of the key. At the receiving end, the impulses are combined through one relay. With this system, the messages may be readily copied if both wires are tapped, and it is quite possible to decipher the messages even if only one wire is tapped.

Proposals have also been made to use complex devices or methods, or so to mutilate the normal impulses that they become unintelligible to anyone tapping the line circuit or intercepting the signals if sent

by radio. Any secrecy system of this general class can be readily "broken" by anyone having a knowledge of the methods used and the ability to assemble and operate the necessary apparatus.

Tapping Duplex and Multiplex Circuits

It has also been considered that a full duplex circuit or a multiplex printer circuit, in which messages are being transmitted simultaneously in opposite directions, could not be tapped and that circuits of this character insured secrecy to the communications thus being handled. This is not true, however, and means have been invented by which a message originating at one station of an ordinary duplex circuit can be tapped at any part of the circuit, even though a second message is also going over the same circuit simultaneously in the opposite direction. This means that a multiplex printer circuit, in which as many as eight messages, four in each direction, are handled simultaneously, may be tapped and a person who is familiar with the system can readily analyze the multiplex impulses to distinguish between adjacent channels and the letters of each message in each channel.

An arrangement for tapping a duplex circuit is shown in Fig. 4. A single sensitive polar relay may be used to receive the signals from either end of the circuit, or by using two such relays, the signals in both directions may be read simultaneously. Each relay may control a sounder or a suitable recording device. One winding of each relay is connected in series with the line, the other winding being connected in a circuit from line to ground through an "artificial line" composed of adjustable resistances and con-

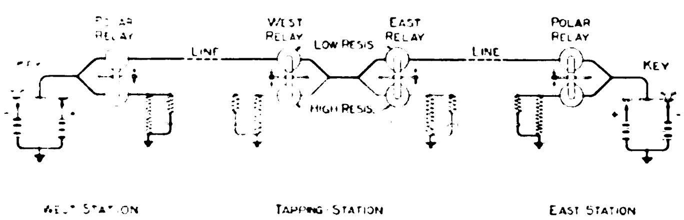

Fig. 4—Method of Tapping a Duplexed Line

densers. The line winding of each relay should have relatively few turns and should be of low resistance, the other winding having a large number of turns. Each artificial line should be adjusted to be substantially equivalent to the impedance of the corresponding section of line including that of the terminal station equipment multiplied by the ratio of turns of the relay windings.

Signals transmitted from the west station will pass through the line windings of both relays at the tapping station, a small part of the signal currents also going through the lower windings and artificial lines to ground. The signal currents pass through both windings of the west relay in series, the magnetic effects of the two windings aiding each other, so that the armature of this relay will follow the signals. The same signals pass through both windings of the east relay in parallel, the magnetic effects opposing and balancing so that this relay does not respond to signals from the west station.

In a similar manner, signals from the east terminal station will energize the east relay but not the west relay at the intermediate station, so that by using suitable recording devices associated with each relay, a copy of signals in both directions may be obtained.

Tapping a Multiplex Circuit

This method may be used to tap a multiplex printer circuit, in which case a tape record of the form shown in Fig. 5 will be obtained. If this is taken from a

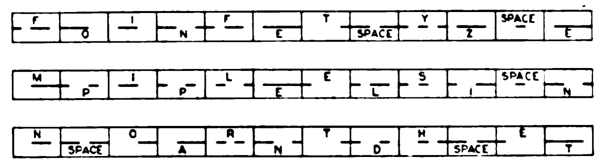

Fig. 5—Tape Record of Multiplex Printer Signals

"double-duplex" circuit alternate letters must be read as indicated, to get the message from either channel. Every third or every fourth letter must be chosen if the circuit is operated by the "triple-duplex" or "quadruple-duplex" method. The individual letters are in the ordinary five-unit printer code, the polarities of alternate signals being reversed. To decipher such a tape, it should be divided into units of five dot lengths each. The correct starting point can be found in not more than five trials and can be recognized by the fact that the letters of each message then form sensible combinations.

Codes and Ciphers

Secrecy, in connection with telegraphic communications, is usually obtained at the present time by means of codes and ciphers, the term "code" being applied in cryptography to the method in which entire words, or phrases of a message are replaced by arbitrary groups of letters or numbers usually printed in a code book, identical copies being kept by those using the code, "cipher" referring usually to a system in which the individual letters of a message undergo a change either in arrangement or nature.

It is obvious that the combinations of letters in a cipher message will not form pronounceable groups or genuine words except occasionally by accident, but "code" systems can be arranged to use pronounceable artificial "words" or actual dictionary words, if desired. This is usually done, as such "code words" are handled by the telegraph and cable companies at a cheaper rate than the unpronounceable so called cipher "words."

Each of these two general systems has advantages and disadvantages which cause them to be used for

certain classes of work, depending upon the conditions. The code system has the outstanding advantage, especially for commercial work, of enabling messages to be shortened so that the tolls are reduced, and it is chiefly for this reason that commercial codes are used. Code is not very accurate, as a mistake in a single code group or even a single letter may change the meaning of an entire message, or necessitate its repetition. If secrecy is required, it is necessary to use carefully guarded private code books, the maintenance of secrecy and accuracy during the printing and distribution of which may cause great trouble. Such books must be carefully used to maintain secrecy, and must be immediately replaced, sometimes at great expense and inconvenience if they should become compromised.

Ciphers, in general, are slower than codes unless machines are used, but then they may be very much faster. They are more accurate, and depending on the system used, cipher messages may be more or less secret than code messages.

There are two general classes of ciphers, known respectively as transposition ciphers and substitution ciphers. In the first class, as the name suggests, the letters of the original message are rearranged, according to a definite system, and in the second class, substitutions for the original letters are made according to some prearranged key. In one, the relative positions of the letters are changed and in the other, the letters themselves.

Transposition Ciphers

A transposition cipher may be distinguished from a substitution cipher by a study of the frequency of occurrence of the letters of the message by comparison with a frequency table of the language of the original message. Studies which we have made of the frequency of the different letters of the English language as they occur in telegrams sent over our private wires, indicate that they are used about as shown in Fig. 6. It is apparent that some letters are used very frequently, the vowels a, e, i, o, u, forming approximately 40 per cent. of the total, e being the most commonly used letter of all. [4]This chart is similar to those used by cipher experts.

In a transposition cipher the letters must be rearranged according to a definite system known to the receiving correspondent. Those who make a study of ciphers tell us that such systems are usually easy to discover, particularly if a considerable number of messages are intercepted including two or more of exactly the same length. Transposition ciphers are not suitable for use with machines.

Substitution Ciphers

In substitution ciphers the order of the letters remains unchanged, but for each letter is substituted its equivalent in one or more cipher alphabets. For example, using the table below, for each letter in the plain text alphabet we may substitute its equivalent in the cipher alphabet. To decipher, this process is reversed.

Plain Text–A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Cipher –F Q R U K A H G Z S E M L Y P O B C J V D T X W N I

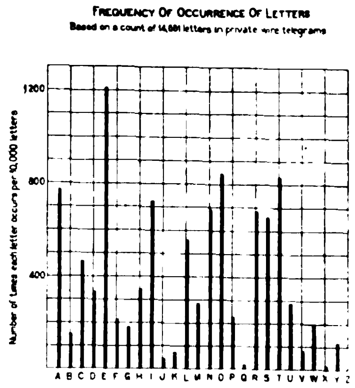

Fig. 6

If a chart is prepared from a frequency count of the letters in such a cipher message, it will have the general appearance of Fig. 6 but the crests will correspond to different letters. Messages of this type are readily deciphered by an expert even when a "mixed" alphabet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	E	G	F	R	A	C	B	Q	M	J	K	Z	I	O	N	Y	H	D	U	W	S	X	T	V	P	L
B	G	N	Q	T	O	H	A	F	X	L	P	J	S	B	E	K	C	W	M	D	V	U	R	I	Y	Z
C	F	Q	R	U	K	A	H	G	Z	S	E	M	L	Y	P	O	B	C	J	V	D	T	X	W	N	I
D	R	T	U	J	E	K	W	X	P	D	F	N	Y	L	Z	I	V	A	S	B	C	Q	G	H	M	O
E	A	O	K	E	D	S	N	Y	V	R	C	W	X	G	B	Q	P	J	F	Z	U	I	L	M	H	T
F	C	H	A	K	S	J	Q	B	L	F	D	I	Z	P	Y	N	G	U	E	X	R	W	V	T	O	M
G	B	A	H	W	N	Q	L	C	S	Z	Y	G	M	E	O	V	F	T	I	R	X	P	D	U	K	J
H	Q	F	G	X	Y	B	C	O	J	I	N	P	T	K	H	L	A	V	Z	M	W	R	U	D	E	S
I	M	X	Z	P	V	L	S	J	W	H	T	F	A	Q	U	D	N	Y	G	K	O	E	I	B	R	C
J	J	L	S	D	R	F	Z	I	H	A	U	B	Q	T	W	X	M	E	C	N	K	Y	O	P	V	G
K	K	P	E	F	C	D	Y	N	T	U	A	X	W	H	Q	B	O	S	R	I	J	Z	M	L	G	V
L	Z	J	M	N	W	I	G	P	F	B	X	T	C	D	R	H	S	O	Q	L	Y	V	E	K	U	A
M	I	S	L	Y	X	Z	M	T	A	Q	W	C	G	U	V	R	J	P	B	H	N	O	K	E	D	F
N	O	B	Y	L	G	P	E	K	Q	T	H	D	U	W	A	F	I	Z	V	J	M	S	N	X	C	R
O	N	E	P	Z	B	Y	O	H	U	W	Q	R	V	A	G	C	K	L	X	T	I	M	J	S	F	D
P	Y	K	O	I	Q	N	V	L	D	X	B	H	R	F	C	T	E	M	W	P	Z	G	S	J	A	U
Q	H	C	B	V	P	G	F	A	N	M	O	S	J	I	K	E	Z	X	L	U	T	D	Y	R	W	Q
R	D	W	C	A	J	U	T	V	Y	E	S	O	P	Z	L	M	X	R	K	G	F	H	B	Q	I	N
S	U	M	J	S	F	E	I	Z	G	C	R	Q	B	V	X	W	L	K	D	Y	A	N	P	O	T	H
T	W	D	V	B	Z	X	R	M	K	N	I	L	H	J	T	P	U	G	Y	O	Q	C	A	F	S	E
U	S	V	D	C	U	R	X	W	O	K	J	Y	N	M	I	Z	T	F	A	Q	E	B	H	G	L	P
V	X	U	T	Q	I	W	P	R	E	Y	Z	V	O	S	M	G	D	H	N	C	B	L	F	A	J	K
W	T	R	X	G	L	V	D	U	I	O	M	E	K	N	J	S	Y	B	P	A	H	F	Z	C	Q	W
X	V	I	W	H	M	T	U	D	B	P	L	K	E	X	S	J	R	Q	O	F	G	A	C	N	Z	Y
Y	P	Y	N	M	H	O	K	E	R	V	G	U	D	C	F	A	W	I	T	S	L	J	Q	Z	B	X
Z	L	Z	I	O	T	M	J	S	C	G	V	A	F	R	D	U	Q	N	H	E	P	K	W	Y	X	B

Fig. 7

is used, such as that illustrated above in which the letters of the cipher alphabet are not in the usual alphabetic order.

By using more than one alphabet, the cipher may be made more difficult to "break." The method may

4. See "Manual for the Solution of Military Ciphers" by Lt. Col. Parker Hitt.

be described by referring to the "cipher square" shown in Fig. 7. In this table, the top alphabet represents the plain text, whi e below it are shown 26 cipher alphabets, each designated by a "key" letter given in the left-hand column. Some form of key, usually a word, is used, the letters of this key word designating the alphabets and the order in which they are to be used. A different cipher alphabet is used in a repeating manner, with each successive letter of the message.

This type of cipher may be distinguished by the fact that the frequency chart is rather flat, the frequency of occurrence of all letters being roughly the same. Each cipher alphabet is used repeatedly at regular intervals. By first finding this interval and then studying each alphabet separately, messages of this type can be deciphered readily by an expert.

Running Key Ciphers

If the key used with this type of cipher is made very long, so that it never repeats and if any portion of this key is never used for more than one message, the operation of "breaking" the cipher becomes very much more difficult. If, now, instead of using English words or sentences, we employ a key composed of letters selected absolutely at random, a cipher system is produced which is absolutely unbreakable.

This method, if carried out manually, s slow and laborious and liable to errors. If errors occur, such as the omission of one or more letters, the messages are difficult for the recipient to decipher. Certain difficulties would also be involved in preparing, copying and guarding the long random keys. The difficulties with this system are such as to make it unsuitable for general use, unless mechanical methods are used.

Cipher Printing Telegraph System

By using machine methods, this type of cipher may be made practicable for use. Fig. 1 is an illustration of the cipher machine previously referred to, and which operates on this principle. As previously mentioned, this machine was developed during the recent war and adopted by the Signal Corps, U. S. Army.

Certain parts of this machine are the same as those used for ordinary printing telegraphs, such as those described in recent papers before the Institute. For this reason, it will not be necessary to describe in detail the parts which are commonly used in such systems, such as the keyboard perforator, the transmitters, and printer.

Cipher Machine—Method of Operation

The messages are first punched in a paper tape by means of the keyboard perforator. The code used is shown in Fig. 8. This is the well-known five-unit printing telegraph code. Each letter is represented by a small feed hole and one or more larger holes which may be punched in five different positions across the tape. Since n each of these five positions a hole may or may not be punched, there are $(2)^5$ or 32 possible different combinations in this code of which 26 are used to designate letters, the other 6 representing the so-called "stunts," which are the "space," "carriage return," "line feed," "figure shift," "letter shift," and the "blank" or "idle" signal.

The cipher "key" may take the form of another tape of similar form having characters punched in it at random and with every tenth character numbered, so that the tape may be set to any designated starting position. The key tapes are prepared in advance, the original key being perforated by hand, as by working

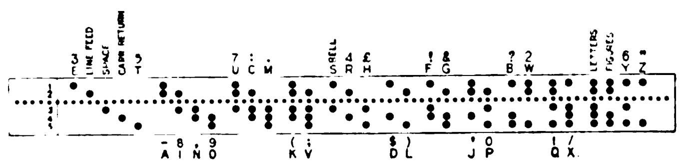

Fig. 8—Tape Showing Printing Telegraphic Code

the keyboard at random, additional copies being made automatically by the machine.

The message tape is passed through a unit known as a transmitter, where the holes in the tape serve to control the positions of five contact levers, each of which makes contact with either of two bus-bars. The key tape controls the contacts of a second tape transmitter. The contacts of the two transmitters are connected to a set of five magnets or relays as shown in Fig. 9. Each magnet wil be energized if the correspondingly numbered contacts of the two transmitters are against opposite bus-bars, but not if they are making contact with similar bus-bars. In the diagram, contacts 1 and 2 of the message transmitter, are against the left or positive bus-bar, this setting representing the letter *A*. Contacts 1, 4 and 5 of the key transmitter are against the positive bus-bar, representing the letter *B* in the printer code. This will energize magnets 2, 4 and 5, which combination represents the letter *G*.

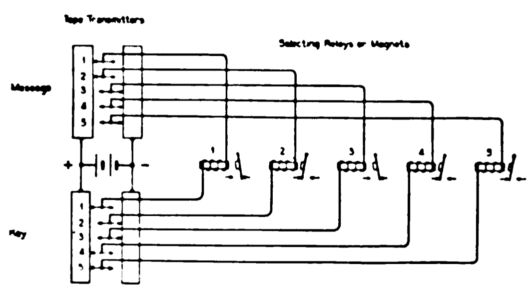

Fig. 9

All of the possible combinations resulting from various characters in the two tapes might be shown in a cipher square similar to that of Fig. 7 except that it would have 32 characters on a side instead of 26.

The characters of the cipher messages, formed in this

way, may be recorded as perforations in a third tape. For this purpose a "machine perforator" is used. This device is similar in many respects to a keyboard perforator and is shown in Fig. 10. The tape, from a reel on the top of the machine, passes through the punch block at the front left corner of the machine. Here it passes under a die plate and over a group of six punches, which may be forced up through the tape by the action of an electromagnetic hammer. Five of these punches are too short to be acted on directly by the hammer and are pushed through the tape only when an individual "selecting finger" is interposed between the punch and hammer. The five selecting fingers are actuated by five magnets which may be controlled by the relays shown in Fig. 9. A ratchet-operated, star-wheel feeds the tape forward after each character has been punched.

The cipher message tape prepared in this way is unintelligible in form and may be sent to the receiving station by messenger or by mail, or if desired, it may

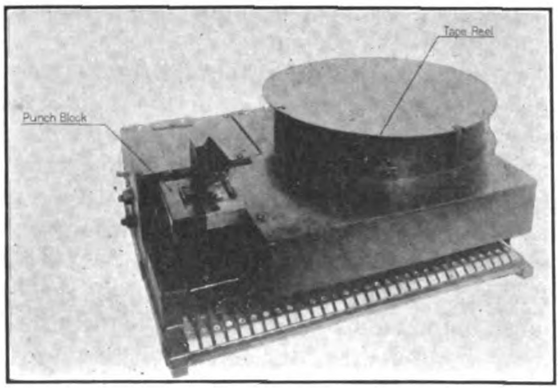

FIG. 10—MACHINE PERFORATOR

be transmitted by wire or radio and reproduced by another machine perforator at the receiving point. The cipher tape is there run through the message transmitter, where its characters combine with those of a duplicate key tape to reproduce the original message, which will be printed out in page form and in "plain text."

LENGTH OF KEY TAPE

With the system as described above, the key tape must be at least as long as the sum of all the message tapes used with it, as the messages will lose their secrecy to some extent if the key tape is used repeatedly. The use of a short repeating key may give sufficient secrecy for some uses however.

A roll of tape eight inches in diameter contains about 900 feet of tape and would serve to encipher about 18,000 words counting five printed characters and a space per word, without repeating the key. If sent at an average speed of 45 words per minute this number of words would require 400 minutes or nearly 7 hours to transmit.

In order to reduce the amount of key tape required for handling large amounts of traffic, the "double key" system was devised. In this system two key tapes are used, the ends of each tape being glued together to form a loop preferably about seven feet in circumference. The tapes should differ in length by one character or by some number which is not a factor of the number of characters in either tape. A separate transmitter is used for each tape, and the characters of the two key tapes are combined, by a method similar to that shown in Fig. 9, with those of the message tape to form the cipher message.

The result is the same as though the two key tapes were first combined to produce a long single non-repeating key, which was later combined with the message tape. This long, single key is not, strictly speaking, a purely random key throughout its length as it is made up of combinations of the two original and comparatively short key tapes. The characters in this key do not repeat in the same sequence at comparatively short regular intervals, however, as would be the case if only one key tape loop were used.

The number of characters in this equivalent single key is equal to the product of the number of characters in the two tape loops, and may easily exceed 600,000 before any part of the key begins to repeat. If proper care is taken to use the system so as to avoid giving information to the enemy regarding the lengths of the two key tape loops or their initial settings and to avoid the possibility of ever re-using any part of the resultant single key, this system is extremely difficult to break even by an expert cryptanalyst having a large number of messages and full knowledge of the construction of the machine and its method of operation.

Captain W. F. Friedman, Cryptanalyst of the Signal Corps, U. S. Army, has recently invented some modifications[5] of this system intended to eliminate the loss in secrecy that results from using the two more convenient comparatively short repeating key tapes instead of the single long non-repeating key tape. These modifications consist of changing at intervals the order of connection of the five contacts of one or more of the tape transmitters or of adding a third key tape and transmitter so arranged that the extra key tape does not step ahead in unison with the other two key tapes, but starts and stops at irregular intervals. Either of these methods, properly used, makes unauthorized decipherment practically impossible and, at the same time, does not unduly complicate the machine or its method of operation.

With the double key tape system, the handling of large volumes of traffic is greatly simplified. The tapes should be numbered so that the deciphering operator can set them at the correct starting point for each message, and rules should be adopted so that both key tapes will never be set twice at the same

5. See Patents 1,522,775 of Jan. 13, 1925 and 1,516,180 of Nov. 18, 1924.

starting point. Information regarding the proper settings for the key tapes for deciphering each message must be sent to the deciphering operator. These settings may be prearranged or they may be selected arbitrarily by the sending operator. In the latter case the numbers representing the key tape settings should be prefixed to the message. These "key indicators" should preferably be enciphered by running them through the machine together with a special key tape which is used only for this purpose.

Speed of Operation

This type of machine was operated by the Signal Corps over its private wire telegraph circuits. In service tests made by the United States Army, each outgoing message was checked by running it again through the machine to decipher and print it, and the deciphered copy was then compared with the original message, so that each message tape was run through

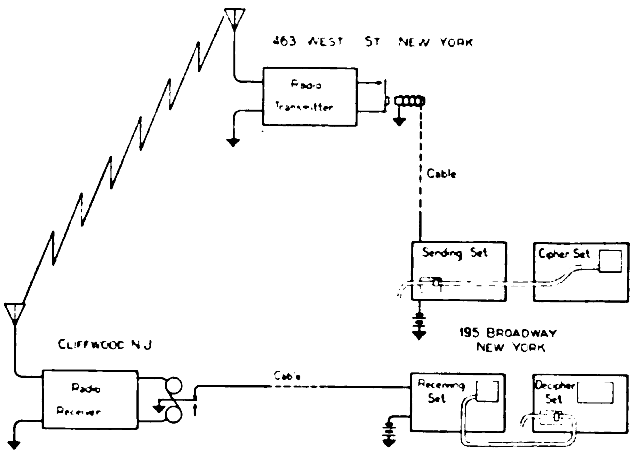

Fig. 11—Circuit for Radio Cipher Demonstrations

twice. A certain amount of time was lost, due to setting and resetting the key tapes, checking, etc., for each message, but an average enciphering speed of 10-15 words per minute was readily maintained. We understand this to be many times faster than those manual methods for enciphering or coding, which are used where a high degree of secrecy is required. Incoming messages were deciphered at the rate of 30-40 words per minute.

Operation by Radio

This cipher system was demonstrated before the delegates to the Preliminary International Communications Conference in October, 1920. During this demonstration, cipher messages were sent over a circuit containing a radio link, as illustrated in Fig. 11. The radio equipment was the same as that employed a year previous in tests on the operation of multiplex and start-stop printing telegraphs by radio and is described elsewhere.[6]

A considerable number of cipher messages was transmitted over this radio circuit during this demonstration, these messages being automatically enciphered before and deciphered after transmission, so that they they were absolutely secret, even though transmitted by radio. No interference from atmospherics or from other radio stations was noticed, all messages being received without error.

In conclusion, we wish to express our appreciation of the assistance given us by the officers of the Signal Corps and the General Staff, of the United States Army, in making tests and trials of cipher printing telegraph systems; and we wish particularly to acknowledge our indebtedness to Lt.-Col. J. O. Mauborgne, of the Signal Corps, for his advice in connection with this development and for his assistance in arranging to have tests made to determine its secrecy and demonstrations and service trials to determine its practicability for Army use. We also wish to express our appreciation of the services rendered by the Cipher Department of the Riverbank Laboratories, Geneva, Illinois, and by Col. George Fabyan, the head of these laboratories, in making tests of the secrecy of messages enciphered in various ways with these machines.

6. "Printing Telegraph by Radio" by R. A. Heising, *Journal* of the Franklin Institute, January 1922, pp. 97-101.

DIELECTRIC PHENOMENA

An important contribution to the study of dielectric phenomena in electric cables was made by Capt. P. Dunsheath in a recent I. E. E. paper. Developing a theory first propounded by Clerk Maxwell, the author showed how, without any hypotheses regarding the molecular structure of a dielectric, the familiar absorption effect can be explained by the lack of homogeneity of the dielectric. In such a dielectric the ratio of capacities of adjacent layers will not be identical with the inverse ratio of their resistances. The potential distribution due to the capacities will, then, differ from that due to the resistances. The latter distribution being the one obtaining when the steady state is reached, compensating capacity currents have to flow into the various condensers to adjust their potentials to the required values. The circuit for these currents consists of capacity in series with a very high resistance; they will therefore follow an exponential law and persist for a considerable time. The charging current of a cable subjected to a steady potential consists, accordingly, of three parts, the initial rush giving a potential distribution corresponding to capacity, a steady leakage current, and a transient current which gives the final potential distribution. Developing this theory, Capt. Dunsheath gave a simple explanation of the well-known V curve connecting A. C. dielectric loss with temperature, based on the negative temperature coefficient of electrolytic conductors. Although the difference between the Maxwell and the molecular theories may be purely verbal, the advantage of the former cannot be questioned, as giving a clearer insight into the electrical properties of dielectrics, and marking an advance towards the more perfect knowledge which will enable dielectric phenomena to be subjected to exact calculations.—*World Power*, December, 1925.

Supervisory Systems for Electric Power Apparatus

BY CHESTER LICHTENBERG[1]

Member, A. I. E. E.

Synopsis.—A general survey and description of the various types of supervisory systems for control and indication of remotely located electrical apparatus is given in the paper, the author first of all comparing the better known remote-control system with the supervisory system in general practise today. Description is given of the selector, distributor, audible, code-visual, synchronous-relay-visual and the carrier-current systems, the principles and features of each being discussed. The subject of telemetering is also included, together with an expression of the author's ideas of future possibilities for each of the systems above enumerated.

INTRODUCTION

SUPERVISORY systems for the control and indication of remotely located electric power apparatus can best be introduced by comparing them with the better known and more widely applied remote control systems in general application today.

The usual remote control scheme employs at least one continuous individual metallic connection between each device to be controlled and the controlling switches or keys. Supervisory systems use no individual and one, two, three or more common metallic connections between the devices to be controlled and the controlling switches or keys for as many as fifty or sixty or even more devices. Remote control systems ordinarily use control currents of the order of magnitude of one to ten amperes. Supervisory systems usually use currents of the order of magnitude of three to ten milliamperes. Remote control systems require a definite and usually very short time interval to elapse between the closing of the control switch or key and the closing of the contacts at the remote point. Supervisory systems require an appreciable and variable time to elapse between the operation of the control switch or key and the closing of the contacts at the remote point. Remote control schemes are usually designed into the electrical operating sequence of the power apparatus. Supervisory systems are invariably superimposed upon the usual sequence. Briefly, supervisory systems provide improved means for the supervision of electric power transmission and distribution.

HISTORY

Supervisory systems were developed to meet the requirements of the railway and central station industries as these expanded. The grouping of generating stations under the direction of a centrally located load dispatcher made it desirable that the dispatcher have prompt and accurate information concerning the electric power system. The widespread application of automatic switching to railway substations made it important that the power director have immediate and correct information in regard to his substations at all times.

One of the first supervisory systems was installed between the Sherman Creek Station of the United Electric Light & Power Co. at 201st Street and Broadway, New York City, and the load dispatcher's office of the New York Edison Co. at 38th Street and First Avenue, New York City in 1915. It used a form of step-by-step selector relay developed about that time for automatic telephone application. It gave indication at the dispatcher's office of the open and closed position of about one hundred oil circuit breakers using a total of six wires between the generating station and the load dispatcher's office.

The next step was made when the Receiver of the Des Moines City Railway expressed a desire for some means of isolating his automatic railway substations in case of an emergency such as a fire or an accident. This demand was met by the development of the selector supervisory system and followed promptly by the development of the distributor supervisory system. Next in order came the code visual, the audible, the synchronous relay and lastly the carrier current supervisory system. Beside these, developed and standardized by the manufacturing companies in this country, there has been a number of systems developed by the employees of many corporations not only in the railway field but also in the central station and industrial fields. These, however, have usually been limited to a definite field of application and have not been extended to become a commercial article of trade.

SELECTOR

The selector system was the first one developed for commercial application which is still on the market. It uses the essential elements of the telephone train dispatching call system modified for the control and indication of remote electric power apparatus. An installation made in 1920 is still in active service.

A key, a selector, some indicating lamps, and three line wires form the essential elements. The key when turned and then released makes and breaks an electric circuit through two of the wires to which all of the selectors in the outlying stations are connected in multiple. The key in operating sends out a predetermined number of electric impulses spaced in a definite time sequence thus forming a code. The selectors are provided with contacts mounted so as to make an electric circuit when a ratcheted wheel moves a given number of steps. The code sent out by the key starts all of the selectors simultaneously.

1. Engineering Dept., General Electric Co., Schenectady, N. Y.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

Only that selector, however, which is arranged to respond to the code sent out by the key closes its contacts. The other selectors drop out successively as the code being sent fails to give their combination. Thus, there is usually one hand-operated key at the controlling station for each selector contact at the outlying station. For the return indication

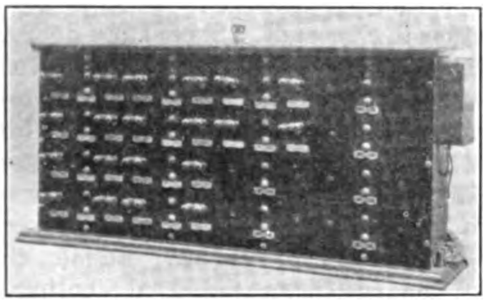

FIG. 1—LAMP AND KEY CASE FOR DISPATCHER'S OFFICE OF SELECTOR SUPERVISORY SYSTEM

there is provided at the outlying station a motor operated key for each group of four or less pairs of functions at that station to be indicated. Upon the operation of any supervised device in an outlying station, auxiliary contacts upon it start the motor key. This then sends back to the controlling station a code

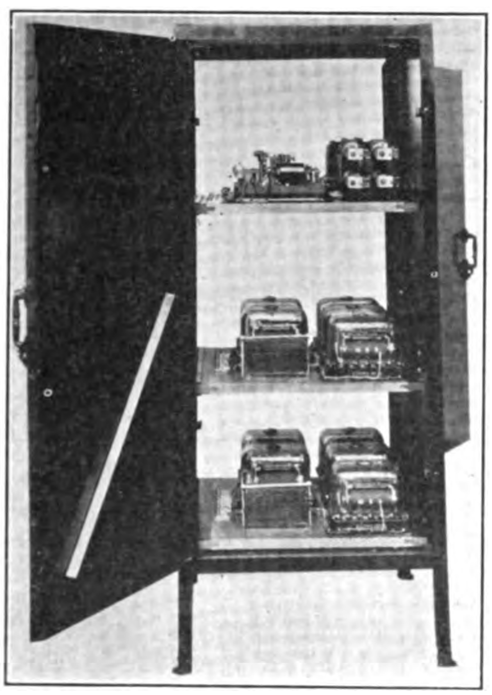

FIG. 2—SENDING APPARATUS IN CABINET OF SELECTOR SUPERVISORY SYSTEM

similar to that sent out from the controlling station to perform an operation. The selector located at the controlling station which is set to close its contacts upon the receipt of the code operates indicating lamps to show the position of the device supervised.

All of the outlying stations of a selector supervisory system are connected to one controlling station by three line wires. At each outlying station, the equipment is multipled to two of the wires as they pass by while the third wire loops into each station. The two wires as before mentioned are used for sending out the code for causing an operation to be performed and for transmitting back the code which results in giving an indication by lamps of the position of the equipment supervised. The third wire is used to lock out all the stations connected to the system excepting the one being controlled or the one sending in a code for causing an indication to be shown.

An arbitrary maximum of fifteen outlying stations may be connected by the usual selector systems to the controlling station. Each outlying station may have a maximum of eight devices to be supervised if there are as many as fifteen stations, or if there are fewer, each

FIG. 3—LAMP AND KEY UNIT FOR DISTRIBUTOR SUPERVISORY SYSTEM

outlying station may have a maximum of twelve or fifteen. The maximum number of devices, however, which can be most economically supervised by a single selector system depends largely on circumstances but under present conditions should never exceed fifty or sixty.

The selector system requires about nine seconds to send out each code, and complete an operation. Therefore, if ten outlying devices were to be operated it would take about one and two-thirds minutes to send out the code and operate these devices.

DISTRIBUTOR

The distributor system was the next type of supervisory system to be developed. It is an adaptation of the automatic printing telegraph in commercial use today on practically all the principal telegraph circuits. An installation of this type of supervisory system made in 1921 is still in active service.

A key, a distributor, a polarized relay, some indicating lamps, and four line wires form the elements. The key is usually a two-position one and is the equivalent of a double-throw switch. When turned to either

position it makes a circuit between a common wire and either the positive or negative side of a source of power and a segment on the distributor. The distributor consists essentially of three sets of coaxial segments insulated from each other. Each segment of one set is connected individually to its control key. Each segment of the second set is connected to the coil of a two-position polarized relay which is

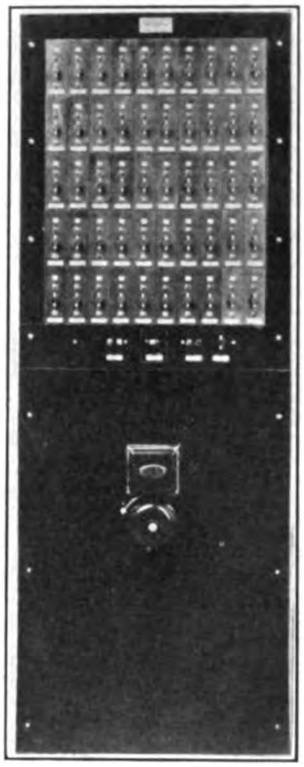

FIG. 4—PANEL CONTAINING LAMP AND KEY UNITS

For the control and indication of fifty circuit breaker equivalents in distributor supervisory system

associated with the appropriate indicating lamps. A set of segments midway between these two is used for synchronizing the distributor in the outlying station with the distributor in the dispatcher's office, synchronism being checked each five segments or ten times per revolution.

The distributors are each provided with three sets of brushes which rotate over the coaxial segments and make connections successively between each individual segment and a continuous segment in each set thus permitting a momentary electric circuit to be made through the distributor. The brush arms of each distributor are driven through a reduction gearing by a direct-current motor from a trickle-charged storage battery and are provided with a centrifugal governor for maintaining constant speed within quite narrow limits. The brush arm has a speed of about twelve rev. per. min.

At the controlling station are located the control key, indicating lamps, one distributor for each group of fifty or less devices to be supervised, and one relay for each device to be supervised, as well as suitable battery or other power equipment. At the outlying station are located a similar distributor for each group of fifty or less devices to be supervised in that station, one relay for each device to be supervised and the necessary battery or other power equipment.

The system operates continuously. This means that the positions of all devices which are supervised are automatically checked twelve times per minute or once each five seconds. Should any device change its position the change is indicated at the controlling station within five seconds of the time the operation has occurred. If several devices or the entire group connected to the system change position simultaneously, the lamps at the controlling station will give correct indication of the new position within five seconds of the time the change has occurred. Besides, the workability of the system is indicated continuously in much the same manner as the pulse indicates the general health of a human being.

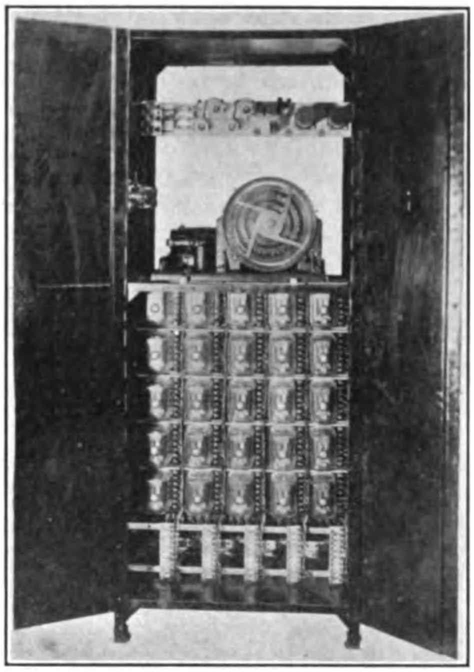

FIG. 5—RELAY AND DISTRIBUTOR CABINET

For control and indication of fifty circuit breaker equivalents in the distributor supervisory system

To open or close an oil circuit breaker or perform any similar function it is merely necessary to turn first one key and then a master key. This changes the polarity of a segment on the distributor at the controlling station and within five seconds momentarily energizes a corresponding segment on the distributor at the outlying station. This causes the position of the polarized relay connected to that segment at the outlying station to change in accordance with the impulse sent out from the controlling station and the operation desired is performed. Immediately the operation is completed auxiliary switches on the device supervised

change the polarity on an associated segment on the distributor at the outlying station. This, within a maximum time of five seconds, changes the polarity of a corresponding segment on the distributor at the controlling station which in turn changes the position of associated polarized relays located there. The relays then change the lamp combinations to indicate the new positions of the devices supervised at the outlying station.

Audible

The audible system is an adaptation of the automatic telephone being applied in many large and small telephone systems today. Its essential elements are a dial, a telephone line, telephone lamps, selectors and a

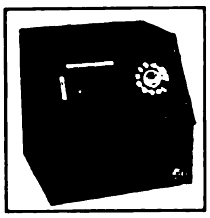

Fig. 6—Dispatcher's Sending Station for Westinghouse Audible Supervisory System

receiver or loud speaker. Operation is secured by dialing as in calling a number by an automatic telephone. The first dialing selects the station to be supervised, it being possible to connect as many as six to a single controlling station by a single pair of tele-

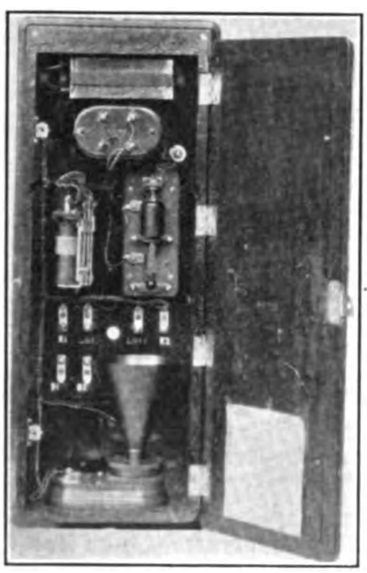

Fig. 7—Dispatcher's Sending Cabinet for G. E. Audible System

phone lines. The stations not selected are locked out by the operation of suitable devices in their equipment.

The station selected sets up a series of impulses indicated at the controlling station by a series of tones in code through a receiver or loud speaker located at that point.

The next dialing causes the desired operation to occur in the outlying station by setting up a suitable path in a relay combination finally closing the contacts of an operating relay. When the operation directed has been performed, auxiliary contacts on the device actuate other relays which in turn set up impulses indicated at the control station by a series of tones in code as before.

Code Visual

The code visual system is similar in principle to the selector system but differs quite markedly in its detailed design. It consists essentially of a key, with

Fig. 8—Lamp and Key Unit
For code visual supervisory system

its associated lamps, groups of relays at the controlling station and similar groups at the outlying station. It uses two common wires between the control station and all of the outlying stations and in addition one

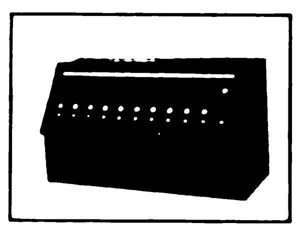

Fig. 9—Dispatcher's Lamp and Key Cabinet
For code visual supervisory system

individual wire from the controlling station to each outlying station. Thus, if there were three outlying stations, there would be five wires starting from the controlling station and running to the first outlying station, four running to the second outlying station and three to the third outlying station.

An operation is performed by moving a three-position key to either of the two extreme positions. This com-

pletes an electric circuit which causes groups of relays at the control station to send out a code of successive impulses. These impulses select suitably coded groups of relays at the outlying station. If the code is not received correctly at the outlying station, the controlling station then again starts the code out and continues to send it at intervals until correct code is received at the outlying station. If the code, however, is repeated correctly at the outlying station, then an

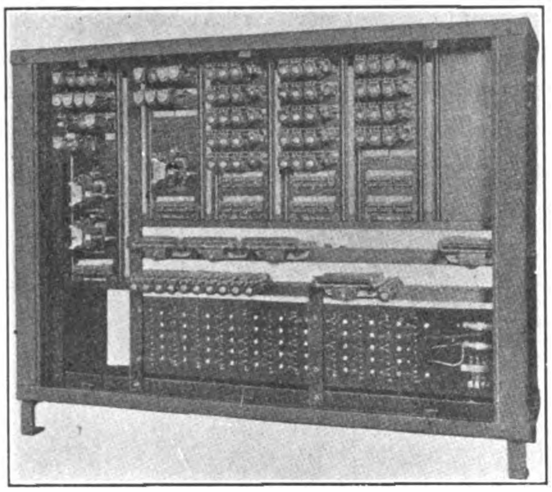

Fig. 10—Relay Equipment in Dispatcher's Office
For code visual supervisory system

impulse is sent out from the controlling station which causes the operation desired to be completed.

When the operation of a supervised device has occurred an auxiliary switch connected to it causes a code to start from the outlying station. This is formed and transmitted to the control station in the same fashion as is the operating sequence from the controlling station. When the correct code is checked the lamp signals at the controlling station are changed to indicate the new position of the supervised device.

This system operates devices successively and it requires about nine seconds per device to cause a series of operations. If, therefore, ten devices were to be operated it would take about ninety seconds to operate the devices.

Synchronous Relay Visual

The synchronous relay visual supervisory system is an all relay system which uses the principle of step-by-step synchronous selection. It consists essentially of a two position key with its associated lamps, a start key and relays in the controlling station, four wires between the controlling station and the outlying station, and relays in the outlying station.

When an operation is to be performed, the two-position key is turned from the position it occupies to the other position and the start key is pushed. This immediately causes a simultaneous operation of relays in the control station and the outlying station until the point is reached in the sequence in the outlying station corresponding to the position of the key in the controlling station. Operating current then passes through the signaling circuit from the control station to the outlying station and causes the desired operation to be performed. When the device supervised has had its position changed, auxiliary contacts on it transmit a return signal in a similar fashion to the controlling station causing the lamps located there to change in accordance with the changed position of the apparatus in the outlying station.

Two of the four wires between the control station and the outlying station are used for keeping the signaling relays at the two stations in step as they are moved from point to point in a definite sequence. The other two wires are switched by the operation of these relays from one device to another as occasion demands to cause operation or indication of that device.

Carrier Current

Carrier current has been developed for use with the selector and code visual systems. Both systems use codes of impulses for causing an operation to be performed and for causing an indication of that operation to be registered. The carrier current equipment consists of the necessary tubes, reactors, condensers

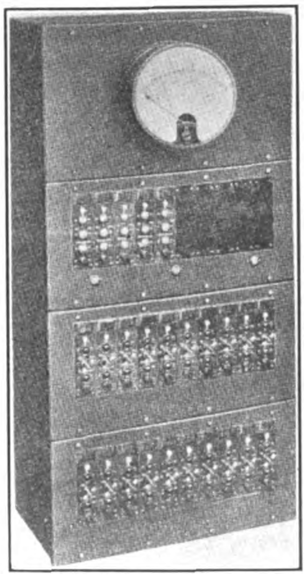

Fig. 11—Cabinet Containing Lamp and Key Units and Ammeter
For the control and indication of three circuit breaker-equivalents by the synchronous relay supervisory system

and resistors for generating high frequency at the controlling and outlying stations.

In general, the code is transformed from pulsating alternate polarity impulses to high frequency impulses and is transmitted over one line and ground or a pair of lines which may at the same time be used for communication or power transmission purposes. The carrier current equipment is connected to the transmission circuit by a condenser or other suitable coupling.

Carrier current for use with supervisory systems takes the place of the special line wires required where direct-current impulses are employed. It permits the use of practically the same equipment, so far as the controlling station and outlying stations are concerned as is used for direct-current. The only difference is that where direct-current is employed, special line wires are required, while where carrier current is employed, any existing wires can usually be used.

Wireless

Wireless has been considered for use with supervisory systems but to date no commercial development or application is known by the writer. The art seems not yet to have developed sufficiently.

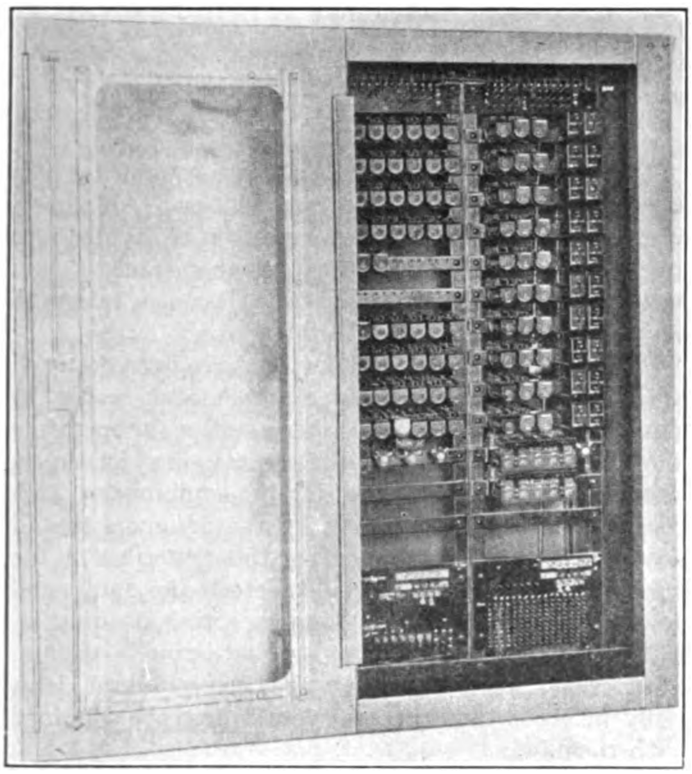

Fig. 12—Relay Cabinet for Dispatcher's Office—Synchronous Relay Supervisory System

Control Station

The control station equipments provided for the various types of supervisory systems which have been described vary one from another.

The selector system uses two keys, one to perform a closing or similar operation, the other to perform an opening or opposite operation. The key is quite similar to that used in the call stations of the Western Union Telegraph Company. The key is turned but nothing happens in the external circuit until it is released. The turning of it winds up a helical spring. As soon as the key is released the helical spring rotates it in the reverse direction under the control of a fly ball governor in order to obtain practically constant speed. In rotating back to its original position it opens and closes contacts in a definite sequence. If these contacts are suitably connected in an electric circuit they thereupon form a code of successive impulses.

As before stated two keys are required for each pair of functions. Associated with these two keys are two telephone lamps, capped with suitable lenses. These indicate the open or closed position of the device supervised. In place of indicating the position of a device if it is desired to indicate the position of water level or the position of a gate then the lamps only are used and as many of them are employed as positions to be indicated are desired.

The distributor system uses a combination of three telephone lamps and one two-position key to obtain control and indication. The two position key performs the same connections as a single pole double throw switch having no mid position. Associated with it are three telephone lamps. One is capped with a red lens, one with a green lens and one with a white lens. The red and green capped lamps indicate the closed and open position of the device supervised or any other indication usually desired. The white capped lamp is lit only during the time that a function has been called for and is put out immediately after that function has been completed and a return indication showing the completion of this function recorded at the controlling station. It is also lit should a device supervised at the outlying station automatically change its position, in which case it remains lit until the key in the controlling station is turned to acknowledge the operation at the outlying station. For each group of fifty two-position keys with their associated lamps there is one master key. The master key is turned after the two-position keys have been placed in the positions corresponding to the one which it is desired that the outlying supervised devices take.

The audible supervisory system employs a dial similar to that used for automatic telephones. In one commercial scheme, this dial is identical with that used for automatic telephones; in another commercial scheme this dial is similar but has had its speed altered to make it correspond to that of the selectors used. No lamps are used with the audible system, the operator depending upon hearing certain code tones in a receiver or loud speaker for indications.

The code visual supervisory system uses a three-position key associated with three telephone lamps capped by red, green and white lenses in much the same fashion as does the two-position key with its associated lamps in the distributor system.

The synchronous visual supervisory system employs a dispatcher's equipment consisting of a two-position key, a locking-type push button and three-telephone lamps capped by red, green and white lenses. The two-position key is to fix the operation while the push button is to stop the synchronous relay control equipment at any point.

Various methods have been employed for mounting the controlling lamps and keys. They may be placed on vertical panel boards, set into desk tops or even placed in a system diagram. The mounting best suited for any particular application depends to a large measure upon the individual requirements.

Application

The application of supervisory systems to any existing or new electric power transmission or distribution systems requires careful study in order that a maximum benefit may be derived. It is necessary to know intimately the method of operating the network of lines, feeders, and machines as well as the electric power traffic requirements. For congested districts where an emergency may at times require the rapid re-establishment of service, the speed of operation of a supervisory system is quite essential. On interurban railway projects, however, where automatic substations are located at intervals along a narrow strip of territory and where there are only three or four devices or functions to be supervised in each station, speed is not as important as line maintenance so another type of supervisory system is usually chosen. In some cases, the revenue derived from a station warrants only the most inexpensive supervisory system. Hence, here would be a place for the so-called audible type where the operator checks manually and at intervals determines by sound the condition of the equipment in the outlying station. Again, on a high-tension transmission system where distances often exceed one hundred miles the carrier current supervisory system is the best choice.

In applying supervisory systems it must be clearly borne in mind at all times that they are quite different in their performance as contrasted with the usual types of remote control systems. Each has its limitations. Remote control systems are in general limited to distances of several miles while the supervisory systems may be used for distances up to several hundred miles. Supervisory systems require an appreciable time interval averaging about five seconds for the completion of an operation through their medium while remote control systems operate practically instantaneously. So in applying supervisory systems, care must be exercised to take into account all of the electric power system characteristics as well as the limitations of the supervisory system.

Installation

The correct installation of a supervisory system is quite as important as its selection if the best results are to be obtained. Supervisory systems use currents of telephonic magnitude while remote control systems use currents of power magnitude. Hence, insulation and current leakage require very careful attention for the successful installation of a supervisory system, telephone practise being the standard toward which the installation of these systems must tend. The steam railroads have recognized these requirements when installing the selector type telephone train dispatching call system. More and more of them are going to the higher grade lead-covered paper-insulation telephone cable for their train dispatching circuits. The same cable and the same type of insulation are generally recommended as best practice for supervisory system installations.

Checking

Supervisory systems from a checking standpoint may be classified into two groups. One group requires checking at intervals, the other group is automatically checked at intervals.

All systems excepting the distributor system require manual checking at intervals. The distributor system has a distinct advantage in that it automatically checks the position of all of the devices connected to it at frequent intervals besides indicating its readiness to serve continuously.

Maintenance

The maintenance of a supervisory system depends upon its initial design and installation. All supervisory systems may for this comparison be divided into two classes. One class uses telephone relays and auxiliaries throughout. The other class uses telegraph relays and similar devices throughout.

The telephone relays and devices have been designed with the fundamental idea that someone would be present not only at the subscriber's station for operating the equipment but also at the central office for supervising and constantly inspecting the equipment. This results in a tacit assumption by the designers that if anything should go wrong either the subscriber or the wire chief or operator would detect the fault and correct it, no harm being done excepting possibly an interruption of service from one subscriber's station. Such relays particularly require inspection at least daily in order that the best results may be obtained with them.

The systems using telegraph devices may be typified by the selector system. Here the devices are large and substantial and so designed as not to require attention for years at a time. To be sure, there is quite a difference in the cost of the individual devices since the telegraph devices are made in very much less quantity than are the telephone devices. Contrasted, however, one with the other is the fact that the telephone type of devices require more maintenance and adjustment than do the telegraph devices.

Protection

Supervisory systems operating over special wires require protection particularly where these wires are subjected to lightning, inductive and similar high voltage disturbances. In general, isolating transformers or drainage coils cannot be used because these transformers would interrupt the flow of signals and the drainage coils would drain off the signal current. So

far as is known the best type of protection is for the conductors to be placed in cables. For this purpose paper-insulated lead-covered cable having an insulation which will withstand 1000 volts between conductors and 3500 volts between conductors and lead sheath is usually recommended.

The question of protection is an active one at the present time and many of the operating companies as well as the manufacturers would be interested to hear what other operators are doing to maintain their supervisory systems with a maximum of protection and a minimum of interruption.

TELEMETERING

A discussion of supervisory systems would not be complete without brief mention being made of telemetering. Telemetering furnishes the concluding link in the development of the art of supervising remotely located power apparatus.

Telemeters have been developed for transmitting the readings of ammeters, voltmeters, watthour meters, wattmeters and power factor meters over telephone lines the same distance as supervisory systems can be operated. They use practically the same type of relays at the originating and receiving ends of the telephone lines and in certain designs it has been found possible to combine the telemetering and supervisory functions on the same wires. In one particular installation recently made, two incoming lines, two synchronous converters and nine feeders were controlled and indicated and the readings of two watthour meters transmitted back to the controlling station, all over two pair of telephone lines between the controlling station and the outlying station. This is not a limiting number of things which could be done over these four wires but represents only about one-third of the functions and readings which could have been obtained if desired.

FUTURE

Supervisory and telemetering systems are just about being recognized by the engineering public. They are relatively new although a number of installations are now in operation. Nevertheless, it is believed that only an initial advantage has been taken of them and that they are not yet as thoroughly a part of electric power transmission and distribution engineering as are transformers, turbines, and the more commonly accepted pieces of electrical apparatus.

It is my firm belief that supervisory and telemetering systems in combination with automatic stations represent as distinct an advance in the electric art as has the development of the automobile in the transportation problem. It is also believed that a very great change will be effected in electrical engineering practise during the next ten years as a result of the economic application of supervisory and telemetering systems.

FLUX IN A CIRCULAR CIRCUIT

By CARL HERING

Fellow, A. I. E. E.

The flux density, H, at the center of a circular circuit of one turn is known accurately to be $2\,\pi\,i/r$; in fact, it has been made the quantitative connecting link between current and magnetism and the basis of the ampere. But the H in any other part of the circle is very difficult to calculate as it involves elliptical integrals, and to integrate these for getting the total flux is almost hopelessly complicated and then at best only approximate.

The density at any point outside of a single, straight, conductor (one far removed from its return) is definitely known to be $H = 2\,i/r$, and the total flux around any length l and radius a, up to any radial distance r, is also known definitely to be $F = 2\,l\,i \log_e\,(r/a)$. This, however, does not include the flux inside of the wire.

By calculating the total flux in a circular circuit indirectly from Kirchhoff's well-known, though only approximate, formula for self-inductance, $L = 2\,l\,(\log_e\,(l/a) - 1.508)$ in which a is the radius of the wire, and l the length, the author found, over extremely wide ranges of the radius r (a being constant),

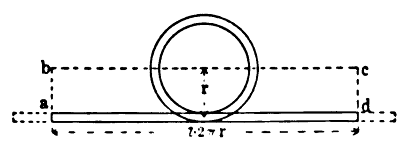

FIG. 1

the interesting result that the total flux in a circle of radius, r, seems to be equal to that around a length, l, of single, straight, conductor of equal length (that is, equal to the circumference of the circle) and up to a distance r from the axis, that is, to that in the rectangle $a\,b\,c\,d$.

There is a small, though constant, difference (always greater for the circle) due undoubtedly to the flux inside of the wire, which is included in the formula for the circle but not in that for the single conductor; these lines have only a fractional effect in the induction. The agreement is of the kind that strongly indicates that this equality would probably be found to be theoretically exact for the same size of wire if the theoretically definite value of the flux in a circle could be found; when a result is indicated or known, a proof is sometimes more easily found. Such being the case, the total flux in a circle could be expressed by a simple, theoretically exact, definite formula, independent of the self-inductance, and the latter checked by it, so far as quantity of flux is concerned.

Had our forefathers, in formulating our units, adopted as their fundamental the single conductor instead of the circle, the factor π would have dropped from some of the present fundamental relations.

The Ratings of Electrical Machines As Affected by Altitude

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Fellow, A. I. E. E.

Synopsis.—*The paper contains equations applicable to machines cooled by forced air convection currents. It is to be hoped that the A. I. E. E. Standards Committee will find some helpful suggestions in the paper.*

Ignoring differences in ambient temperature, the effect of altitude may be considered from two standpoints:

(a) The change in temperature rise, the rating remaining the same; or (b) the change in rating, the temperature rise at a given altitude equaling that at sea-level. The applications of both are considered, and equations are solved in both ways. The difference in ambient temperature at sea-level and at altitude is also taken into consideration in other equations.

The present A. I. E. E. rule is known to be faulty, applies only on the basis of temperature change, and starts at 1000 meters. These and other objections are believed to be met in this paper.

Several of the equations are plotted in families of curves, which should be of assistance to the reader. By assuming other values for some of the factors, other similar curves can be drawn.

In Appendix I, the derivations of equations are given. Appendixes II and III cover discussions of two of the factors used in the equations. In Appendix IV, some cases other than a slotted core are discussed.

A number of assumptions were made in the derivations of the equations: (1) The temperature coefficient of resistance was neglected. (2) The heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level. The equations are intended to apply to a slotted core, although they may be used for other parts of an electrical machine. Some examples are given in Appendix IV.

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It has long been known that the density of a gaseous cooling medium influences the rate at which heat is dissipated from a heated surface, and at the February 1913 Convention of the American Institute of Electrical Engineers an attempt was made to correlate the temperature rise of an electrical machine with the barometric pressure. The revised A. I. E. E. standardization rules of December 1914 contained a statement for correcting temperature rise or rating to correspond to higher altitude, but the rule was intended only to be temporary, and it is now recognized as faulty. Several articles on this subject have recently appeared in the *Technical Press*[2] and in this article another method of attack is presented. It is to be hoped that the A. I. E. E. Standards Committee will find some helpful suggestions herein.

If the change in ambient temperature is ignored, it is evident that the effect of altitude may be considered from two standpoints: (a) The change in temperature rise, the rating remaining the same; or (b), the change in rating, the temperature rise at a given altitude equaling that at sea-level. Perhaps the most usual case, in which the purchaser of apparatus is interested, is how much less the temperature rise of the machine should be at sea-level than at a given altitude for the same load. The machine usually is tested near sea-level, and the customer wishes to know how much to decrease the test temperature rises to equal approximately those at the higher altitude. This is the most useful way for the correction to appear in the A. I. E. E. Standards. It is well, however, to include another method to cover the change in permissible output with altitude for operating recommendations. Equations in this form should also be of value to the designing engineer, as with their use he can tell how much the rating of a machine should be altered if transferred from sea-level to a higher altitude.

In the 1925 A. I. E. E. Standards, the rule reads: "For apparatus intended for service at altitudes greater than 1000 meters, it is provisionally agreed that the permissible temperature rises (to be included in contracts and checked by test at low altitude) shall be less than specified in these standards by one per cent of the specified rise for each 100 meters of altitude in excess of 1000 meters." The "Usual Service Conditions" are given as "(a) When and where the temperature of the cooling medium does not exceed 40 deg. cent. (b) Where the altitude does not exceed 1000 meters."

From the above it will be seen that in the existing A. I. E. E. rules:

(1) The correction for altitude is only on the basis of temperature change, not on a change in rating.

(2) The correction for altitude starts at 1000 meters, there being no correction for altitudes lower than that elevation.

(3) The correction for altitude is in very simple form, and as such cannot possibly bring in the various factors upon which such correction depends.

(4) The correction for altitude is empirical, and is based upon a limited amount of data; it is consequently liable to be considerably in error.

It is believed that these objections are met in this article. The derivation of the equations are given in Appendix I. The final equations may be put into various forms, according to what the point of interest is, what items are to be considered and what ones are to be ignored. They may be classified according to whether the solution is for temperature or for rating.

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2. Particularly the paper by Doherty and Carter: "Effect of Altitude on Temperature Rise," TRANS. A. I. E. E., 1924, p. 824.

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The solutions are applicable to forced convection conditions only. The equations are intended to apply chiefly to a slotted core, in which some of the losses are constant, and some are proportional to the square of the load. The factor k is the fraction of loss in the core that is proportional to the square of the load at sea-level rating. (Thus, in estimating k, the numerator is the embedded copper loss, and the denominator the embedded copper loss plus the core loss). For the more usual applications of the equations 1 and 2 below, k fortunately does not appear. The equations can be applied to other parts than the slotted core, such as field coils in synchronous alternators, but then, although $k = 1$ and the equations are therefore simplified, account must be taken of the rate at which the field current changes with the load, and that is beyond the scope of this paper. In Appendixes II and IV, k and cases other than a slotted core are briefly discussed.

The final equations are as follows: (The list of symbols follows the equations.)

(a) Solutions for temperatures:

I. Surface temperatures only considered.

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m \qquad (1)$$

II. Internal (copper) temperatures considered:

$$\frac{1}{b} = \frac{\theta_1}{\theta_2} = \frac{1}{a + (1-a)\left(\frac{B_1}{B_2}\right)^m} \qquad (2)$$

(b) Solution for Ratings.

I. Surface temperatures only considered.

1. Permissible temperature rise at a given altitude the same as at sea-level.

$$K = \sqrt{1 - \frac{1}{k}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]} \qquad (3)$$

2. Permissible temperature rise at a given altitude different from that at sea-level:

$$K = \sqrt{1 - \frac{1}{k}\left[1 - b\left(\frac{B_2}{B_1}\right)^m\right]} \qquad (4)$$

II. Surface drop and drop through insulation considered.

1. Permissible temperature rise at a given altitude the same as at sea-level.

$$K = \sqrt{\frac{1 - (1-k)(1-a)\left(\frac{B_1}{B_2}\right)^m}{a + k(1-a)\left(\frac{B_1}{B_2}\right)^m}} \qquad (5)$$

2. Permissible temperature rise at a given altitude different from that at sea-level:

$$K = \sqrt{\frac{b - (1-k)(1-a)\left(\frac{B_1}{B_2}\right)^m}{a + k(1-a)\left(\frac{B_1}{B_2}\right)^m}} \qquad (6)$$

In the above equations,

a = ratio of the thermal drop from the copper to the iron to the total temperature rise, at sea-level.

b = ratio of the total temperature rise at a given altitude to the total temperature rise, at sea-level.

B_1 = barometer reading at sea-level.

B_2 = barometer reading at a given altitude.

k = fraction of loss in the core that is proportional to the square of the load at sea-level rating.

K = fraction of sea-level rating that should apply at a given altitude.

m = exponent of barometric pressure ratio, and is the power to which that ratio should be raised to determine how much the surface temperature rise is altered by a change in density. Its value is between 0.75 and 1, and for most purposes 0.9 may be used.

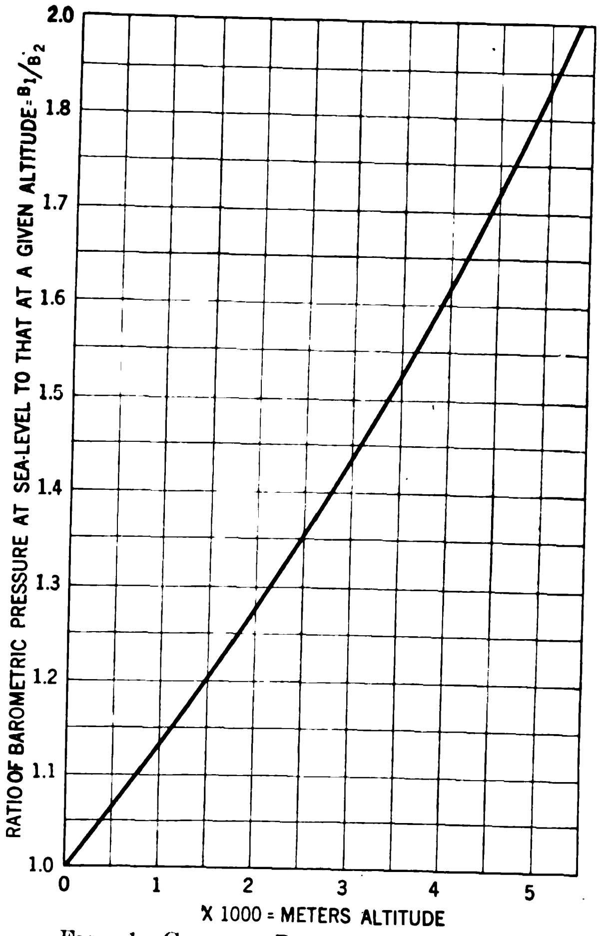

FIG. 1—CURVE OF BAROMETRIC PRESSURE

θ_1 = total temperature rise at sea-level.

θ_2 = total temperature rise at a given altitude.

θ_{s1} = temperature rise of the cooling surface above the ingoing air, at sea level.

θ_{s2} = same as θ_{s1}, but at a given altitude.

In Fig. 1 is plotted the ratio of the barometric pressure at sea-level to that at a given altitude. With these data, and that contained in equation (1), the curves in Fig. 2 have been plotted. They show what the ratio of the temperature rise at sea-level to that

at altitude should be, outside surface temperatures only being considered. They are plotted for three different

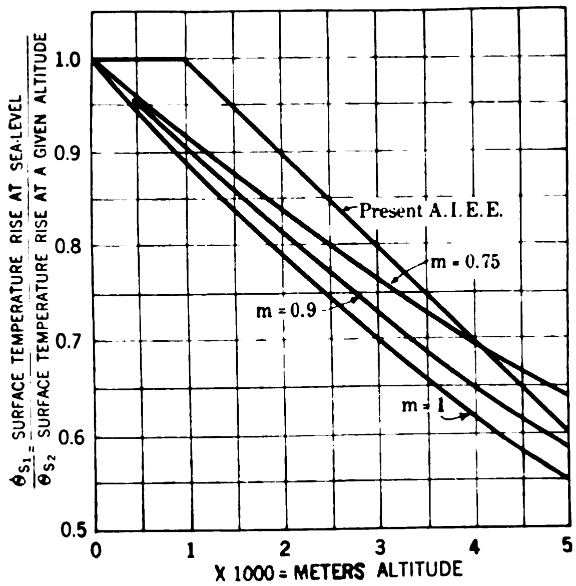

FIG. 2—RATIO OF SURFACE TEMPERATURE RISE AT SEA-LEVEL TO THAT AT A GIVEN ALTITUDE. "m" HAS A DIFFERENT VALUE FOR EACH CURVE

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m$$

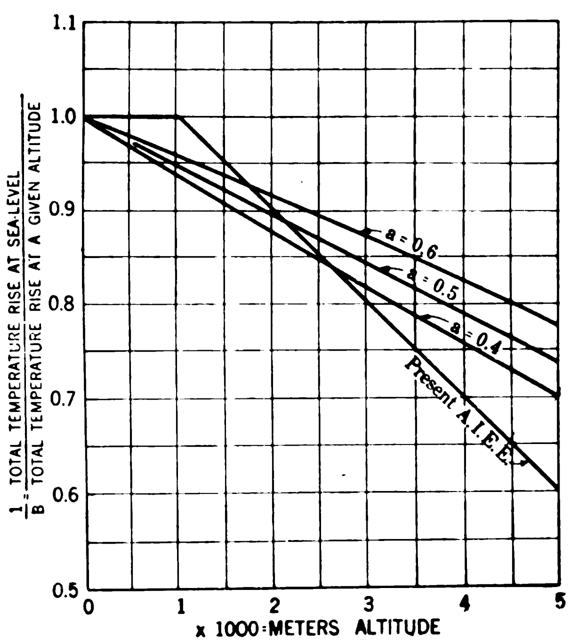

FIG. 3—RATIO OF INTERNAL TEMPERATURE RISE AT SEA-LEVEL TO THAT AT A GIVEN ALTITUDE. "a," THE RATIO OF DROP FROM COPPER TO IRON TO TOTAL TEMPERATURE RISE, HAS A DIFFERENT VALUE FOR EACH CURVE

$$\frac{1}{b} = \frac{\theta_1}{\theta_2} = \frac{1}{a + (1 - a)\left(\frac{B_1}{B_2}\right)^m}$$

m = 0.9 FOR ALL CURVES

values of m. The corresponding ratio, using the provisional A. I. E. E. rules, is also plotted. If the assumption is made that the probable most usual value of m is say 0.9, data from the curve corresponding to that value could conveniently be incorporated in the rules. Or, for m = 0.9, the data may be quite accurately represented by the equation

$$\frac{\theta_{s1}}{\theta_{s2}} = 1 - 0.09 \times \frac{\text{alt.}}{1000} \text{ up to about 4000 meters.}$$

In those machines in which temperatures are measured by embedded temperature detectors, equation (2) may be used. The plots for a = 0.4, 0.5, and 0.6 are given in Fig. 3 for m = 0.9. Those three

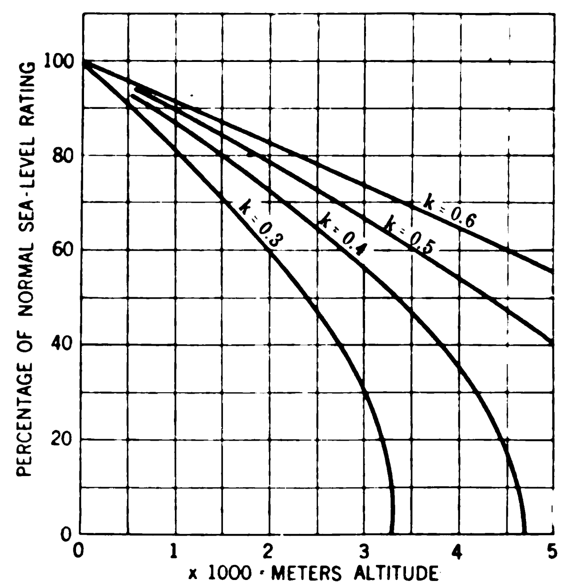

FIG. 4—RATINGS AS AFFECTED BY ALTITUDE. m = .9 FOR ALL CURVES, SURFACE TEMPERATURE ONLY CONSIDERED k, THE FRACTION OF LOSS IN THE CORE THAT IS PROPORTIONAL TO THE SQUARE OF THE LOAD AT SEA-LEVEL, HAS A DIFFERENT VALUE FOR EACH CURVE

$$K = \sqrt{1 - \frac{1}{K}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]}$$

curves are so nearly straight lines, that their approximate equations may be written as follows:

$$a = 0.4, \frac{1}{b} = 1 - 0.0604\left(\frac{\text{Alt.}}{1000}\right)$$

$$a = 0.5, \frac{1}{b} = 1 - 0.0526\left(\frac{\text{Alt.}}{1000}\right)$$

$$a = 0.6, \frac{1}{b} = 1 - 0.044\left(\frac{\text{Alt.}}{1000}\right)$$

Alt. = Altitude in meters.

The error for the high altitudes is not negligible, when the present A. I. E. E. rule is used. Thus, for a = 0.5, the temperature rise at sea-level is 0.6, instead of 0.785, of the rise at 5000 meters.

It will be noted that equations (1) and (2) do not contain k, the fraction of the loss in the core that is proportional to the square of the load. This follows

because the temperature of the external surface of, say an armature, is independent of the distribution of losses in the copper and iron. This is fortunate, as one less variable means simplification.

When the equations are solved for the rating ratio K, the term k is present. When so solved, the simplest solution, equation (3), applies when surface temperatures only are considered, and when the permissible temperature rise at a given altitude is the same at

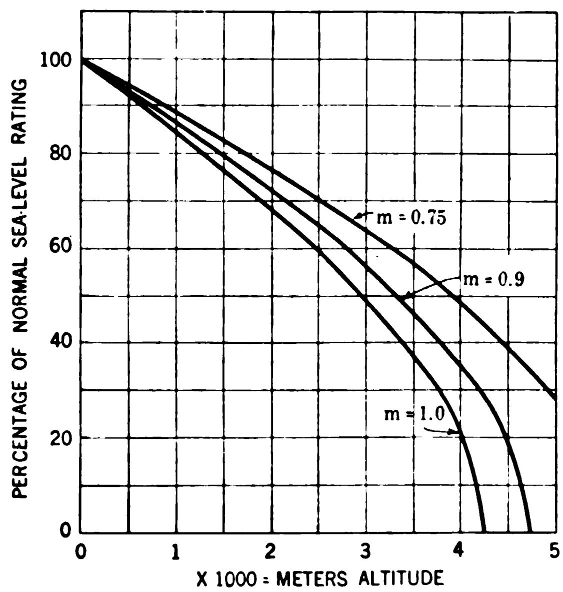

FIG. 5—RATINGS AS AFFECTED BY ALTITUDES. SURFACE TEMPERATURE ONLY CONSIDERED. "m" HAS A DIFFERENT VALUE FOR EACH CURVE. $k = .4$ FOR ALL CURVES.

$$K = \sqrt{1 - \frac{1}{K}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]}$$

sea-level. Perhaps that is the form of "rating" equation that an engineer would use most frequently. The percentage of normal sea-level rating may then be read directly from a family of curves, such as are shown in Fig. 4. Those curves were calculated on the basis that the barometric pressure ratio = 0.9, and that the value of k, the fraction of total loss that, at sea-level, is proportional to the square of the load, is constant along any one curve. The value to assign to k is considered in Appendix II. If a fixed value is chosen for k, the equation may again be plotted in the form of a family of curves, the exponent m being fixed for each curve. The value of 0.4 has been chosen for k in the plot in Fig. 5. From data on various machines, it seems as though 0.4 is a fair average value. As stated elsewhere in this paper, a value of 0.9 for m is probably the one that may generally be adopted. It is, therefore, suggested that for machines on which surface temperatures only are measured, the data from either Fig. 4 or 5, for $m = 0.9$ or $k = 0.4$ be used.

If again, surface temperatures only are considered, and values be assured for m and k, a family of curves may be plotted with the use of equation (4). As shown in Fig. 6, $m = 0.9$ and $k = 0.4$. Equations (3) and (4) are the same except that in (3) the temperature rise is taken to be the same at altitude as at sea-level, for a given rating $\left(b = \frac{\theta_2}{\theta_1} = 1\right)$. The ratio b is constant along any curve in the family in Fig. 6. It will be seen that it is quite within the range of possibilities for a machine to be good for a higher rating at a higher altitude than at sea-level. For example, if the air temperature is 40 deg. at sea-level, and the rise is 40 deg., then at a certain location at 3000 meters altitude, where the air temperature is 20 deg., the permissible rise is $40 + 40 - 20 = 60$ deg. to secure the same total temperature. The rating may then be, from Fig. 6, 110.5 per cent of sea-level rating.

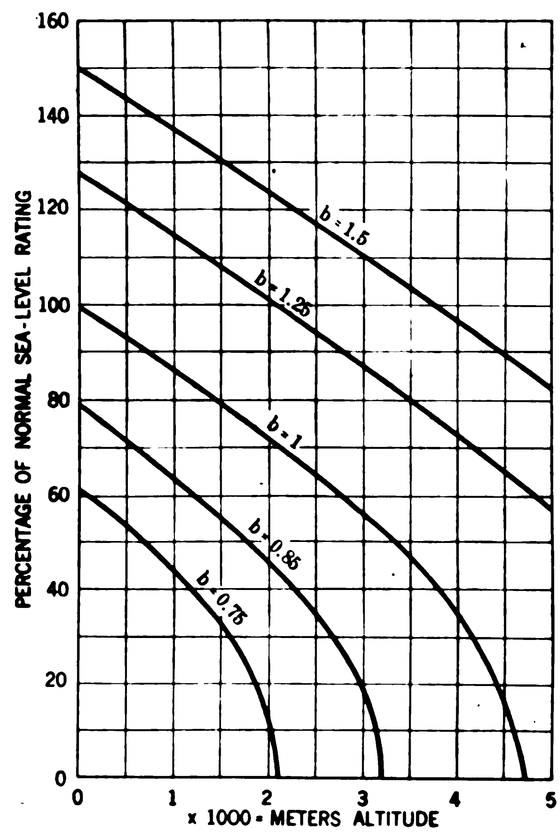

FIG. 6—RATINGS AS AFFECTED BY ALTITUDE. SURFACE TEMPERATURE ONLY CONSIDERED $m = 0.9$ AND $K = 0.4$ FOR ALL CURVES. B, THE RATIO OF THE TEMPERATURE RISE AT ALTITUDE TO THAT AT SEA-LEVEL, HAS A DIFFERENT VALUE FOR EACH CURVE.

Equations (5) and (6) are solved for the percentage of sea-level rating, account being taken of the drop through the insulation. Thus, the factor a is the ratio of the thermal drop from the copper to the iron to the total temperature rise, at sea-level. The assumption is made that the heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level. Evidently these two equations apply only when the temperatures are measured by embedded

temperature detectors. Equation (**5**) is the same as (**6**), except that in (**5**) the temperature rise at altitude is taken to be the same as at sea-level.

With the number of factors, as given in equations (**5**) and (**6**), it becomes more difficult to plot them in families of curves, and such curves are, therefore, not included in this paper. As those equations will probably be of value chiefly to the designer, and as it is necessary to evaluate such factors as k and a, with which frequently only the designer is familiar, he can readily substitute the numerical values in the equations and solve for K.

Appendix I

Derivation of Equations

For the usual case, the slotted core construction is of greatest interest. While that construction is the one chiefly considered, the equations are applicable to other parts. Some cases are considered in Appendix IV.

The derived equations take into account the relative values of $I^2 R$ loss, the percentage thermal drop through the insulating wall, and the comparative allowable temperature rises at altitudes and at sea-level. The equations are simplified if any of these are neglected. Furthermore, the equations can be readily applied if tests have been made at the factory where such items as the barometric pressure, ingoing air temperature, the temperature rise of the iron surface, and of the embedded copper have been measured, or whose approximate values may be assumed. The assumption is made that all heat is dissipated by forced convection currents of air, natural convention and radiation being of negligible influence. The equations, therefore, are not applicable to transformers, totally enclosed machinery, or other apparatus in which those two effects are predominant. The assumption is also made that in a slotted core the heat that flows transversely through the insulating wall is the same percentage of the heat generated in the copper at altitude as at sea-level.

Call L_1 the losses upon which the temperature in the member under consideration are dependent when operating at sea-level. (Usually embedded copper losses plus iron loss). Also k = fraction of loss L_1 that is proportional to square of the load, at sea-level. Then:

$$L_1 = k\,L_1 + (1 - k)\,L_1 \qquad (7)$$

Thus, $k\,L_1$ = variable losses that are proportional to the square of the load, and the remainder, $(1 - k)\,L_1$ = constant losses. At a given altitude, the constant losses are still $(1 - k)\,L_1$, and the variable losses are as at sea-level multiplied by the square of the ratio of ratings. If L_2 is the loss at altitude,

$$L_2 = k\,K^2\,L_1 + (1 - k)\,L_1 \qquad (8)$$

The difference between the surface temperature and that of the cooling medium adjacent to the surface is proportional to the losses, and inversely proportional to a fractional power of the density of the medium. The fractional exponent is probably between 0.75 and 1, and its value is further discussed in Appendix III. The cooling medium, air, is itself heated by the absorption of losses up to the particular surface, and that air temperature rise must be added to the thermal drop from the surface to the adjacent air. The air rise is inversely proportional to the density of the cooling medium. The temperature rise of the surface above the air entering the machine is then made up of two parts, one of which is inversely proportional to the first power of the density ratio and the other is inversely proportional to a power of that ratio whose value is between 0.75 and 1. In the general case, in which the temperature rise above the ingoing air is considered, the resultant exponent is probably not far from 0.9, but in these equations it is written as m. The equation coordinating losses and barometric pressures with surface temperature rise may then be written as:

$$\frac{\theta_{s2}}{\theta_{s1}} = \frac{L_2}{L_1}\left(\frac{B_1}{B_2}\right)^m \qquad (9)$$

Here θ_{s1} = temperature rise of cooling surface above the ingoing air, at sea-level. θ_{s2} = same as θ_{s1}, but at altitude. B_1 and B_2 are respectively the barometric pressure readings at sea-level and at altitude.

From equations (**7**), (**8**) and (**9**),

$$\frac{\theta_{s2}}{\theta_{s1}}\left(\frac{B_2}{B_1}\right)^m = \frac{L_2}{L_1} = k\,K^2 + (1 - k) \qquad (10)$$

Whence, for $\theta_{s2} = \theta_{s1}$,

$$K = \sqrt{1 - \frac{1}{k}\left[1 - \left(\frac{B_2}{B_1}\right)^m\right]} \qquad (11)$$

Equations (**11**) and (**3**), in the text are identical. Assuming that the load at sea-level and at altitude are the same, $K = 1$, and the equation may be written:

$$\frac{\theta_{s1}}{\theta_{s2}} = \left(\frac{B_2}{B_1}\right)^m \qquad (12)$$

This is the same as equation (**1**) in the text.

Consider next the transverse flow of heat through the insulation wall adjacent to the copper in the slot, the total temperature rise of the copper above the ingoing air θ_2 is the sum of the drop through the insulating wall θ_{i2} and the surface rise θ_{s2}. That is:

$$\theta_2 = \theta_{s2} + \theta_{i2} \qquad (13)$$

Similarly at sea-level, using subscripts 1 instead of 2,

$$\theta_1 = \theta_{s1} + \theta_{i1} \qquad (14)$$

The heat flows in part transversely through the insulation from the copper to the iron, and in part longitudinally and the relations are too complex to embody in these equations.[3] (In some cases the flow may be from the iron to the copper). It is believed, however, to be reasonable to assume that the percentage of the total heat generated in the copper that flows trans-

3. Those equations will be found in a paper by the author: "Longitudinal and Transverse Heat Flow in Slot Wound Armature Coils." Trans. A. I. E. E., 1921, p. 589.

versely is the same at a given altitude as at sea-level. The difference in temperature between the copper and the cooling surface may then be taken as proportional to the copper losses:

$$\frac{\theta_{i2}}{\theta_{i1}} = \frac{K^2\, k\, L_1}{k\, L_1} = K^2 \qquad (15)$$

Call a the ratio of the drop from the copper to the cooling surface to the total temperature rise at sea-level:

$$a = \frac{\theta_{i1}}{\theta_1} \qquad (16)$$

One other factor may enter, as the permissible temperature rise at a given altitude is frequently greater than at sea-level, due to the lower ambient temperature at the higher altitudes. The ratio of the permissible rise is:

$$b = \frac{\theta_2}{\theta_1} \qquad (17)$$

Equations (10), (13), (14), (15) and (16) may readily be combined, and the solution may be written as:

$$K = \sqrt{\frac{b - (1-k)\,(1-a)\left(\dfrac{B_1}{B_2}\right)^m}{a + k\,(1-a)\left(\dfrac{B_1}{B_2}\right)^m}} \qquad (18)$$

This is the same as equation (6) in the text. By taking the ambient temperature at sea-level to be the same as at altitude, $b = 1$, equation (5) is obtained. If in (18), a, the ratio of the drop from the copper to the iron to the total temperature rise at sea-level, be taken as zero, equation (4) is obtained. Then, again, if in equation (4), $b = 1$, equation (3) follows. Also, if in equation (18) the ratio of ratings at altitude and at sea-level be taken as unity, equation (2) is obtained. Equation (1) may be obtained from (2) by placing $a = 0$. Then the surface rises (θ_{s1} and θ_{s2}) are taken to be equal to the total rises θ_1 and θ_2.

Appendix II

Discussion of Values of k

The value of the fraction of the embedded loss that is proportional to the square of the load k is necessarily largely dependent upon the type of machine, upon the speed, upon the voltage, upon the choice of proportions by the designer, etc. A number of machines of three types were chosen at random, as given in the table.

SALIENT POLE ALTERNATORS

Rating at Sea Level

Kv-a.	Volts	Frequency	Rev. per min.	k
18750	12000	60	150	0.498
1250	13200	60	112	0.302
850	2200	60	100	0.730
12500	13200	60	720	0.370
10000	15000	50	600	0.590
				0.498 = Av. k

LARGE INDUCTION MOTORS

H. p.	Volts	Frequency	Syn. Rev. per min.	k
1200	2200	60	600	0.206
1200	6600	25	500	0.475
1400	2200	60	514	0.448
1500	6600	25	375	0.320
1200	2200	60	300	0.316
1500	2200	60	360	0.357
				0.353 = Av. k

D-C. GENERATORS AND MOTORS

Kw.	Volts	Rev. per min.	k
500	250	1200	0.216
1000	250	720	0.380
1500	250	514	0.420
300	250	150	0.407
600	250	100	0.450
1000	250	100	0.508
			0.397 = Av. k

Mean of the three values of k = .416

From Fig. 4 it will be seen that the value of k has considerable influence upon the rating. For the general average case, the value of 0.4 is probably not far wrong. The curves in Figs. 5 and 6 were plotted for that value. Inasmuch as the equations involving k are of principal value to the designer, he can readily determine the proper value to assign to it, and estimate the rating at the higher altitude by substituting in the proper equation. For short machines the longitudinal flow affects the distribution, and for such machines the value of k should be reduced.

Appendix III

Discussion of Values of m

The value to assign to m, the barometric pressure ratio exponent, could easily be made the subject of an entire paper. Only a brief outline of the subject and mention of several papers are given in this note. As stated in Appendix I, m is dependent upon two factors which are additive, (a) the rate at which heat is transferred from a heated surface to the moving fluid, and (b) the temperature increase of the cooling fluid from entrance to the machine up to the point under consideration. These two do not bear a fixed relation to each other; in one type of machine the relation may be quite different from another type. For example, in a d-c. armature, the temperature rise of the air up to the parts of the radial vents considered is probably quite small; on the other hand, in a high speed steam-turbine driven alternator the air rise is usually considerable before it reaches those parts of the vent ducts which are closest to the points where the temperatures are measured.

The volume of air per unit time which passes through a machine is independent of the barometric pressure. (This follows because the pressure generated by the fans, and the pressure drop through the various paths of the machine are both proportional to the density, and the generated and consumed pressures are equal to

each other). As the mass of air per unit of time is proportional to the density, the mass varies directly with the density or with the barometric pressure. As the temperature rise of the air is inversely as its mass, (assuming that the same heat is taken up by the air), the temperature rise is inversely as the barometric pressure.

In regard to the rate of transfer of heat from the surface to the cooling medium, there are a number of papers available. Perhaps the best work is that of Nusselt[4], and he found experimentally that the density ratio exponent is 0.786. Pohl[5] used that value in the derivation of equations applicable to machines using a closed circuit system of cooling. One of the most recent publications is that of Rice[6], who obtains his results largely theoretically, using the dimensional method, and in his final equations for heat transfer for the turbulent state of ideal gases, for smooth and for moderately rough surfaces, the exponent of density is given as unity. Rice's paper contains a large number of references, and any one interested can consult that paper. In the paper by Doherty and Carter[7], the exponent for forced convection was found to be 0.73, and to simplify calculations, they used 0.75. This value seems to be approximately correct for the machines for which they give data in their paper. As we understand their results, the exponent 0.75 takes account of the air rise as well as the surface transfer. It is felt, however, that their tests are too limited to warrant us to draw conclusions.

It is believed that, since the total drop is made up of two items which are additive, and since the exponent for one of them is probably not far from 0.80, and the other is unity, a mean of 0.9 may be chosen for the general case. It would be well to obtain further experimental checks. As may be seen from Figs. 2 and 5, if 0.9 be adopted, the error in temperature or in rating is not great for probable departures above or below this value.

Appendix IV

Cases Other Than A Slotted Core

The manner of treatment of a few cases other than a slotted core will be considered.

1. Commutators.

The losses are evidently the brush friction and $I^2 R$, the influence of windage loss upon temperature being negligible. The friction losses are evidently constant and the $I^2 R$ losses are proportional to the square of the load. Equations (**1**), (**3**) and (**4**) are applicable.

4. Nusselt. "Heat Transmission in Conduits," *Zsch. d. V. D. I.*, 1909, p. 1808.

5. Robert Pohl. "Fundamentals of Heating Calculations of Electric Machines, Especially Turbo Generators, Cooled by the Circular Process." *Arch. f. Elek.*, 1923, p. 361.

6. C. W. Rice. "Forced Convection of Heat in Gases and Liquids." *Industrial and Engineering Chemistry*, May, 1924, p. 460.

7. "Effect of Altitude on Temperature Rise." TRANS. A. I. E. E., 1924, p. 824.

2. Stationary Field Coils as in D. C. Machines.

A. Shunt Coils. If the field current may be assumed to be the same at all loads, and surface temperatures are to be measured, equations (**1**), (**3**) or (**4**) may be used; otherwise, if the temperature rise is measured by resistance, equations (**2**) (**5**) or (**6**) may be used, taking $k = 1$. If the field current changes with the load, the temperature equations (**1**) or (**2**) may still be used. Unless the change in current with load can be incorporated in a simple equation which can be combined with other elementary equations, the rating may be approximated by a cut-and-try method.

B. Series or interpole coils, or compensating windings. The current is proportional to the load, and the losses to the square of the load. If the surface temperatures only are to be measured, equations (**1**), (**3**) or (**4**) may be used, taking $k = 1$. If these windings are insulated and temperatures are measured by resistance, equations (**2**), (**5**) and (**6**) may be employed.

It is recognized that, due to change in armature losses with load, the temperature of the cooling air changes with the load. That introduces a complication, and furthermore, its influence is usually small, if consideration is given to the fact that at the higher altitude the rating and losses are reduced.

3. Revolving Field Alternator Field Coils.

A. Single layer edgewise winding. Temperatures measured by resistance. The temperature rise for a given load may be estimated by equation (**1**). The changed rating may be estimated by approximating the field current for various loads, and with the use of equation (**1**), calculate the temperature rise ratio. A curve may then be plotted coordinating temperatures with ratings.

B. Embedded windings, such as for turbo alternator rotors; or field coils for salient pole alternators with insulation. Temperature rise measured by resistance. Equation (**2**) may be used for temperature rise ratio. The changed rating may be estimated in the same manner as for single layer edgewise winding, except that equation (**2**) should be used instead of equation (**1**).

RAILWAY ELECTRIFICATION IN JAVA PLANNED

According to recent reports the electrification of the line Manggarai-Buitenzorg has been sanctioned by the Government. Plans for the project are now entirely completed, the execution of the work has already been commenced, and the necessary material will be ordered immediately. Barring unforeseen circumstances, it is expected, therefore, that the electrification of the entire line will be completed in two years. Furthermore, an amount of 100,000 guilders (the guilder now = $0.40) has been appropriated for preliminary work in connection with the electrification of the Poerwakarta-Bandoeng line, which will probably be the next to be electrified.

A New Wave-Shape Factor and Meter

BY L. A. DOGGETT, J. W. HEIM and M. W. WHITE*

Member, A. I. E. E. Non-Members

***Synopsis.**—A star-connected circuit consisting of two voltmeters and one variable condenser has certain properties upon which a wave-shape factor may be based. When the voltmeter resistances are equal to each other and equal to the condenser reactance, the ratio of the voltmeter readings will always be $(2 + \sqrt{3})$ for an alternator producing sine waves and always less than $(2 + \sqrt{3})$ for all other wave shapes. From any measured ratio of voltmeter readings, the purity of the voltage wave may be determined; furthermore, the maximum possible percentage of any single harmonic present in the wave can be immediately obtained (See Table III). For the experimental application of this method a wave shape meter is proposed for practical application which consists essentially of two voltmeters and a variable condenser. Such a meter has advantages over the method of analysis based on oscillograms, namely: (1) cost, (2) portability, (3) ease of experimental procedure and (4) rapidity of arriving at results. This method of attack is not intended to supplant the oscillograph but rather to supplement it. The method has been checked with the aid of a harmonic alternator and has been applied to the local power system and to various alternators available in the Electrical Engineering laboratories of the Pennsylvania State College.*

* * * * *

INTRODUCTION

FOR a long time the wave shape standard of the A. I. E. E. has been based on oscillograms. Recently† copies of seven oscillograms were sent to ten electrical manufacturing and power companies for measurement of deviation factor. The results obtained showed very considerable variations. For one oscillogram, the values found for this factor ran from 1 to 4.2 per cent, with an average value of 2.25 per cent. In other words, the maximum value was in excess of the average by 86½ per cent of the average value, while the spread between the maximum and minimum values was 3.2 or 142 per cent of the average value. For the other six curves the spread was less, but still considerable. The excess of the maximum values over the average values for each of the six other cases was 57 per cent, 54 per cent, 52 per cent, 47 per cent, 31 per cent, and 14 per cent. Quoting from the reference given, "The variations between results cannot be attributed to the processes of calculation employed, for neither the maximum nor the minimum spread occurred with the same party. The variations must, therefore, arise from difficulties inherent in the method such as, difficulty in evaluating exactly the ordinates of the oscillogram, errors in evaluating the area included by the squares of the ordinates in finding the effective value, errors in measuring the maximum differences between the ordinates of the oscillogram and the equivalent sine wave, especially when these differences occur in the steep part of the curve."

Another test was made to determine the accuracy attainable in the determination of the amplitudes of harmonics by analysis of oscillograms. Three waves were prepared by the synthesis of known harmonics and fundamental, the waves traced, and the results turned over to various parties to be analyzed. The results indicated that for harmonics below the 15th, average variations from the correct values of amplitudes of harmonics of ± 5 per cent might be expected.

The usual alternative to the use of the oscillograph is some sort of a circuit method of which many have been proposed but so far no one has been permanently adopted. Here still another circuit method is proposed, differing primarily from other circuit methods in that it is based on a three-phase circuit.

DESCRIPTION OF THE METHOD

Two voltmeters, V_2 and V_3 (Fig. 1) having equal resistances, and a variable condenser, C (whose range of reactance can be varied above and below the resistance of the voltmeters) are connected in star to the three-phase source whose wave shape is to be investigated. The value of C is adjusted until the ratio of the larger to the smaller voltmeter readings is maximum. That this ratio, R, is $(2 + \sqrt{3})$ for a pure sine wave is proved in the Appendix. The greater the deviation from a pure sine wave, the lower this ratio will become. It is the dependence of this ratio upon the harmonics present in the wave which makes it possible to use such a voltage ratio as a measure of the purity of the wave.

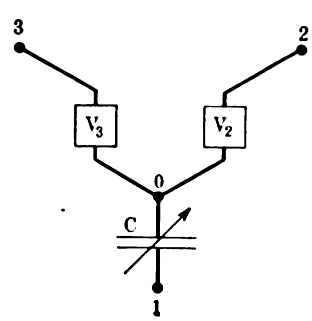

FIG. 1 A—A NEW WAVE-SHAPE FACTOR

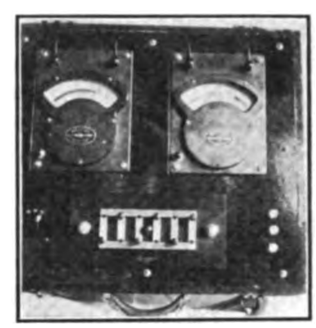

FIG. 1 B—WAVE-SHAPE FACTOR AND METER

The vector diagram of Fig. 2 gives an idea of the displacement of the neutral as the wave shape departs from a true sine wave.

By the use of the following formula, also proved in the

*All of Pennsylvania State College, State College, Pa.

†*Revue Generale de L'Electricite*, January 10, 1925, pp. 43-46.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

Appendix, the voltage ratio for any combination of harmonics may be calculated,

$$R = (2 + \sqrt{3}) \left[\frac{100 + a_2\,(\%\,H_2)^2 + a_3(\%\,H_3)^2 + \ .\ .\ .\ a_n(\%\,H_n)^2}{100 + b_2\,(\%\,H_2)^2 + b_3(\%\,H_3)^2 + \ .\ .\ .\ b_n(\%\,H_n)^2} \right]^{1/2} \qquad (1)$$

Where $\%\,H_2$ is the per cent second harmonic.
$\%\,H_3$ " " " " third "
$\%\,H_n$ " " " " n^{th} "

The a and b constants for the various harmonics are given in Table I.

TABLE I

Harmonic	a	b
2	0.0026	0.1967
4	0.0160	0.0939
5	0.0080	0.2230
7	0.0157	0.1330
8	0.0101	0.2165
10	0.0153	0.1500
11	0.0110	0.2106
13	0.0149	0.1590
14	0.0115	0.2066
16	0.0147	0.1640
17	0.0119	0.2036
19	0.0145	0.1680
20	0.0122	0.2014
22	0.0144	0.1710
23	0.0124	0.1993
25	0.0142	0.1730
∞	0.0134	0.1866

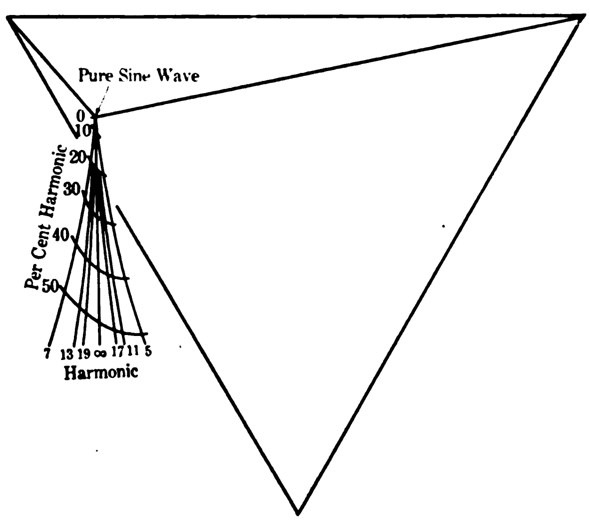

Fig. 2—Loci of Floating Neutral for Various Percentages of Harmonics. (Line Voltage Constant)

Since in the experimental application of this method, two voltmeters having equal resistances are required and as one meter must have a range approximately three times that of the other, some difficulty was experienced in selecting suitable meters from standard models, those of the dynamometer type being desired.

The meters first selected were a Weston instrument with a resistance of 301 ohms and a range of 30 volts, and a General Electric instrument having a resistance of 920 ohms and a range of 150 volts. Each voltmeter was equipped with a multiplier so as to arrange the resistance of V_2 in Fig. 1 equal to that of V_3. The voltmeters were then calibrated. Three one-μf mica and one eight-μf paper condenser were used. The capacities of these condensers were also checked.

The final arrangement, as shown in the photograph, Fig. 1, consists of two Weston dynamometer type voltmeters of 40- and 120-volts range respectively and of 1000.7- and 1000.0- ohms resistance respectively.

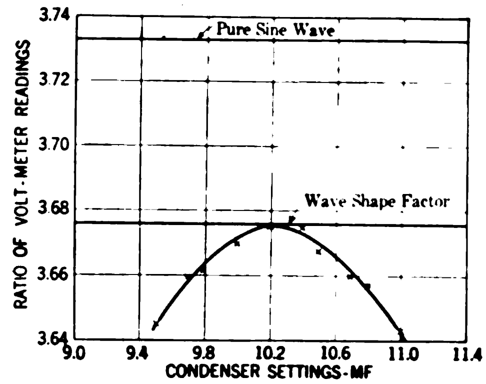

Fig. 3

Mounted in the same box are a one-μf. mica and two one-μf. paper condensers. The mica condenser is a Leeds and Northrup instrument, variable by steps of one twentieth μf. from 0 to one μf. The small switch in the lower left hand corner controls the paper condensers, giving zero, one, or two μf.

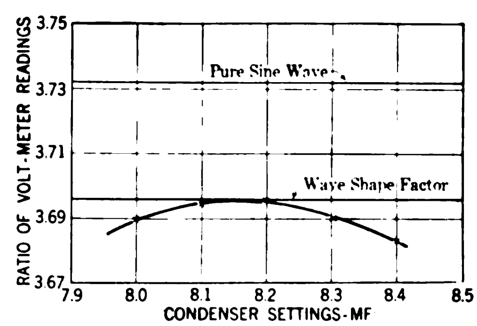

Fig. 4

Some Applications of the Method

With the apparatus as originally set up, tests were made on waves obtained from the Keystone Power Corporation System, from the Pennsylvania State College Power Plant (300 kv-a. turbo alternators), and various laboratory alternators. In the curves of Figs. 3 and 4 are plotted the data for two representative cases.

To obtain data for the curves of Fig. 5 the final arrangement shown in the photograph of Fig. 1 was used. If the following technique is employed, and if the frequency remains constant for about five minutes,

the results obtained are independent of voltage, capacity and magnitude of line frequency. The technique employed in obtaining the five dotted curves of Fig. 5 was to vary rapidly the capacity from 2.0 to

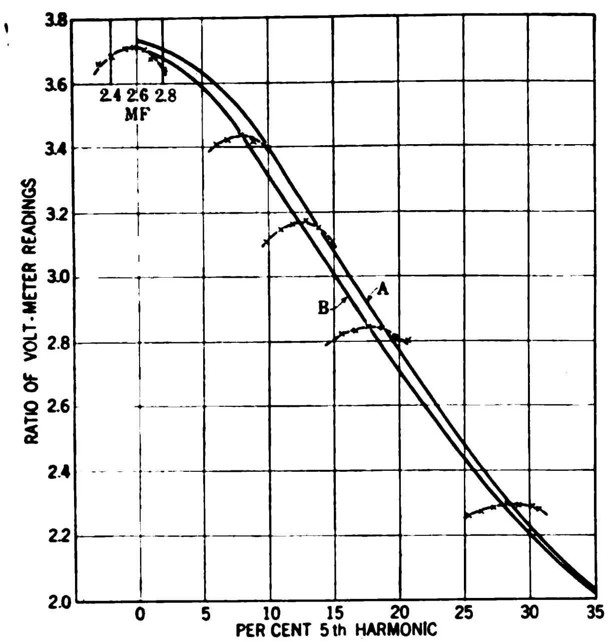

FIG. 5

three-phase supply was connected to the wave shape meter (Fig. 1). Ratio curves, such as shown in Fig. 5 were obtained for 0 per cent, 8.0 per cent, 12.8 per cent, 17.5 per cent, and 28.0 per cent fifth harmonics. Through the maximums of the five dotted curves is drawn a curve, *B*, which should check with curve *A*, the latter being calculated from formula (1). Discrepancies between curves *A* and *B* are chargeable to deviation from a pure sine wave on the part of the fundamental machine and to slight inequalities in the magnitudes of the three-phase voltages of the fifth harmonic machine. In searching for various factors to account for this discrepancy it was proved by test that the wave-shape factor is independent of the phase position of the harmonics.

CONCLUSIONS

1. *Value of Voltage Ratio to Be Met in Practise.* In addition to the values of wave shape factors given above for systems and dynamos tested in our laboratories, there is given in Table II, a compilation of wave-shape factors for some waves whose analyses into component harmonics have been found in the literature. It will be seen that wave-shape factors varying from 3.448 to 3.730 appear in practise. These factors were obtained by substituting the given percentage harmonics in formula (1).

TABLE II

Wave-Shape Factor	Per cent Harmonic									Reference
	3	5	7	9	11	13	15	17	19	
3.712	0	2	1.44							1
3.605	0	5.3	2.46	0	1.04	1.2				2
3.715	0	1.77	1.22	0	0.48	0	0	0.395	0.294	2
3.633	13¼	5	1.2	0.9						2
3.676	0	3.5	1.6							3
3.493	3.67	8.05	1.63	0.058						4
3.520	0.98	7.6								4
3.448	7	9								5
3.670	3	4								5
3.730	0.46	0.724								6
3.724	5.5	1.25	0.49	0.55	0.37					6
3.591	2.92	5.2	0.66	1.07	0.62	3.77	4.6	0.48		6
3.555	2.83	5.43	5.51	0.26	1.28	0.51	0.23	0.09		6
3.624	1.0	2.73	2.2	0.41	4.4	0.79	0.23	0.09		6

1. "Specification and Design of Dynamo-Electric Machinery," Miles Walker, p. 332.
2. TRANS. A. I. E. E., Vol. 32, 1913, p. 781.
3. TRANS. A. I. E. E.., Vol. 38, 1919, p. 1185.
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5. *Electrician*, Aug. 6, 1909.
6. Bureau of Standards, Vol. 9, 1913, p. 567.

3.0 μf. by 0.1 μf. steps, reading the two voltmeters at each step. The maximum ordinate of the plot of the ratio of these observations is the wave-shape factor.

CHECK OF OBSERVATIONS AGAINST CALCULATIONS

In order to check this method the following test was carried out. The fundamental and fifth harmonic members of a three-phase harmonic alternator were used. A description of this machine is given in the Appendix. The phases of the fundamental machine were star connected, and each phase joined in series with the proper coil of the fifth-harmonic machine. This

Oscillograms were obtained from 19 machines of Table I of the 1919 report of the A. I. E. E. Subcommittee on Wave Shape Standards[13]. Based on analyses of these waves, the following wave shape factors were calculated:

3.717, 3.706, 3.717, 3.719, 3.698, 3.723, 3.715, 3.724, 2.746, 3.700, 3.700, 3.696, 3.698, 3.702, 3.700, 3.708, 3.702, 3.553, 3.349; *i. e.*, a range of 3.724 to 2.746.

2. *Interpretation of Voltage Ratios.* As previously stated a ratio of voltmeter readings of $(2 + \sqrt{3})$ or

13. Osborne

3.732 corresponds to a pure sine wave. Consequently the purity of a voltage wave may be immediately determined by noting whether or not the observed voltage ratio is equal to 3.732.

In case the ratio is found to be less than $(2 + \sqrt{3})$ it follows that the wave is not a pure sine wave. We may assume the absence of third harmonics or any multiple thereof in the ordinary commercial three-phase circuits. Furthermore, no second or fourth harmonics will be found in the waves from commercial alternators.

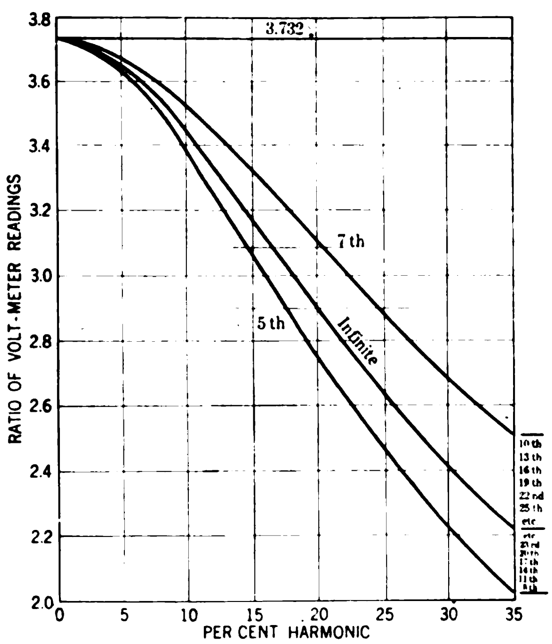

FIG. 6

The fifth and seventh harmonics are usually the most pronounced of all the harmonics, and Fig. 6 shows the ratio curves for these harmonics. If only a seventh harmonic is present, reference to Table III will immediately give the percentage harmonic corresponding to any observed voltage ratio.

TABLE III
7th Harmonic

Per cent Harmonic	Voltage Ratio
0	3.7320
1	3.7298
2	3.7232
3	3.7123
4	3.6974
5	3.6753
6	3.6530
7	3.6248
8	3.5999
9	3.5685
10	3.5298
11	3.4962
12	3.4572
13	3.4163
14	3.3742
15	3.3312

Reference to the curves of Fig. 6 shows that a given voltage ratio corresponds to a smaller percentage harmonic when this is a harmonic of an order other than the seventh. Consequently the *maximum* possible percentage of any single harmonic present may be immediately obtained from the observed voltage ratio by reference to Table III. For example, a voltage ratio of 3.33 corresponds to the presence of a 15 per cent seventh harmonic (From Table III) and inasmuch as this ratio corresponds to a smaller percentage of any single harmonic other than the seventh, it is quite conservative to state that in a circuit which gives an observed voltage ratio of 3.33, there is no single harmonic present which amounts to more than 15 per cent of the fundamental. In other words, this last deduction holds not only for the case where the seventh alone is present but also where there are other harmonics found in addition to the seventh.

In brief, it can be stated that this method is capable of giving at once from a single observation of voltage ratio, the maximum possible percentage of any harmonic present in a wave, when the experimental conditions have been properly adjusted as described above.

3. *Accuracy of Results.* The accuracy with which the data may be obtained is quite high. The method is independent of voltage, since only the ratio of the two phase voltages is required and this ratio is independent of the actual voltage used. The frequency need not be measured, provided means of checking its constancy are available; this can be conveniently done by any frequency meter. If good mica condensers are used the accuracy with which they are guaranteed by the manufacturers (say ¼ per cent) is more than sufficient for our purpose, since the actual value of the capacitance does not enter directly into the computations. Consequently, the main factor which limits the precision of the measurements is the accuracy of the calibration of the voltmeters and our ability to read the same. The probable error of the voltage ratio, including instrumental and observational errors, will not exceed 0.2 per cent.

Our experiments have indicated that the use of the iron-vane type of voltmeter is not very satisfactory for this purpose.

Appendix I

Proof that $\dfrac{V_2}{V_3} = R = 2 + \sqrt{3}$. for a pure sine wave: The following formula has been derived in a previous paper* for calculating the voltage to neutral for any branch of the star-connected circuit of Fig. 1.

$$I_p Z_p = E\left[a^{p-1} - \frac{a^0/Z_1 + a^1/Z_2 + \dots \dots a^{n-1}/Z_n}{1/Z_1 + 1/Z_2 + \dots \dots 1/Z_n}\right] \quad \text{(a)}$$

*Doggett. "Floating Neutral n-Phase Systems" TRANS. A. I. E. E., Vol. 42, 1923, p. 800.

where,
E is the numerical value of the impressed voltage to geometrical neutral.

$a = \cos 2\pi/\phi + j \sin 2\pi/\phi$ for counter clockwise rotation.

$a = \cos 2\pi/\phi - j \sin 2\pi/\phi$ for clockwise rotation.

ϕ = number of branches or phases.

Z_1 = impedance between 0 and 1 (see Fig. 1)

Z_2 = impedance between 0 and 2 (Fig. 1).

Z_n = impedance between 0 and n (Fig. 1).

p = 1, 2 or 3 for a three-phase system.

Assuming that the impedance of each meter is 1000 ohms resistance (inductance negligible†) and that of the condenser is also 1000 ohms (capacitive reactance), the reading of the voltmeter V_2 according to equation (**a**) is,

$$I_2 Z_2 = E\left[(-1/2 - j\sqrt{3}/2) - \frac{\dfrac{1}{-j\,1000} + \dfrac{-1/2 - j\sqrt{3}/2}{1000} + \dfrac{-1/2 + j\sqrt{3}/2}{1000}}{\dfrac{1}{-j\,1000} + \dfrac{1}{1000} + \dfrac{1}{1000}} \right]$$

$$= E\left[-1/2 - j\sqrt{3}/2 - \frac{j-1}{j+2} \right]$$

Rationalizing the last term, reducing and collecting,

$$I_2 Z_2 = \frac{E\,[-3 - j\,(6 + 5\sqrt{3}\,)\,]}{10} = V_2$$

Proceeding in a similar manner, the reading of V_3 is,

$$I_3 Z_3 = \frac{E\,[-3 - j\,(6 - 5\sqrt{3})\,]}{10} = V_3$$

Then the ratio R,

$$= \frac{V_2}{V_3} = \frac{-3 - j\,(6 + 5\sqrt{3})}{-3 - j\,(6 - 5\sqrt{3})}$$

Combining real and j terms of both numerator and denominator, and rationalizing,

$$R = 2 + \sqrt{3} = 3.732.$$

(Q. E. D.)

Appendix II

Proof of Equation (1). (General formula for calculating R for any number of harmonics of known percentage).

Notation.

E_1' = Fundamental component of voltage across V_2.

E_2' = 2^d harmonic component of voltage across V_2.

E_3' = 3^d harmonic component of voltage across V_2.

E_n' = n^{th} harmonic component of voltage across V_2.

E_1'' = Fundamental component of voltage across V_3.

E_2'' = 2^d harmonic component of voltage across V_3.

E_3'' = 3^d harmonic component of voltage across V_3.

E_n'' = n^{th} harmonic component of voltage across V_3.

Then,

$$R = \left[\frac{(100\,E_1')^2 + (\%\,2^d\,E_2')^2 + (\%\,3^d\,E_3')^2 + \ldots (\%\,n^{th}\,E_n')^2}{(100\,E_1'')^2 + (\%\,2^d\,E_2'')^2 + (\%\,3^d\,E_3'')^2 + \ldots (\%\,n^h\,E_n'')^2} \right]^{1/2} \quad (\mathbf{b})$$

Constants are worked out for the fundamental and fifth harmonic, in the following sample calculations, Using formula (**a**),

$$E_1' = -0.5 - j\,0.866 - \frac{-1+j}{2+j}$$ (Calculated in Appendix I)

Rationalizing the last term and collecting,

$E_1' = -0.3 + j\,1.466$

Combining real and j terms and squaring,

$(E_1')^2 = 2.24.$

Similarly,

$$E_1'' = -0.5 + j\,0.866 - \frac{1+j}{2+j}$$

$(E_1'')^2 = 0.161.$

Similarly, remembering that the phase rotation of the fifth harmonic is opposite to that of the fundamental*,

$$E_5' = -0.5 + j\,0.866 - \frac{-1+j\,5}{2+j\,5}$$

$(E_5')^2 = 1.794.$

$$E_5'' = -0.5 - j\,0.866 - \frac{-1+j\,5}{2+j\,5}$$

$$= -1.293 - j\,1.383$$

$(E_5'')^2 = 3.585$

Equation (**b**) can be transformed into equation (**1**) by factoring out the ratio for the fundamental sine wave, $(2 + \sqrt{3}.)$ The b constants are derived from the E'' constants in equation (**b**):

$$b_5 = (E_5'')^2 \times \frac{1}{0.161} = \frac{3.585}{0.161} = 22.3$$

The a constants of equation (**1**) are derived from the E' constants of equation (**b**):

$$a_5 = (E_5')^2 \times \frac{1}{0.161} \times \frac{1}{(2+\sqrt{3})^2}$$

$$= 1.794 \times \frac{1}{0.161} \times \frac{1}{13.92} = 0.80$$

†The inductance of the meters was found to be too small to affect these calculations appreciably.

*Fortescue, TRANS. A. I. E. E., Vol. 37, 1918, p. 1027.

Appendix III

The Harmonic Alternator. The various harmonic voltages were obtained by means of a special harmonic alternator. This machine consists of three three-phase a-c. generators of the revolving field type, one of which is a 15 kw., 60-cycle machine; the second has a capacity of 7½ kw. at 180 cycles, and the third, 3-kw. at 300 cycles. All three machines are mounted on the same bed-plate and have a common frame while the field coils of all machines are mounted on the same shaft. The armature of the 60-cycle machine is stationary, but the armature of the 180-cycle machine may be moved by means of a hand wheel through an angle corresponding to 360-electrical degrees, and the armature of the 300-cycle machine by similar means can be moved through an angle corresponding to 600-electrical degrees. The six terminals of the armature winding of each machine are connected to a switchboard so that the three-phase windings may be connected either in star or delta. The field control of each generator is independent of the other two fields. The machine is driven by a d-c. shunt motor and the field winding is separately excited.

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For a more complete bibliography see references 6 and 11 above.

U. S. HAS FIVE RADIO STATIONS TO EVERY ONE IN EUROPE

In the United States there are more than five times as many radiocasting stations as in all Europe. The total for the United States, according to the most recent statistics, is about 575, while the European total is but 110 radiocasting stations.

England leads European countries; Germany comes next; Spain is third.

By countries, the number of radio stations in Europe is as follows: Finland, eight; Norway, six; Sweden, one; Holland, one; Belgium, four; Irish Free State, two; Great Britain and the North of Ireland, twenty-one; Germany, twenty; France, twelve; Spain, thirteen; Portugal, none; Switzerland, four; Italy, six; Austria, five; Hungary, two; and Czechoslovakia, five.

TERMS OF APPLICATIONS FOR BROADCASTING LICENSE IN INDIA CHANGED

The Government of India has amended the conditions to be complied with by private enterprise in applying for a license to provide a broadcasting service in British India and Burma. It is now provided that at the expiration of the first five years the government will reserve the right to reduce the proportion of license payable to the company so that it will cover the cost of an adequate service, provide a reasonable reserve fund, and pay a dividend of 15 per cent per annum on the subscribed capital. This dividend was originally limited to 10 per cent. It has also been agreed that consideration will be given to applications which provide that importers shall pay a royalty on imported apparatus to the broadcasting company.

VOLTAGE FOR HOME USE

It is apparent that domestic loads have grown so large that serious attention must be given both to voltage regulation in the homes and to wiring in the homes. The houses are becoming miniature machine shops with a variety of motors and heating devices which are bound to cause voltage fluctuations if the wiring does no more than comply with the formal Underwriters' regulations. Some of the appliances, such as the electric refrigerators, automatic pumps, ventilating motors and oil-burner motors, have no respect for time or load and may start up at the peak period or at night when all lights are burning. These voltage fluctuations are annoying because of their effect on the lights, and they may become more so as relays and controls are developed and used for household applications.

The utility may enlarge transformers and secondary distribution copper and yet not improve the situation materially. The answer to the problem lies in the wiring of each home, the motors used on devices and the development of some kind of house voltage regulator.—*Electrical World.*

Current Limiting Reactors
with Fire-Proof Insulation on the Conductor

BY F. H. KIERSTEAD[1]

Associate, A. I. E. E.

Synopsis.—*In a previous paper, tests were described which proved conclusively that if conducting material were lodged between the turns of a reactor having bare conductor, the reactor would flashover at the instant a failure occurred on the circuit in which the reactor was placed. In this paper, tests are described which were made during the development of a proper insulation for the conductor of reactors.*

Short Circuit Tests. *Reactors tested consisted of one reactor with enameled conductor and two reactors with asbestos insulated conductor; one having a thin covering of asbestos; the other a thicker covering.*

The reactor with enameled conductor flashed over during the first short circuit test. That with a thin covering of asbestos stood one short circuit and arced over in the second short circuit. The reactor with the thick covering stood many short circuit tests without any failure or sign of distress.

These tests established the fact that thin insulation on the conductor will not prevent such failures, even though it has sufficient dielectric strength to withstand the voltages placed across it for the reason that the magnetic force exerted on iron and steel objects will cause them to break through thin insulation. On the other hand, thick insulation will adequately protect the reactor from failure due to foreign substances.

Thermal Tests. *Thermal tests on the asbestos insulation established the following facts:*

First: That this insulation does not smoke excessively at temperatures below 350 deg. cent.

Second: That it does not burn even at temperatures of melting copper.

Third: That its insulation and mechanical strength is not appreciably affected when heated rapidly as high as 350 deg. cent.

Thermal Capacity. *The thermal capacity of the conductor is affected by the insulation, as follows:*

First: Under the effects of extremely high short circuit currents for a very brief interval, the thermal capacity is not affected by the asbestos.

Second: With a moderate short-circuit current for a longer length of time, the thermal capacity of the insulated conductor is increased due to the storage of heat in the insulation.

Third: During normal operation, at rated current, the temperature rise of conductor is increased due to the drop in temperature in the insulation.

Costs. *The asbestos insulation increases the cost of the reactor directly by the addition of the cost of the insulation itself and indirectly by making it necessary occasionally to increase the size of the conductor. However, this increase in cost is not a large percentage of the total cost of the reactor.*

* * * * *

IN a previous paper entitled, "The Design, Installation and Operation of Current Limiting Reactors," presented by Kierstead and Stephens, at the Annual Convention of the A. I. E. E., July 1924, short-circuit tests upon reactors were described. These tests proved conclusively that if conducting material were lodged between the turns of a reactor having bare conductor, the reactor would flashover at the instant a failure occurred on the circuit in which it was placed. In other words, if a piece of metal, such as a nut, bolt, washer, or screw drops or is magnetically drawn into a reactor and becomes lodged between two of its turns, there may be no indication of its presence in the reactor during the normal operation of the circuit but at the instant of a fault on this circuit, the voltage between these turns jumps to many times its previous value, incipient arcs shoot out at the points where the metal bridges between turns and this is followed instantly by a complete flashover of the reactor. Since that paper was presented, an investigation has been carried out to determine a suitable insulation for the conductor of reactors to prevent such foreign conducting material causing reactors to flashover. The purpose of this paper is to describe the tests which were made to determine the kind and thickness of insulation to be used.

The primary requisites of such insulation are as follows:

First: It must have sufficient dielectric and mechanical strength to prevent short circuits between turns by foreign conducting materials.

Second: It must conform to the well established practise of using only fire-proof materials in the construction of current-limiting reactors.

The first part of this paper is devoted to a description of the short-circuit tests made upon reactors to determine the insulation to be used, while the second part describes thermal tests made to determine the fire-proof characteristics of the insulation.

Short-Circuit Tests

Enamel and asbestos were chosen as the most suitable insulations because of their fire-proof characteristics. One reactor was built with enameled conductor and two reactors with asbestos-insulated conductors; one having a thin covering of asbestos, the other a thicker covering. The reason for making tests on reactors with these different insulations was to determine the thickness of insulation necessary.

The short-circuit tests made upon the reactors consisted of bringing up the terminal voltage on a 26,700-kv-a., 25-cycle generator to 13,200 volts, and then

1. Transformer Engineering Dept. General Electric Company, Pittsfield, Mass.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

short-circuiting two of its phases through the reactor under test. All three reactors were the "cast-in concrete" type, rated: 60 cyc es, 68 kv-a., 229 volts, 300 amperes, and were designed for use in introducing 3 per cent reactive drop in a 13,200-volt circuit. A diagram of the connections used in the tests is shown in Fig. 1. The tests made upon the different reactors are described under the following headings: (A), Reactor with Enameled Conductor. (B), Reactor with

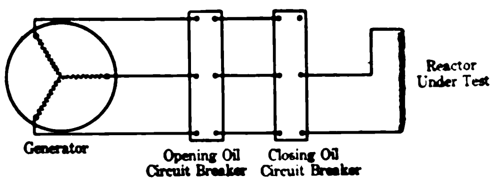
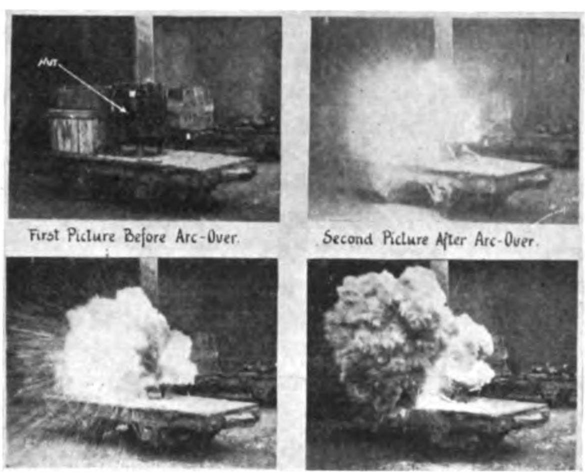


FIG. 1—DIAGRAM OF CIRCUIT USED WHEN MAKING SHORT CIRCUIT TESTS

a Thin Covering of Asbestos Insulation on the Conductor. (C), Reactor with a Thick Covering of Asbestos Insulation on the Conductor.

A. Reactor with Enameled Conductor. The conductor of the reactor on which these tests were made was enameled and the purpose of the tests was to determine whether the enamel would afford sufficient insulation to prevent a flashover if conducting material bridged between the turns.

The test was made by placing a steel nut between



Third Picture After Arc-Over Sixth Picture After Arc-Over

FIG. 2—REPRODUCTION FROM MOTION-PICTURE FILM TAKEN DURING SHORT-CIRCUIT TESTS ON REACTOR WITH ENAMELED CONDUCTOR

Arcing due to steel nut. *Enamel did not afford* sufficient insulation.

two adjacent turns of the reactor midway between the top and the bottom and then short-circuiting the generator through the reactor. The reactor as it appeared immediately before the test is shown in the upper left hand corner of Fig. 2 which is an enlargement of a portion of the motion pictures taken during these tests. The nut is painted white and is clearly visible in the photograph.

Although the reactor had previously been tested several times under short circuit (without giving any indication of distress), after the nut was placed in it, it flashed over during the first half cycle of the first short-circuit test. This test proved that enamel is not sufficient insulation to prevent a flashover, due to foreign conducting material.

The nut was thrown violently from the reactor to a distance of about 30 ft. where it struck a board and dented it to a depth of $\frac{1}{16}$ in. In short-circuiting a portion of the reactor winding, the nut carried a current in opposition to the main current in the reactor and the magnetic force between these opposing currents was probably the propelling force which expelled the nut. In this respect, foreign conducting material partakes of lifelike characteristics in that it may cause a lot of damage and then clear out and leave no clue as to the cause of the damage.

B. Reactor with a Thin Covering of Asbestos on the Conductor. The reactor on which the tests under this heading were made had a thin wall of asbestos covering

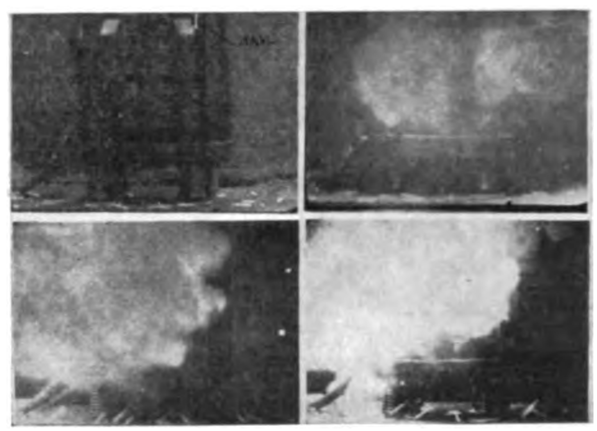


FIG. 3—REPRODUCTION FROM MOTION-PICTURE FILM TAKEN DURING SHORT-CIRCUIT TESTS ON REACTOR WITH CONDUCTOR INSULATED WITH THIN ASBESTOS

Arcing due to nail. Asbestos *was not thick enough* to afford sufficient insulation

on its conductor. It received the same tests as those applied to the preceding reactor, except that in this case, a nail was tied to the conductor so as to span between the outside turns of the upper two layers. The reactor with the nail attached is shown in the upper left hand picture of Fig. 3 which is a reproduction of a portion of the motion pictures taken during this test. This reactor stood the first short-circuit test without showing any visible signs of distress but flashed over during the first half cycle of the second test. The other pictures shown in Fig. 3 immediately followed the instant of flashover.

These tests showed that while the thin asbestos covering afforded more protection than the enamel (since it was able to pass through one short-circuit test without failure) still it was not thick enough to adequately protect the reactor from foreign conducting material.

C. Reactor with a Thick Covering of Asbestos Insula-

tion on Its Conductor. The reactor tested next had thicker asbestos insulation on its conductor than that of the preceding reactor. Many short-circuit tests similar to those previously described were made on this reactor with steel bolts and nuts variously located in an endeavor to make the tests as severe as would be encountered in actual service. In this reactor, however, the insulation on the conductor was sufficient to afford the conductor adequate protection from the foreign conducting material to which it was subjected. Some of the reproductions of the motion pictures taken during these tests are of interest, for the reason that having been taken at the rate of 125 pictures per second they show the movement of loose steel objects around and in the reactor. Fig 4 shows four pictures taken when a loose bolt was placed on the winding midway between the top and the bottom. The pictures are consecutive in the order in which they are numbered. The first picture shows the bolt resting on the winding. The next picture taken 1/125 of a second later, shows one end of the bolt raised up by magnetic force so that it is striking against one of the turns above while the other end is resting on one of the turns below. The pictures also show nails which had been strewn on the floor near the reactor being lifted by the magnetic field. Fig. 5 shows a similar group of pictures except that the bolt is first resting on top of the winding but is later pulled down so as to span between the top and next adjacent layers. The picture again shows nails being lifted from the floor. In Fig. 6, the bolt was placed so that it spanned the space between the top and next adjacent layers before the test and did not move during the test. The chief interest in these latter pictures is that they show nai s being lifted from the floor and being drawn into the windings with considerable force.

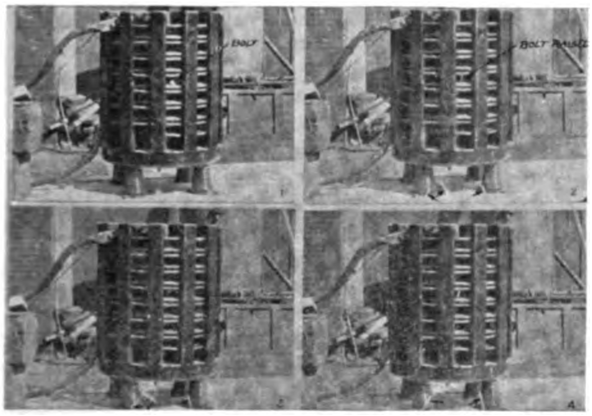


Fig. 4—Reproduction from Motion-Picture Film of Short-Circuit Tests on Reactor with Conductor Insulated with Thick Asbestos Insulation. Showing Bolt in Winding being raised and Nails being drawn toward Reactor by Magnetic Field. Arrows Indicate Nails

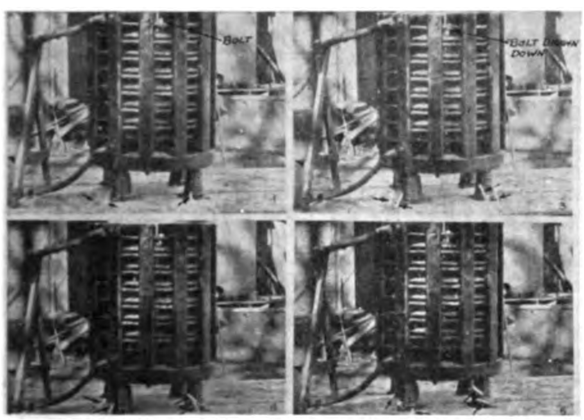


Fig. 5—Similar to Fig. 4 but shows Bolt being drawn by Magnetic Field from Top Layer to a Position Bridging between the Two Top Layers. Arrows Indicate Nails being drawn toward Reactor

The reproductions of the motion pictures show that the magnetic field of a reactor exerts a considerable force on magnetic substances. Therefore, the insulation on the conductor not only must be strong enough to withstand the electric stress which may be placed upon it, but must also be strong enough mechanically to withstand without injury, the cutting or piercing action of iron and steel objects when drawn against it by the magnetic force. It was this latter action that was the primary cause of the failures of the first two reactors.

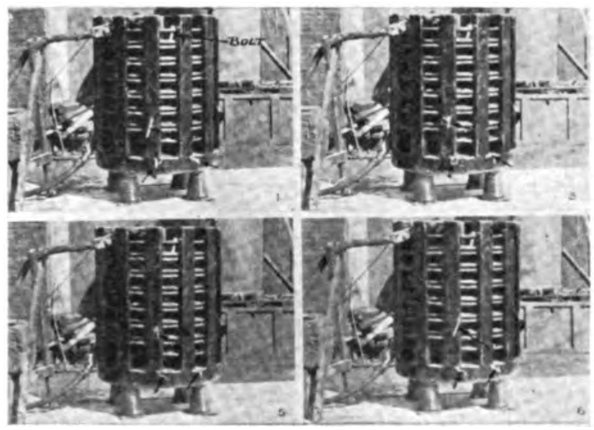


Fig. 6—Similar to Fig. 5 but shows Nails being drawn from Floor into Reactor by Magnetic Field. Arrows Indicate Nails

The thicker insulation on the last reactor tested had sufficient resilience to resist the blows delivered to it by the steel objects without being cut and in addition being thicker, could be indented to a greater depth without being pierced through to the conductor. Therefore, it was able to withstand the many short circuit tests it was subjected to without failure.

Summarizing, the foregoing tests established the following facts:

First: That a reactor with bare conductor will flashover during a short-circuit if conducting material is lodged in its winding.

Second: That thin insulation on the conductor will not prevent such failures, even though it has sufficient dielectric strength to withstand the voltages placed across it, for the reason that the magnetic force exerted on iron and steel objects will cause them to break through thin insulation.

Thermal Tests

Having established the thickness of asbestos insulation required to prevent electrical failures in reactors,

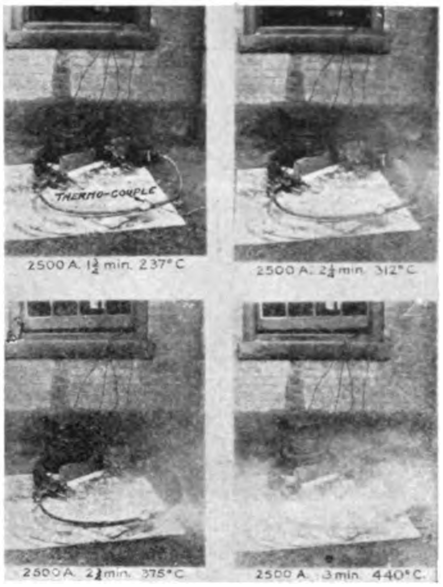


Fig. 7—Successive Pictures taken during High Temperature Test on Asbestos Insulated Cable

it was next required to determine if this insulation was fire-proof.

Test to determine whether the insulation would burn were made on 5 ft. lengths of 250,000-cir. mil. cable insulated with asbestos insulation. The equipment used in making these tests is shown in Fig. 7 and is comprised of a transformer for use in obtaining high current, a current transformer for measuring the current, and a thermo couple placed in the center of the cable. The tests consisted of holding 2500 amperes in the conductor until it melted. The amount of smoke emitted from the cable during these tests is more clearly shown by Fig. 7 than can be described. The figure shows that smoke just began to make its appearance at 312 deg. cent. while it became most dense at 440 deg. cent. As the temperature increased above this figure, the denseness of the smoke gradually decreased and had discontinued before the melting point was reached. At no time did the insulation show any tendency to burn. After the cable had been raised to the melting point of copper, the binding materials which held the asbestos fibers together had been destroyed and as a result the mechanical strength of the asbestos was practically zero.

The next tests were made to determine to what temperatures the cable could be raised without damaging the asbestos insulation.

It was felt that the insulation should be cabable of resisting the effects of having the conductor rapidly heated up to a temperature of 350 deg. cent. without injury to its mechanical or electrical strength. Therefore, a test was made by holding 2500 amperes in the cable until 350 deg. cent. was reached. This required about 2½ minutes. The insulation showed no indication that its mechanical strength had been injured by this test and the puncture tests showed that its insulation strength had not deteriorated.

Summarizing, the foregoing high temperature tests have established the following facts:

First: That this asbestos insulation does not smoke excessively at temperature below 350 deg. cent.

Second: That it does not burn even at temperatures of melting copper.

Third: That its insulation and mechanical strength is not appreciably affected when heated rapidly to temperatures as high as 350 deg. cent.

In actual service with the reactor carrying full short-circuit current, there will be no tendency for the reactor to smoke or the insulation to be injured for the reason that the current will be interrupted by the circuit breaker long before the temperature of the conductor has risen to 350 deg. cent.

The question quite naturally arises as to what effect the asbestos insulation will have on the thermal capacity of the conductor. Of course, if a short circuit is maintained for such a brief period of time that practically all the heat is stored in the copper then the insulated conductor will rise to practically the same temperature as the bare conductor. On the other hand, if the short circuit continues until an appreciable part of the heat generated is dissipated, there will be a period during which the flow of heat from the insulated conductor into its insulation will be more rapid than the flow of heat from the bare conductor into the air. During this period, the insulated conductor will be cooler than the bare conductor.

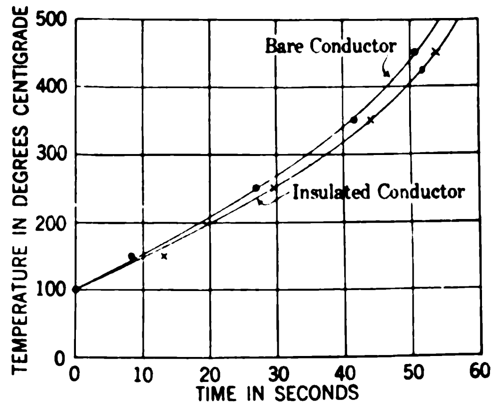


Fig. 8—Comparative Rate of Heating of Bare and Insulated Conductor for Short Periods

The accuracy of the above statement was checked by comparative tests on bare and insulated 250,000-cir. mil. cable. The tests consisted in holding 4000 amperes in each cable and measuring the time required for the conductors to rise to a given temperature. The temperature of the conductor was measured by thermo couples soldered to the conductor. In Fig. 8, the results of these tests are plotted. It will be noted that in all the tests the bare conductor was the hottest.

During the normal operation of the reactor when it is carrying rated current continuously, all the heat generated is, of course, dissipated and naturally the insulated conductor becomes the hottest. It has been found, however, that although asbestos is one of the best insulators of heat, the asbestos covering used on the conductors for reactors does not impede the flow of heat from the conductor to a great degree. The explanation for this is that the asbestos fibers are so

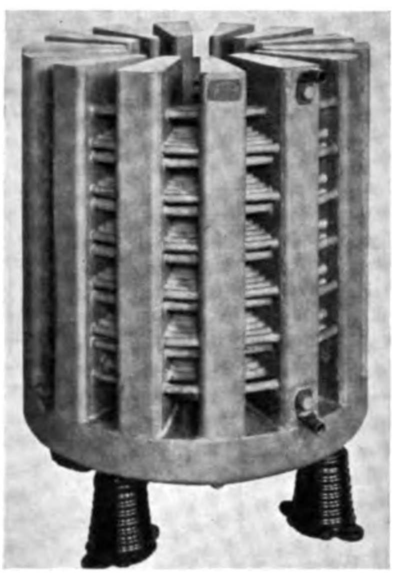


Fig. 9—"Cast-In Concrete" Reactor with Conductor Insulated with Asbestos Covering

densely formed around the conductor that the rate of conduction through them is many times more rapid than through the forms of asbestos used for heat insulation.

As has been shown in the preceding pages, the use of thick asbestos insulation removes the danger of flashover that a reactor without such insulation is subject to and yet does not affect its fire-proof qualities or the simplicity of its construction. Fig. 9 shows a reactor with asbestos insulation on its conductor. It will be noted that it is of the same general construction that has typified the "cast-in concrete" type of reactors for the past ten years. The asbestos fibers are closely and firmly woven on the conductor. They are treated with a compound which makes them very strong and able to resist cutting or tearing very tenaciously.

Insulating the conductors of reactors with asbestos increases their cost directly by the addition of the cost of the insulation itself and indirectly by making it necessary occasionally to increase the size of the conductor to compensate for the reduction in the rate of heat dissipation caused by the insulation. However, the cost of the insulation is not a arge percentage of the total cost of the reactor and the additional cost of a larger conductor is greatly offset by the reduced operating charges resulting from the reduction in losses occasioned by use of a larger conductor. Furthermore, as stated above, the asbestos covering has not been found to impede the flow of heat from the conductor to a great degree. These cost increases, therefore, are slight and will make no material difference in the present economies of a system which includes reactors.

In conclusion, attention is again called to the fact that the tests described in this paper have proven that any conductor insulation, which will afford adequate protection to a reactor from foreign conducting material not only must have sufficient insulation strength to stand the voltage stresses placed upon it, but also must have sufficient mechanical strength to withstand without injury the cutting and piercing action of iron or steel objects that may be drawn against it by the magnetic field of the reactor. Furthermore, the tests have shown that the asbestos insulation which has been developed for reactors affords protection from foreign conducting materials without sacrificing the fire-proof qualities which modern central station practise demands.

The author wishes to acknowledge the valuable assistance which Mr. L. P. Burgess rendered when the tests herein described were made.

PREVENTION OF DETERIORATION OF VULCANIZED RUBBER

It has been known for some time that deterioration of vulcanized rubber by oxidation can be delayed by the use of substances which are themselves easily oxidized and which act as anticatalysts of oxidation. Recently two of the largest rubber companies simultaneously patented almost identical antioxidants. A sample of the material received by the Bureau of Standards has been employed in rubber compounds which were then subjected to an accelerated aging test. The bureau's results substantiate the claim that the durability of rubber with respect to the effects of light and heat can be increased about 600 per cent.

Practical Aspects of System Stability

BY ROY WILKINS[1]

Associate, A. I. E. E.

Synopsis—*During the past few years there has been much discussion regarding the behavior of long transmission lines under transient conditions, such as flashovers, short circuits, arcs and grounds which would tend to make them unstable, but unfortunately this discussion has been largely theoretical due to the absence of any actual operating data upon which to base assumptions. It has only been recently that an opportunity has been afforded to make field tests on one of the two existing 220-kv. systems and the results of such a series of tests made on the system of the Pacific Gas and Electric Company are presented in the paper.*

This is the first instance where tests of this nature have been attempted and the lack of proper testing equipment proved a serious handicap. It was necessary to develop a special high-speed oscillograph wattmeter, a high-speed oscillograph filmholder and a pilot generator. Moreover the technique of testing was developed so that it was possible to secure oscillographic records 200 mi. apart by telephone signal.

The tests established the following important facts:

1. System stability as a problem is inextricably entangled with operating economics, and cannot be handled solely as a problem in design, except for very simple cases. 2. For any adequate conclusions to be reached much more fundamental data is necessary. 3. Requisite equipment for obtaining such data is not now available. 4. Studies of models and artificial transmission lines are not adequate because too little is known about the relative importance of the several factors to allow intelligent duplication. 5. Proper relay equipment and action is vital. 6. Oil-switch operation is an important factor. 7. Only a certain part of the stored energy of a system is available in any given case of trouble. 8. Operating distribution of excitation current is one of the major problems.

As transmission networks have grown in economic importance and kilowatt capacity, the problem of stable operation has assumed an increasingly greater importance, culminating in 1922-23 in studies of the proposed long distance transmission of large blocks of power to important market centers in the Atlantic States. In the consideration of these proposals a detailed study of system stability was considered essential. Preliminary theoretical analysis of the several problems encountered was presented at the Midwinter Convention of the Institute in 1924, and showed a decided lack of agreement on the methods of attack and the results obtained.

Opportunity was afforded to carry out tests on one of the two existing transmission systems having long 220-kv. transmission lines feeding a large load network, consequently a series of tests were carried out early in 1925 on the transmission system of the Pacific Gas and Electric Company to secure definite operating data on several of the points in question. The data accumulated on the test was an attempt to determine what was required on a network in order to predict its characteristics with respect to stability. It cannot be too strongly emphasized that data secured is for a specific condition on a given system and that such lack of agreement as evidenced in the calculations made in the past is due not so much to differences in mathematical treatment as to differences in assumptions made in regard to the relative importance of the several factors.

In the tests these factors are naturally included in their proper proportion and place, and any calculation made for the same conditions, to be at all adequate, must presuppose a thorough knowledge of all of the factors as well as of their relative importance. Artificial lines and miniature equipment cannot be substituted without such knowledge, for at best the results are

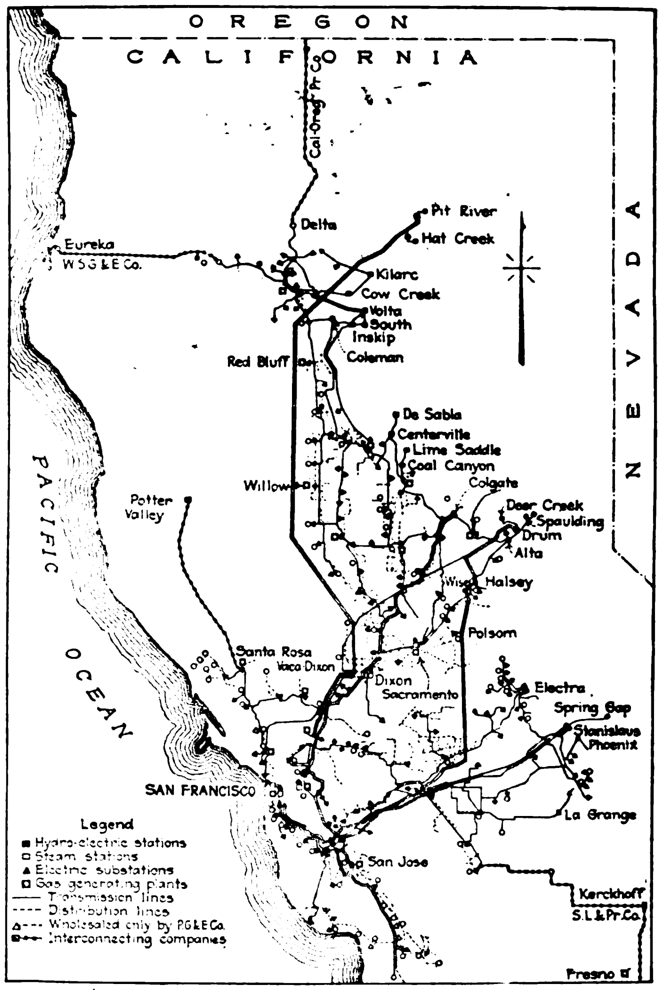


Fig. 1—System Diagram, Pacific Gas and Electric Company

only a reflection of the assumptions made. The difference between values in tests on an actual system and

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To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

calculated or miniature equipment tests represents the numerical value of errors due to such assumptions.

Given enough fundamental data on the network during trouble, the effect of such trouble may, with much patience and persistence, be calculated for very simple cases, but at least for the present the actual quantitative values for this fundamental data must be measured to insure any degree of accuracy in the final result. The tests as carried out are an attempt to evaluate at least a part of the unknown quantities, in order that the necessary assumptions for calculation may be at least reasonably correct.

Outline of Tests

The points on the system of the Pacific Gas and Electric Company selected for the tests were Pit No.1

TABLE I

NETWORK DATA AT TIME OF TEST

202 mi. of two-circuit 220-kv. line connected to three power-houses and one substation.
607 mi. of 110-kv. line connected to six power-houses and 10 substations.
2039 mi. of 60-kv. line, connected to 19 power-houses and 162 substations.
8434 mi. below 60-kv. line connected to 100 substations.
160 mi. of underground.
27—Hydro plants having 69 units and 317,975 kv-a. capacity.
4—Steam plants having 12 units and 142,000 kv-a. capacity.
2—20,000 kv-a. synchronous condensers.
2—12,500 kv-a. synchronous condensers.
1—7500 kv-a. synchronous condensers.

There were also, connected and operating in parallel, the Great Western Power Company, having
196 miles of 165-kv. line.
150 mi. of two circuit; 30 mi. of one circuit of 100-kv. line
520 mi.—below 60 and above 20-kv. line, with:
2—Hydro plants having nine units, 131,000 kv-a.
4—Steam plants having nine units 30,800 kv-a.
3—Synchronous Condensers having three units, 60,000 kv-a.

The California Oregon Power Company having 200 mi. of 66 kv.
513 mi. of 60 and 38 kv. with
10—Hydro plants having 16 units, 56,160 kv-a.

The Truckee River Power Company with five hydro plants and 8650 kv-a.

The Snow Mountain Power Company with,
107 mi. of line below 60 kv. and above 30 kv.
1 Hydro-Electric plant having 1 unit and 6400 kv-a. together with several smaller distributing networks to which the Pacific Gas and Electric Company wholesales power.

There was on the Pacific Gas and Electric Company system approximately 1,500,000 h. p. connected load, of which the average yearly distribution is:
35.0 per cent—Commercial and domestic lighting and heating.
13.5 per cent—Agricultural power (mostly centrifugal pumps).
3.0 per cent—Mining-power induction motors.
21.0 per cent—Manufacturing power.
8.0 per cent—Railway power.
19.5 per cent—Miscellaneous power.

The interconnected companies have roughly the same connected load per kv-a. generating capacity and the same general distribution of load.

For the Pacific Gas and Electric Company the monthly load factor in December is about 61 per cent, for August about 73 per cent, and the yearly load factor 62.5. The daily load factor is 65-79.

Power-House, the generator end of the two 202-mi., 220-kv. Pit transmission lines, and Vaca-Dixon Substation, the receiver end of these lines (see Fig. 1). Physical data on the system network at the time of the test is given in Table I.

Pit No. 1 Power-House has installed two 35,000-kv-a., 3-phase, 60-cycle, 11,000-volt generators driven by 40,000-h. p. Francis turbines, each having a $W R^2$ of 7,365,000 lb. ft. On the same 11,000-volt bus is also connected the two Hat Creek plants, each having one 12,500-kv-a. turbine-driven generator, with 2,800,000 $W R^2$, 6600-volt, 3-phase, 60-cycle connected through 6600- to 60,000-volt transformer banks and approximately five mi. of double-circuit tower lines to a step-down bank 60,000/1100 at Pit No. 1.

Connecting Pit No. 1 with Vaca Substation is a 202-mi. double-circuit 220-kv. transmission line,[2] through two 11,000- to 220,000-volt delta Y-connected 50,000-kv-a. transformer banks at Pit No. 1 and through two 200,000/110,000/10,460-volt 50,000-kv-a. banks at Vaca Substation. The Vaca transformer banks are Y-connected auto-transformers with a delta-connected tertiary from each of which is operated a 20,000-kv-a., 11,000-volt synchronous condenser. At Vaca the power enters the 110-kv. network as shown in Fig. 1. At the time of test, one line was operating at 220-kv. and one at 125-kv., one bank at Pit No. 1 being temporarily reconnected and the line going to the 110-kv. terminal of the bank at Vaca instead of the 220-kv., the 110-kv. is designated as No. 1 and the 220-kv. as No. 2.

The Following is an Outline of the Schedule of Tests.

I. *a.* Start condenser at Vaca.
   b. Trip one condenser at Vaca.

II. Run both generators at Pit, one leading and one lagging.
   a. Trip one.

III. Running both generators at Pit.
   Trip one at ¼ load.
   " " " ½ "
   " " " ¾ "

IV. Line switching at Pit.
   a. Switch out No. 2 line at Pit at 220 kv.
   b. " " " " " " Vaca at 220 kv.
   Vary and repeat.

V. Ground No. 2 line through fuse first tower out from Vaca bus.
   Repeat.

Test Equipment

A description of the equipment used in making the tests is given in Table II. The six-element oscillograph used at Pit No. 1 was a Westinghouse portable permanent magnet type equipped with a special film holder using 6½ in. films 24 ft. long and running up to speeds of about 1 in. per cycle. The 3-element was also a Westinghouse portable permanent magnet type with a special holder, handling films 3¼ in. by 15 ft. at speeds

2. See TRANSACTIONS A. I. E. E., 1924, Page 1148, Corona Loss Test.

TABLE II

TEST EQUIPMENT

Pit River No. 1 Power-House:
One 6-Element Oscillograph
One 3-Element Oscillograph
One 3-Element, 3-phase, oscillographic type wattmeter
One Motor-Generator Set for measuring absolute change in phase position
One Generator for showing rotor phase angle position
One Mechanical recording device to show governor action
Vaca-Dixon Substation;
One 3-Element Oscillograph
Two Recording Wattmeters
One Motor-Generator same as that used at Pit No. 1
Claremont Substation:
One Esterline Wattmeter

MEASURING THE FOLLOWING QUANTITIES

Line Switching—Angular Relations

Pit No. 1 Power-House:
Six-Element Oscillograph
One—Pilot Governor
Two—Motor Generator Set Voltage
Three—Generator Internal Voltage
Four—Vaca Voltage
(One–Four: Same zero line)
Five—Generator Current
Six—No. 1 Line Current
(Five–Six: Same zero line)
Three-Element Oscillograph
One-Hat Creek Current
Two—Generator Terminal Voltage
Three—No. 2 Line Current

High Speed Wattmeter

1—Generator Power
2—Hat Creek Power
3—Line No. 1 Power

Esterline Wattmeter

1—Line No. 2 Power
Vaca Substation:
Three—Element Oscillograph
One—100 kv. Bus Voltage
Two—Condenser Current on Line No. 1
Three—Single Phase Wattmeter-No. 1 Condenser Power
Four—Differential 100 kv. Bus—Motor Generator Voltage

Esterline Wattmeter

One—Power Condenser on Line No. 2
Two—Drum line
Claremont Substation:
Esterline Wattmeter

Line Switching-Flux Relations

Pit No. 1 Power-House:
Six—Element Oscillograph
One—Pilot Generator
Two—Generator Terminal Voltage
Three—Generator Internal Voltage
Four—Generator Current
(One–Four: Same zero line)
Five—Field Current
Six—Field Voltage
(Five–Six: Same zero line)
Three—Element Oscillograph
One—Motor Generator Voltage
Two—Vaca Voltage
Three—Generator Internal Voltage

High Speed Wattmeter

One—Generator Power
Two—Hat Creek Power
Three—Line No. 1 Power

Esterline Wattmeter

One—Line No. 2 Power
Three—Element Oscillograph

One—100 kv. Bus Voltage
Two—Condenser Current on Line No. 1
Three—Single Phase Wattmeter—No. 1 Condenser Power
Four—Differential 100 kv. Bus—M. G. Set

Esterline Wattmeters

One—Power Condenser on Line No. 2
Two—Drum Line
Claremont Substation:

Esterline Wattmeter

Single Phase—Short Circuit

Pit No. 1 Power-House:
Six—Element Oscillograph
One—Pilot Generator Voltage
Two—Motor Generator Voltage
Three—Generator Internal Voltage
(One–Three: Same zero line)
Four—Generator Current
Five—No. 1 Line Current
Six—Hat Creek Current
(Four–Six: Same zero line)
Three—Element Oscillograph

One—Residual Current
Two—Generator Terminal Voltage
Three—No. 2 Line Current

High Speed Wattmeter

One—Generator Power
Two—Hat Creek Power
Three—No. 1 Line Power

Esterline Wattmeter

One—No. 2 Line Power
Vaca Substation:
Three—Element Oscillograph

One—Residual Current—3—220 kv. Bushing Transformer
Two—Positive sequence voltage
Three—Single phase wattmeter—el No. 1 and el No. 4
Four—Residual Voltage

Esterline Wattmeters

One—Power of Condenser on Line No. 2
Two—Power on Drum Line
Claremont Substation:
Esterline Wattmeter

up to 1 in. per cycle. The oscillograph wattmeter was a moving coil instrument having three single-phase elements operating one mirror with straight line charac-

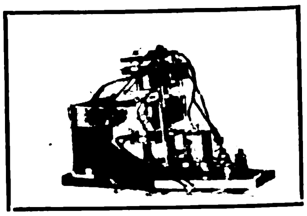


FIG. 2—POLYPHASE ELEMENT OF OSCILLOGRAPHIC WATTMETER

teristics and a natural period of about $^1/_{20}$ second; developed by the Westinghouse Company for the test, see Fig. 2, calibration Fig. 3.

There were three of these 3-phase meters in one case,

all working on the same film. Timing was accomplished by interrupting the beam of light from one meter for a short time every $^1/_{10}$ second by means of a small synchronous motor, giving indications shown as small gaps in the record of one meter on the film. The films were 3¼ in. by 55 in. and had a speed up to 15 in. per second. For measuring the absolute change in phase position a small motor-generator set comprised of a d-c. motor and an alternator with a fly-wheel was run from the station storage battery. There was

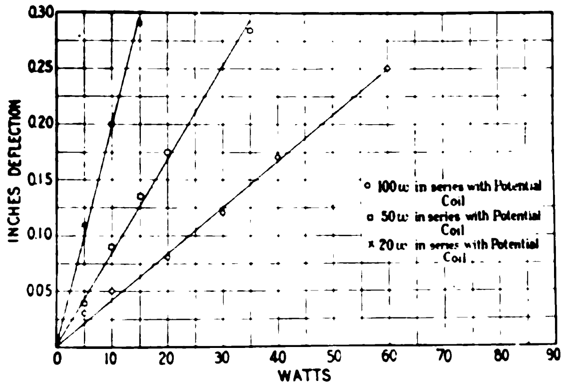


Fig. 3—Calibration of Same (Single-Phase)

Fig. 4—Pilot Governor

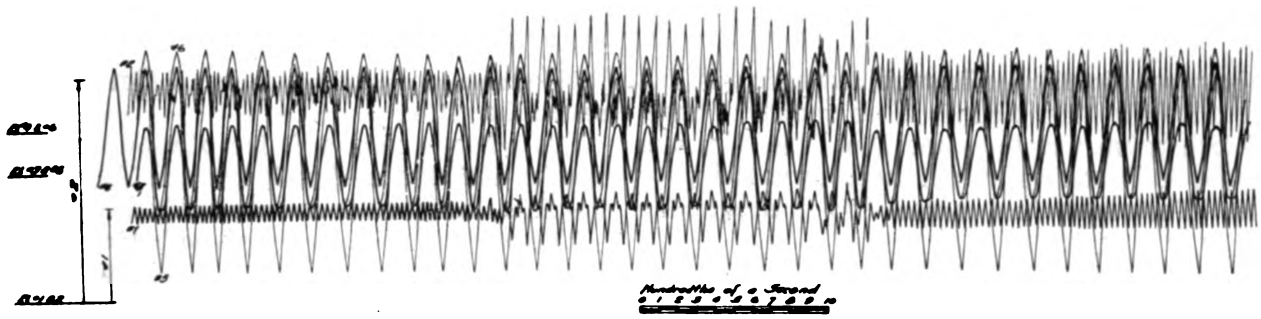


Fig. 5—Section of 24-Ft. Film of a 6-Element Oscillograph

Stability tests at Pit River Power House No. 1, June 18, 1925, 11:40 p.m.

El. No. 1—Field Voltage
No. 2—Field Current
No. 3—Generator Current
El. No. 4—Rotor Voltage
No. 5—Gen. Terminal Voltage
No 6—Gen. Internal Voltage

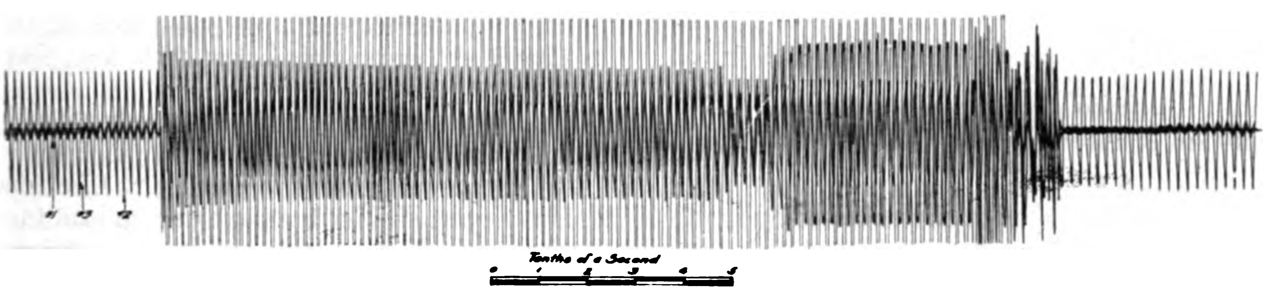


Fig. 6—Section of 15-Ft. Film of a 3-Element Oscillograph at Pit No. 1 during Flashover

Stability Tests at Pit River Power House No. 1, June 18, 1925

El. No. 1—Residual Current No. 2—Gen. Voltage No. 3, No. 2 Line Current, $B\phi$

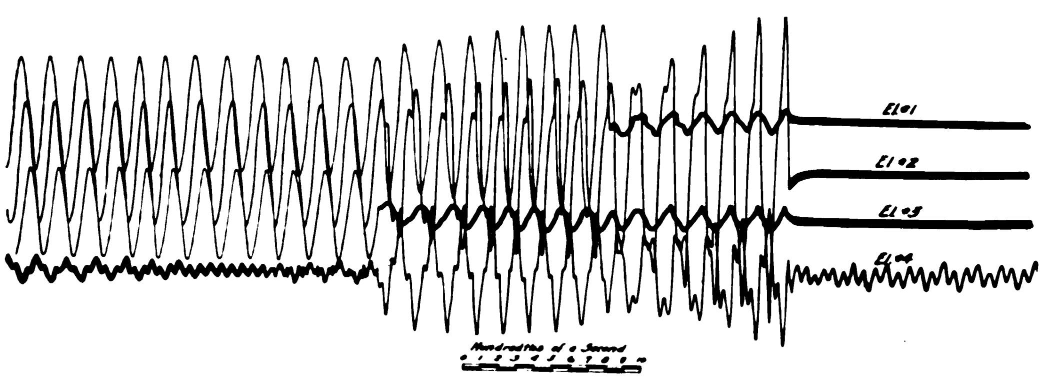


Fig. 7—Film of Oil-Circuit Breaker Action

Stability Tests at Pit River Power House No. 1, June 18, 1925, 10:35 p. m.

El. No. 1—No. 2 Line Current $C\phi$
No. 2—No. 2 Line Current $B\phi$
El. No. 3, No. 2 Line Current, $A\phi$
No. 4 Residual Current

mounted on the generator, with its rotor mounted on the end of the generator shaft, a remodeled "Ford" magneto having the same number of poles as the main generator, (see Fig. 4). This magneto having no load, gave a true record of the field or rotor position at all times and its wave is referred to as the pilot generator voltage. There was also installed a mechanical recording device on the turbine governor giving governor travel.

The 3-element oscillograph used was a Westinghouse electromagnet portable oscillograph, having in addition to the three elements, a single-phase wattmeter using the fourth prism and the same film. The film was 3¼ in. by 55 in. and was run at speeds up to 15 in. per second. There were also two special polyphase graphic wattmeters using high speed charts driven by synchronous motors. All of the data at Vaca was taken by telephone signal from Pit No. 1 as was also the switching. This was satisfactory enough that the two sets of equipment 200 mi. apart were able to catch each test on the standard film within one-quarter of its travel.

FIG. 8—OSCILLOGRAPHIC WATTMETER RECORD OF OPENING ONE LINE
Stability Test at Pit River Power House No. 1, June 17, 1925, 11:40 p. m.
El. No. 1—No. Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

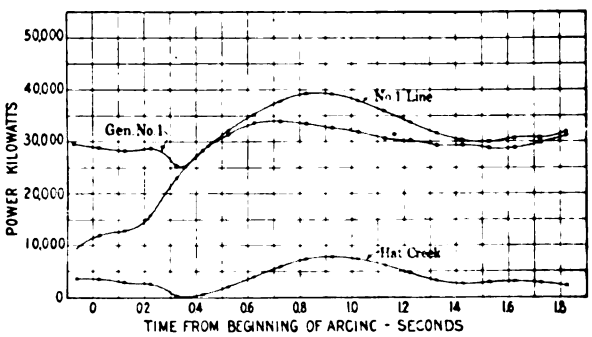


FIG. 9—FIG. 8 PLOTTED TO A COMMON SCALE FOR ALL ELEMENTS

transient and a speed sufficient to make individual cycles available for angular measurement.

Fig. 5 represents that portion of a 24-ft. film during which switching took place, for opening a 220-kv. line at Pit No. 1.

Fig. 6 is a portion of a 15-ft. film taken at Pit No. 1 Power-House during one of the artificial flashovers at Vaca Substation.

This shows the start of the flashover, the point at which the line cleared at Vaca, the point at which Pit No. 1 cleared, and on the original film 7 or 8 seconds record thereafter.

Fig. 7 shows a portion of a film of an oil circuit breaker opening a 220-kv. line lightly loaded. There are shown the three line currents and the residual current.

This record indicates the phase balance action between phases when opening a polyphase circuit; the current ruptured by the last circuit breaker shows nearly four times the original phase current.

Fig. 8 is the record by the oscillographic wattmeter of switching out the 220-kv. line at Pit No. 1 carrying 24,000 kw., thereby increasing the load on the 110-kv. line from 12,000 to 35,000 kw.

The generator instead of dropping from 32,000 kw. to 12,000 kw. drops only about 3000 kw., and that only after $^3/_{10}$ second.

Fig. 9 shows these wattmeter records plotted on a common scale.

Fig. 10 shows the reverse process, *i. e.*, closing the 220-kv. line at Pit No. 1 and picking up load from the 110-kv. line. This action is much more severe, takes place faster and causes more outside disturbance than the opening of a line.

Fig. 11 shows this plotted to a common scale.

Previous articles[3] on this subject have considered that

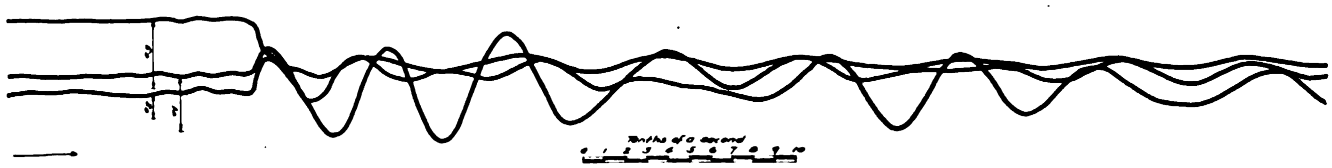


FIG. 10—OSCILLOGRAPHIC WATTMETER RECORD OF CLOSING ONE LINE
Stability Tests at Pit River Power House No. 1, June 18, 1925, 12:12 a. m.
El. No. 1—No. 1 Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

CHARACTER OF DATA

It was necessary that the preliminary data be taken comparatively cheaply and without undue disturbance to normal operation, that the oscillographic records have a length in time sufficient to cover all of the

when one of two parallel lines was opened, the output of the station feeding them dropped instantly to the load on the remaining line while the prime mover stored

3. See J. P. Jollyman, JOURN. A. I. E. E., Sept., 1925, p. 950, Fig. 4. C. L. Fortescue, JOUR. A. I. E. E., Sept., 1925, p. 955, Fig. 4.

energy in the fly-wheel effect of the generator, releasing it to cause as great an overswing of output as the drop represented in kw. hrs.

This view assumes that the energy absorbed must be shown in a change in velocity of the generator rotor caused mechanically by the prime mover, and that there is no damping action. The curves demonstrate that such is not the case and also that closing a line more nearly approximates it than opening one.

In the writer's opinion the same effect is obtained by changing the power-factor of the generator load because this gives the same shift of the generator rotor and rotating armature field as a change in rotor velocity would, with the addition that it can take place as fast as circuit conditions permit. For a generator carrying load, the field poles occupy a certain position with respect to the rotating armature flux, any increase in load causes the armature flux to lag behind the field poles, *i. e.*, to come from the trailing edge of the pole if the power is constant. Given a constant load, a change in power-factor accomplishes the same result.

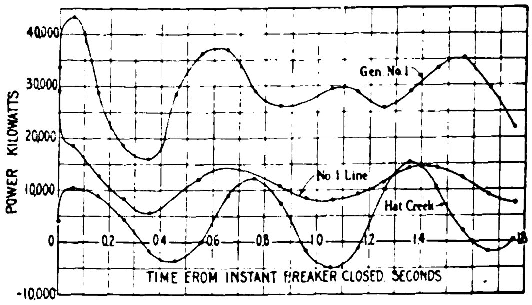


Fig. 11—Fig. 10 Plotted to a Common Scale for All Elements

With such a pilot generator as used at Pit No. 1, these changes may be observed on an oscillograph. Any such shift in armature flux position absorbs from or delivers energy to the field structure rotating as a fly-wheel and it must take place before there is any tendency to change the speed of the prime movers.

The rate at which energy can be absorbed depends on the electrical characteristics of the circuit involving a great number of variables among which is oil-circuit breaker action. No circuit breaker at present in use interrupts a circuit instantly, neither do they interrupt all three phases simultaneously because they interrupt the circuit at the zero point on the current wave of an arc of variable length. When closing the contacts make contact mechanically at a predetermined position and the action is, therefore, much quicker and more uniform. All of these things cause a change in wave shape in both current and voltage in all of the interconnected circuits. In most of the tests described, the speed and length of film were sufficient to permit angular measurement to be taken.

It was found that the change in wave shape was sufficient to materially affect the results.

On one of the tests, shown by Fig. 12, the several

TABLE III

Harmonics Present During Artificial Flashover at Vaca

(See Figs. 12 to 17)

Wave	Per Cent Harmonics	Angle from Actual Wave
Terminal voltage before transient...	99.8 1st	−1.2
	3.5 3rd	12.0
	5.1 5th	7.9
Terminal voltage 0.3 sec. after transient........................	99.4 1st	1.0
	7.9 3rd	18.6
	6.9 5th	−3.8
Terminal voltage 0.95 sec. after transient........................	99.2 1st	−1.5
	10.4 3rd	20.9
	7.4 5th	−7.1
Terminal voltage 1.2 sec. after transient........................	99.3 1st	0
	9.4 3rd	16.6
	7.6 5th	−4.7
Generator current before transient..	100 1st	+2.8
	.5 3rd	−12.5
	.4 5th	38.5
Hat Creek current before transient..	99.6 1st	−2.8
	3.8 3rd	35.9
	7.9 5th	4.0
Hat Creek current 0.40 sec. after transient........................	98.1 1st	−11.9
	4.8 3rd	27.4
	18.8 5th	18.9
Hat Creek current 0.7 sec. after transient........................	99.6 1st	7.1
	5.3 3rd	−27.6
	7.1 5th	−3.0
Hat Creek current 1.3 sec. after transient........................	99.6 1st	−3.2
	1.7 3rd	22.8
	8.2 5th	27.2

waves have been analyzed for fundamental, third and fifth harmonics and the angular position of the fundamental with respect to the actual wave determined.

Fig. 13 gives a polar diagram of the generator terminal voltage before the transient; Fig. 14, the same wave $^7/_{10}$ second after the transient.

Fig. 15 Hat Creek current before the transient. Fig. 16, $^7/_{11}$ second after and Fig. 17 $1^3/_{10}$ seconds after the transient.

Table III, by S. B. Griscom of Westinghouse Electric and Manufacturing Company, gives the numerical values of these harmonics and angles in this particular test.

Fig. 18 shows an oscillographic wattmeter record of an artificial flashover on the 220-kv. line under normal operating conditions caused by closing an air switch; Fig. 19, on a string of insulators over which a 10-ampere fuse had been placed.

This gave an arc from one phase to ground over an insulator string cleared by relays in the normal manner under actual operating conditions.

Oscillograms of current, voltage, etc., were taken both at Pit No. 1 Power-House and Vaca during such a flashover. Fig. 20 and Fig. 21 are illustrations of such an arc.

At Vaca, in addition to the oscillographic record of current and voltage, there was a single-phase wattmeter record of the residual power, *i. e.*, voltage across the corner of an open delta and the common return of the three current transformers connected in Y.

Fig. 22 shows the record for two such flashovers.

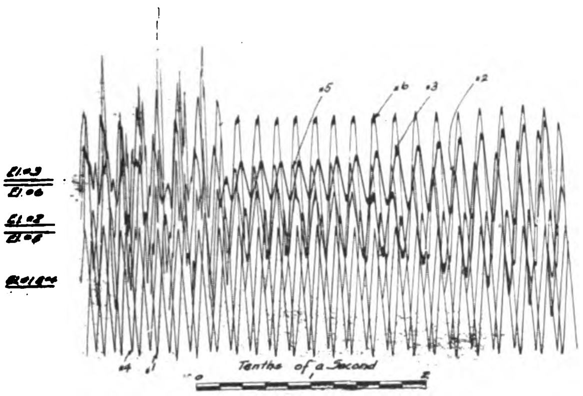


FIG. 12—SECTION OF 24-FT. FILM OF A 6-ELEMENT OSCILLOGRAPH AT PIT NO. 1 FOR ARTIFICIAL FLASHOVER AT VACA

Stability Tests at Pit River House No. 1. June 19, 1925, 1:20 a. m.

El. No. 1—M. G. Set Voltage
No. 2—No. 1 Line Current
No. 3—Generator Current
El. No. 4—Rotor Voltage
No. 5—Vaca Voltage
No. 6—Gen. Int. Voltage

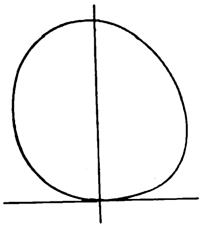


FIG. 13—POLAR DIAGRAM OF GENERATOR TERMINAL VOLTAGE BEFORE TRANSIENT

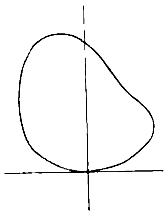


FIG. 14—THE SAME AS FIG. 13 BUT 7/10 SECOND AFTER THE TRANSIENT

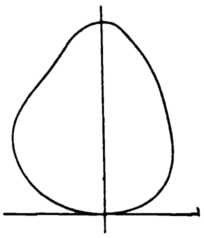


FIG. 15—POLAR DIAGRAM OF HAT CREEK CURRENT BEFORE TRANSIENT

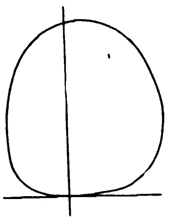


FIG. 16—SAME AS FIG. 15 BUT 7/10 SECOND AFTER THE TRANSIENT

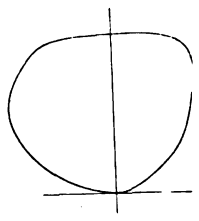


FIG. 17—SAME AS FIG. 15 BUT 1 3/10 SECONDS AFTER THE TRANSIENT

Too strong emphasis cannot be placed on the statement that any such data is for a network in operating condition, and that there are a great number of unknown variables involved, the determination of any one of which is a problem of major importance, worthy of a complete discussion in itself.

The stability problem is inextricably enmeshed with system operating economies and in the greater number of cases the limitations are as much operating difficulties as engineering design. It is not possible to economically build and operate a complete superpower network for ideal conditions at the present time. Such networks grow naturally from the demand for more and better power service, and are made up of interconnected existing networks too valuable to junk outright. They must be adapted to operate together.

NECESSARY CONSIDERATIONS

Trouble, Relays and Switching. On any major line in a network similar to the one on which these tests were made, it is *absolutely essential* to clear arcs quickly; so quickly in fact that neither governors nor automatic voltage regulators of the present type can act sufficiently to make any material change before the line is cleared. With proper relay action a line can be cleared of an arc over an insulator string so promptly that it has been almost impossible to locate the point of trouble. If an arc is left unchecked for anything like the time required for the network to reach a stable condition, the wire in trouble is melted or sufficiently annealed to cause it to part mechanically. Arcs on high tension lines generally strip the top and bottom units of an insulator string first and then cause a burn sufficient to drop a conductor. On any line of 220 kv. the conductor size and stringing tension make it necessary to have heavy equipment, usually gasoline-driven trucks, to handle any work done on the conductors. For this reason it is necessary to clear positively and quickly any trouble. Failure to do this means not a momentary interruption but hours, or more probably days, until the necessary heavy equipment can be assembled at the point of trouble for line repairs.

Experience has shown that the only practical procedure is to clear the smallest practical section of the network around the trouble in the shortest possible time.

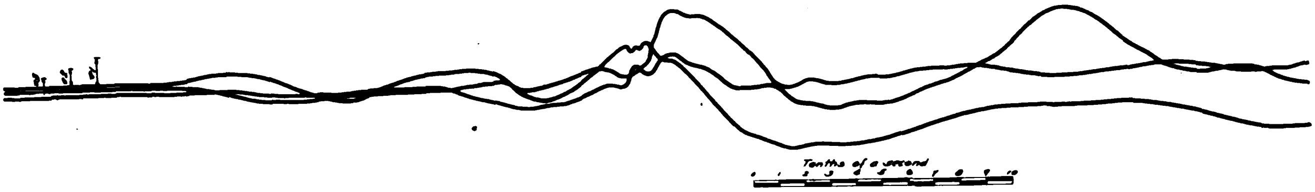


FIG. 18—AN OSCILLOGRAPHIC WATTMETER RECORD OF AN ARTIFICIAL FLASHOVER ON THE 220-KV. LINE

Stability Tests at Pit River Power House No. 1, June 19, 1925, 2:15 a. m

El. No. 1—No. 1 Gen. Power No. 2—Hat Creek Power No. 3—No. 1 Line Power

TABLE IV

ANALYSIS OF RELAY OPERATION ON THE 220-KV., 110-KV., AND 60-KV. TRANSMISSION NETWORK OF THE PACIFIC GAS AND ELECTRIC COMPANY FOR 1923 AND 1924

1		2		3		4		5		6	
						Incorrect relay operations					
Total operations involving relays		Correct relay operations		Relay failures		Due to relay		Due to external causes		Question-able relay operations	
Year	No.	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
1923	1,593	1,490	93.6	24	1.5	11	.7	40	2.5	28	1.7
1924	1,884	1,699	90.2	31	1.6	3	.2	108	5.7	43	2.3

Col. 1—Relay Failures (No Operation of Switch)

Under this heading are listed all cases where subsequent investigation has proved that conditions at the point in question were such as to permit correct relay operation but the relays failed to function. No case is listed as a relay failure if investigation proved the trouble to be due to a break, ground or other fault in the direct-current tripping circuit, or to mechanical defect in the switch or auxiliary apparatus external to the relay itself.

Col. 2—Total Relay Operations

This tabulation includes all cases of relay operation causing the opening of oil switches and is a summation of Cols. 3, 4 and 5. (Note—Cases of relay operation due to accidental shorting or closing of contacts are not included in this report).

Col. 3—Correct Relay Operations

Under this heading are listed all relay operations which have been proved to be correct under the conditions existing at the time. This tabulation includes many cases which were not entirely satisfactory from an operating standpoint, but where, owing to load, voltage and power-factor conditions, it was necessary to give the relays credit for correct operation, even though the results were not precisely as desired. There are also included in this table a number of cases in which unsatisfactory relay operation has occurred due to inadequate equipment. (See Col. 4) In all these cases, however, the relays themselves functioned correctly under the circumstances.

Col. 4—Incorrect Relay Operations Due to Relay

This tabulation includes all cases that have been proved by subsequent investigation and test to be due to faults, either mechanical or electrical, in the relays themselves. (Note—This classification does not include relay operations which were apparently faulty because of inadequate equipment or improper connections.)

Col. 4—Incorrect Relay Operations Due to External Causes

Under this classification are listed all cases of relay operation which investigation has shown to be the result of faults or improper connections in auxiliary apparatus external to the relays themselves.

Col. 5—Questionable Relay Operations

This table covers relay operations which it has been found impossible to classify under Col. 3 or 4. In most cases the operation has been unsatisfactory, but owing to the lack of evidence it was considered unfair to classify it as incorrect, particularly as a test made after the trouble showed the relays to be operating correctly so far as could be determined.

In Table IV is given the high tension relay operations for 1923 and 1924, and in Chart V is given the segregation of all high-tension troubles for the year 1924.

Of manual switching for 182,500 switching operations on the Pacific Gas and Electric Company system in a year, 23 caused trouble.

The greater portion of the high voltage troubles are phase-to-ground arcs caused by conditions fairly well known and to a considerable extent avoidable.

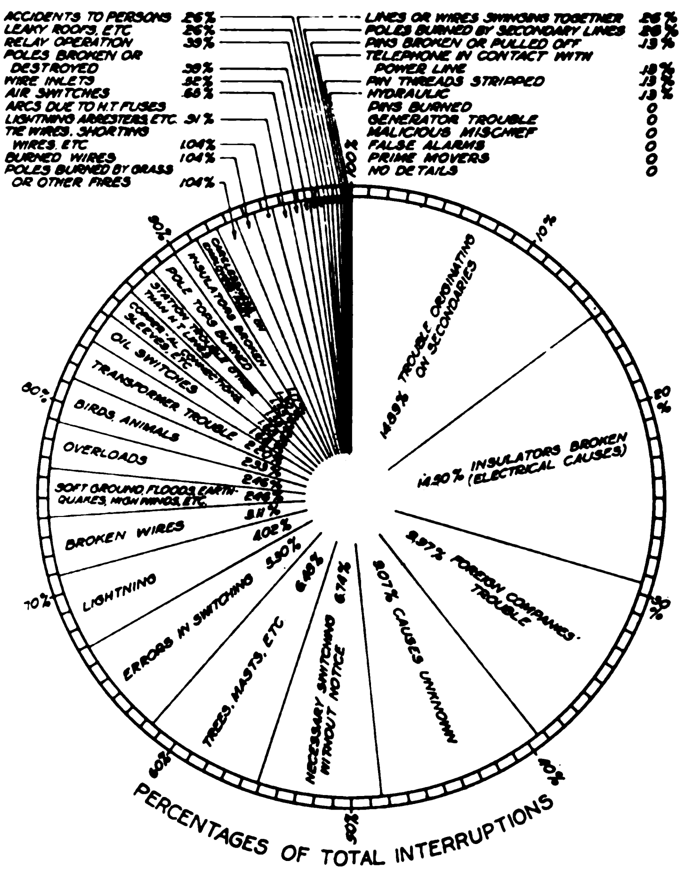
Insulation in any reasonable amount is not a positive insurance against direct strokes of lightning, severe storms or certain birds and no amount is proof against occasional man-made failures.

Stored Energy and Governing

The stored energy or fly-wheel effect of the rotating

TABLE V

Analysis of System Troubles, Pacific Gas and Electric Company



DIAGRAMMATIC ANALYSIS OF TRANSMISSION SYSTEM INTERRUPTIONS
PACIFIC GAS AND ELECTRIC COMPANY INCLUDING LEASED PROPERTIES
1924

equipment on the network varies from 2350 ft-lb. per kv-a. in the larger hydro-electric units to 1195 ft-lb. per kv-a. in some of the smaller high speed units and typical steam turbo alternators. Typical steam turbo alternators have about 5500 ft-lb. per kv-a.

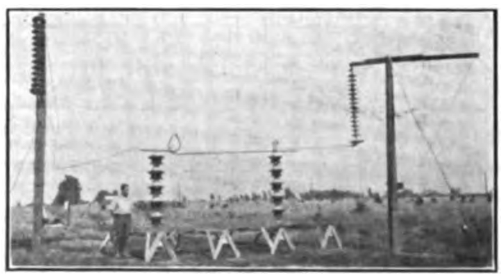


Fig. 19—Air-Switch Arrangement for Closing a Ground on the 220-Kv. Line

The effect of the rotating equipment connection as load is very difficult to determine but it was in the order of 20 per cent of the effect of the generating equipment on the network.

At any given point on the network only a certain portion of this energy is available in a case of switching

or trouble, varying for 3-phase, single-phase and phase-to-ground troubles in the same manner that the short circuit kv-a. varies as far as the distribution over the network is concerned, but the energy delivered is dependent on the rate of change of speed and also on the line and equipment characteristics.

Experience has demonstrated that for a load of 300,000 kw., a drop from 60 cycles to 59 cycles will drop the load about 3.5 per cent, while an increase of from

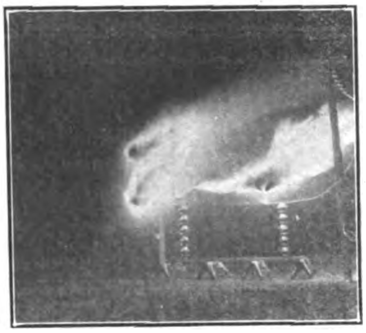


FIG. 20—PHOTOGRAPH OF A 220-KV. ARC DURING THE ARTIFICIAL FLASHOVER

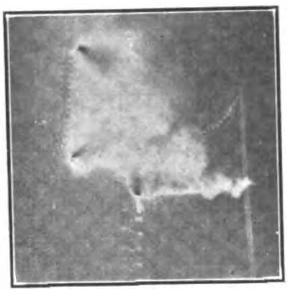


FIG. 21—SAME AS FIG. 20 FROM A DIFFERENT DIRECTION

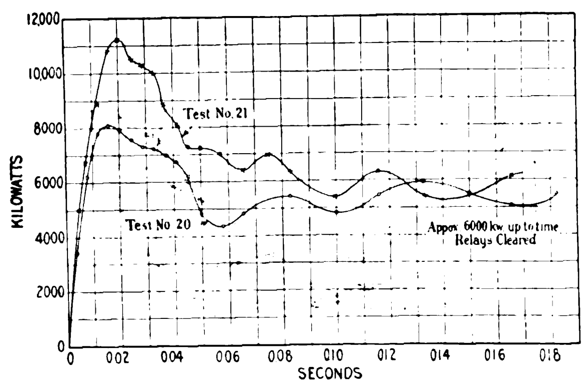


FIG. 22—RESIDUAL POWER IN ARTIFICIAL FLASHOVER

60 to 61 cycles increases the load about 4 per cent. This is due to the character of the load, some of which varies with the cube of the speed and some of which has no variation with speed. The actual percentages vary slightly therefrom with the season. The network is somewhat self-governing and the actual governing is done on one unit in a designated plant with all the remaining plants carrying block loads.

There are two methods of accomplishing this result:

1. Setting all governors on a flat speed characteristic to reject load at approximately ½ cycle above normal speed with a load limit set for a block load on all but the one governor used for regulation on turbines or a given nozzle opening on impulse wheels. Then as the speed varies too near the limit of the governing unit add to or reduce the block load to keep the governing unit in action.

2. Set all governors with a drooping speed characteristic and change the governor setting as load increases or decreases in the manner of the synchronizing motor on a steam turbine.

The Pacific Gas and Electric Company network uses the first on hydro-units and the second on steam, although various combinations have been used in the past.

On the network described above with the present system of relaying,[4] the speed does not drop enough during switching or trouble for the governors to act until after the switching is over. This is true for several reasons:

First, it is not possible to deliver sufficient kv-a. at any given point in the network to drop the speed fast enough to get governor action during the time it takes to clear trouble.

Second, governors, particularly on hydro units, have an operating time determined by the equipment controlled, *i. e.*, turbines, relief valves and penstocks, and this is of necessity a matter of several seconds.

All governors in general use today are used for holding speed and nothing else, and are, therefore, of necessity actuated only by speed. Particularly on hydroelectric units not having a means of by-passing the unit, the governors are definitely limited in action by penstock pressure rise, and are, therefore, a compromise between the cost of generators to stand overspeed and overvoltage and penstocks to stand over-pressure.

CHARGING CURRENT

Charging current on high-voltage lines plays an important part in system stability, and a considerable portion of the reported cases of instability are in fact improper operation. An example of this effect is shown in the tests where it was demonstrated that switching out a 220-kv. line at Vaca Substation and allowing it to trip on over voltage at Pit No. 1 was the most severe condition encountered as regards stability. This has also been checked in actual operation several times. It is due to the action of the line free at one end with nearly 30,000 kw. of corona loss and a leading current in the generator at Pit No. 1 Power-House. The voltage rises at Pit No. 1 Power-House in about 5 cycles and the line relays out in approximately over ¾

4. See *Electrical World*, November 22, 1924.

second under such conditions. In this connection must be considered the excitation characteristics of the generators and the manner and direction from which the charging current is supplied, *i. e.*, either from the system network and receiving-end condensers or from the generators themselves.

a. Corona. Corona load on long 220-kv. lines under certain switching conditions may be several thousand kilowatts and must be considered in stability problems.

b. Phase Balancing. On all 220-kv. switches so far installed and operated the difference in opening time of the three phases varies from 5 to 20 cycles and allows an interchange of power between phases as well as a damping action in the arc.

c. Impedance. Intimately connected with all network disturbances is the system impedance to the point in trouble. This, to be accurate, must include all the connected equipment with its proper characteristics, in most cases transient characteristics, because present-day operating practise developed by trial has demonstrated that the relay equipment must be able to separate equipment and lines in trouble in a time measured in seconds or parts of a second, or the damage done will permanently disable such line or equipment.

Very little is known about transient impedance values, particularly single-phase or phase-to-ground impedances. For most networks such data are not available nor has any practical method been developed for obtaining it.

The oscillographic wattmeter used on the flashover tests in this connection is believed to be an innovation in this respect.

All changes of load caused either by switching or grounds and short circuits are taken up in the network by a transient condition causing a change in speed followed by a readjusted steady state either at a new speed or at the same speed and new loads on one or more units.

The amount of speed change is dependent on the rate at which the stored energy can be absorbed at the point of trouble, and this in turn is dependent on the impedance which is varied by all of those things that affect the short-circuit problem, together with the character of the trouble, the excitation on the rotating equipment, charging current, corona and those things which go to make up the speed load characteristics of the network.

Conclusion

These tests represent the initial attempt to secure data of this character on a large network in actual operation. The manner of using such data and the results obtained therefrom are given in the companion paper by Evans and Wagner who were instrumental in furnishing both personnel and equipment for the tests thus far made.

CORRESPONDENCE

LEAKAGE REACTANCE

To the Editor:

I wish to take vigorous exception to Mr. Boyajian's statement in his closing discussion[1] on his paper, Resolution of Transformer Reactances, etc., that I "seem to be in agreement with the speaker on the main points of the paper." I had no such intention, and Mr. Boyajian has evidently misunderstood my discussion. In fact my position on this question of leakage reactance is entirely opposed to that set forth by Mr. Boyajian. Now it *seems* to me that he has fallen into error on account of the fact that the same "equivalent" circuit may be used to represent the behavior of a two-winding transformer, in which the exciting component of current is *not* neglected; or of a three-winding transformer, in which the exciting component of current is neglected. Since certain relations can be shown to exist in the latter case he argues that the same relations hold true in the former. This logic is entirely erroneous. As a matter of fact the conflicting views that have been expressed are occasioned by different conceptions of what leakage reactance really is. It seems to me that it would be very unfortunate if we were forced to use one value of leakage reactance when considering one component of current and a different value when considering another component; especially so, since the various components are, in reality, nothing but figments of the imagination. This, however, is Mr. Boyajian's conception for he says, "The burden of my paper was to show that the leakage reactance which a winding offers to exciting current is different from that which it offers to a load current, similar, etc."

Of the half dozen books which I have just consulted I find none that supports this view. The late Dr. Steinmetz, for example, in discussing the transformer assigns a definite leakage reactance to the primary and another definite leakage reactance to the secondary. There appears to be no question whatever of using one value of leakage reactance for an exciting component and a different one for a load component.[2] A good exposition of this point of view will be found in "Principles of Alternating Currents," R. R. Lawrence. The definition there given for the leakage inductance of winding No. 1 with respect to winding No. 2 is the difference between the self-inductance of winding No. 1 and the mutual inductance between windings Nos. 1 and 2 multiplied by the ratio of the turns. The leakage reactance of one winding is always given with respect to some other winding. It is not a function of one winding alone but of two windings. In this respect it is like mutual inductance. Of course, in a commercial transformer the self and mutual inductances are variable but their difference as described above is essentially constant except possibly under some extreme condition

1. A. I. E. E. Journal, October 1925, page 1140.
2. "Alternating Current Phenomena," C. P. Steinmetz.

of core saturation, inasmuch as the leakage-flux linkages of one winding with respect to the other must be due to flux that exists at least partly in air. Here I wish to emphasize most strongly that in general reactance is not a function of any particular current but depends solely upon the configuration of the electric circuit or circuits considered and the neighboring magnetic material and its condition. In general the condition of this magnetic material depends upon *all* of the currents and not upon any one or upon any component of any one.

So far as I am aware, any problem that depends upon variable reactances can be handled only by making suitable approximations. There is no doubt that the leakage reactance of one winding of a transformer with respect to another may be different with different core saturations. However, I have never seen any reliable data tending to show that these differences are significant. And even if they did exist, it would not mean that one value of leakage reactance should be used with one component and a different value with another component of current, as Mr. Boyajian implies.

With the foregoing conception of leakage reactance, the vector difference in potential between the primary and secondary potentials of a one-to-one two-winding transformer is the vector sum of the individual leakage-impedance drops in the primary and secondary windings. This use of vectors assumes that the currents are essentially sinusoidal. Ordinarily we assume that the two currents are equal, in which case the "equivalent" leakage reactance is the numerical sum of the individual leakage reactances. It is only when the exciting current is neglected, however, that this summation is allowable.

Now there is another point in this connection that Mr. Boyajian seems not to consider when he proposes his first test. It is that reactance can usefully be defined as the ratio of volts to amperes only when the wave form of the current is sinusoidal. For example, the third-harmonic component of drop in this test is probably much larger than the fundamental component. The test is therefore valueless without the wave form of exciting current, and even if this is known the accuracy is rather poor and the computation rather cumbersome. This same comment in regard to wave form of current applies to Mr. Boyajian's test No. 5. Prof. Dahl mentions this and I am entirely in agreement with him. The small variation that Mr. Boyajian noticed might be due either to transformer unbalance, as Prof. Dahl suggests, or to an actual change in the leakage reactance of the windings due to the change in the saturation of the core as I have previously cited. If oscillographic measurements had been made some useful results might have been presented in regard to this point.

His test No. 2 will give correct results only if the resistance is negligibly small as compared with the leakage reactance at fundamental frequency.[3] The advantage of tests Nos. 1 and 2 is that they may be run at normal core saturation. On the other hand potential transformers must be used if the ratio of transformation is other than unity. This is a real disadvantage, inasmuch as their ratio must agree with that of the transformers being tested to within a few hundredths of one per cent in order that they may introduce a small error. The currents also contain large third-harmonic components.

The disadvantages of tests Nos. 3 and 4 are that auxiliary transformers must be used if the ratio of the transformer being tested is other than unity and that the core is run at low saturation, so that if the leakage is a function of the saturation, this factor is disregarded.

The disadvantages of the third-harmonic method are that three identical transformers are required, and that to be certain of the results oscillographic measurements are necessary. On the other hand, the core saturation is normal and no auxiliary transformers are necessary to correct for a ratio other than unity. On the whole it seems to offer the best method for determining the individual leakages.

Let me emphasize, even at the risk of repetition, that the leakage inductance of one winding with respect to another is determined solely by the configuration of the two windings with respect to each other and to the iron core and by the magnetic condition of the latter. This magnetic condition fundamentally depends upon all of the currents acting and upon nothing less.

Now, in regard to three-circuit transformers, I have shown that the reactances which may be used to represent the individual windings in the equivalent net-work that Mr. Boyajian proposes are *not* the leakage reactances of the windings. Equations **6**, **7**, and **8** in my discussion show clearly what their composition really is. For example, the reactance that should be assigned to winding No. 1 is the *leakage* of this winding with respect to winding No. 2 *plus* the differential *mutual* effect of winding No. 3 upon windings Nos. 2 and 1 respectively.

W. V. LYONS

RADIO SETS ON FARMS

The farmers of the United States as a class have become radio enthusiasts and today have more than twice as many radio receiving sets as they did two years ago. In 1923 there were 145,000 receiving sets on farms throughout the country, while at the close of 1925 the number of these farmer sets had risen to 553,000.

Farmers have discovered that in order to get weather and market reports as well as the entertainment they desire they must have "good distance sets," and dealers selling radios to the farmers report that sets worth from $125 to $400 are much easier to sell than sets costing under $100. Also today 24 agricultural colleges in the United States maintain radio broadcasting stations and are paying a great deal of attention to the programs they put on the air.

3. Except when the ratio of resistance to leakage inductance is the same for the two windings.

Starting Characteristics and Control of Polyphase Squirrel-Cage Induction Motors

BY HORACE M. NORMAN[1]

Associate, A. I. E. E.

Synopsis.—*In the application of squirrel-cage induction motors to such severe service as frequent start and stop or frequent plugging operation, it is desirable to know how much loss the motor will be required to dissipate. Plugging being understood as changing the motor from any speed in one direction to any speed in the opposite direction, by reversing the rotation of the field only.*

The subject of starting loss is also of interest from the control standpoint; such as the application of auto-transformers for starting purposes; or where an external resistance is inserted in the primary as is done in the control of elevator motors.

Consideration is given to the part that the primary and secondary resistance and the total reactance play in the determination and the manipulation of the starting losses; and, as it is true that in many applications the time spent in accelerating the rotor from rest is useless from the production standpoint, consideration is given to the value of secondary resistance that will give minimum starting time for a given field strength. This involves a method for the determination of the time taken to attain a given speed in general.

There are many cases where a motor has already been designed and tested, and is about to be applied on a given job where the cycle of operation is known and includes either starting and stopping or plugging. In such an event, instead of working with the various test values to get the constants of the machine, it is much more convenient and accurate to work from such values as starting torque, maximum torque, slip at full load, locked current and primary resistance.

It will be shown how the proceeding short-cut method can for most cases be made more simple without sacrificing the accuracy of the result to any appreciable extent.

When a motor is plugged the problem is complicated by the difficulty that eddy currents flow in the rotor which give a slight increased effect to the torque at negative speeds. Although this paper does not show how to predetermine its amount, it does show how to handle the losses and the time of reversal, if the test speed-torque values are known or can be estimated from another machine.

* * * * *

When an induction motor is started up in series with an auto-transformer, the ratio of the loss in the motor and auto-transformer at any instant is a constant. The ratio of total loss over the entire starting period must have this same value. As this value can easily be calculated by considering any particular instant, such as the very start, it is obvious that the total loss in the auto-transformer is known when that of the primary of the motor is known. From this it can be seen that the two problems are reduced to that of the motor only.

It is true that in the vast majority of cases the r. m. s. value of starting current is very large compared to the magnetizing current and that sufficient accuracy can be obtained by neglecting the magnetizing current except in so far as it effects the torque.

Reducing the secondary circuit to terms of the primary and neglecting the magnetizing current, the iron, and the friction and windage losses it can be assumed that the secondary current is equal to the primary current. The ratio of the primary loss to the secondary loss during the starting period will then be as their respective resistances. Therefore:

$$\frac{\text{Total primary loss during starting period}}{\text{Total secondary loss during starting period}} = \frac{\text{Primary resistance}}{\text{Secondary resistance}} = \frac{r_1}{r_2}$$

The primary resistance is taken to be per leg of the winding, and the secondary resistance in terms of the primary can be found by

$$r_2 = \frac{T_{st}\, N}{7.04\, \phi\, I_L^2} \qquad (1)$$

where

T_{st} = starting torque
N = synchronous speed in rev. per min.
ϕ = number of phases
I_L = locked amperes per leg

To find the secondary loss during the starting period, it is only necessary to consider the field as at rest instead of the stator. In this case the stator would have to be considered as revolving backwards at synchronous speed and the rotor with it to correspond with the starting condition of the motor: then when the line switch is thrown in, a stationary field is set up which acts as a brake on the revolving rotor and tends to bring it to rest. The only difference between a mechanical and such an electrical brake is that the loss in one is in friction loss and the other in copper loss with perhaps a little iron loss. Since it does not matter to what degree a mechanical brake is applied the total loss is equal to the difference of the kinetic energy before and after, so in this case the loss is proportional to the square of the initial speed less the square of the final speed, the field being considered as stationary, and is also proportional to the total inertia resisting the change of speed. Assuming that there is no friction or hauling load during the starting period, then the rotor loss depends only on the above considerations from which the following formula can be evolved:

$$\text{Rotor loss (Joules)} = .00744\ (M\,I)\ N^2\ (s^2 - S^2) \qquad (2)$$

while changing from speed $N(1 - s)$ to speed $N(1 - S)$, inertia being the only resistance to motion. The total

1. Design Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

Abridgment of paper to be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available to members on request.

inertia of the whole system being reduced to terms of the rotor and being equal to $(M\,I)$.

From this it can be seen that the loss during plugging is about four times as great as that for starting only.

Further, since the primary loss is to the secondary loss as r_1 is to r_2, and since the secondary loss is independent of the value of the secondary resistance, then it follows that the higher the secondary resistance the lower will be the primary loss during the starting or reversing period.

Assuming that the primary resistance varies as the turns squared, which is probable, then it is true that neither the primary nor secondary total joules loss during the starting period can be raised or lowered by changing the number of primary turns.

This is obvious when it is considered that the secondary resistance in terms of the primary varies as the primary turns squared; that is, as the primary resistance. The ratio of resistances is therefore a constant, and since the losses are of the same ratio and remembering that the secondary starting loss is independent of the secondary resistance, then the primary starting loss in joules is independent of the primary turns, assuming that the resistance varies as the turns squared.

It is also obvious that changing the primary voltage will not change these starting losses.

Any increase or decrease in reactance due to change of saturation or variation of turns does not change the total joules loss at start, it merely increases or decreases the time of start.

These arguments neglect friction and windage of the accelerated system which as a rule are of only secondary consideration.

It is, therefore, clear that the only way to decrease the starting loss of a squirrel-cage induction motor is to increase the secondary resistance. This, however, cannot be brought to the extreme because, if enough resistance be added, the accelerating torques will be reduced so much that the time taken to attain a given speed would be excessive and further the full-load slip would be too great, giving a very low running speed and poor efficiency.

The question then arises: What is the value of secondary resistance to best suit a given application?

There are two factors that enter into the determination of the answer. First, is the secondary resistance to be such that the losses in the motor during a complete cycle of operation are to be a minimum; and second, is it desirable to start up in the minimum time.

It is obvious that no mathematics can decide what compromise should be made between the two values of secondary resistance obtained from the two above considerations; but even though neither ideal is finally selected it is well to know what they are, so that the secondary resistance can be made some intermediate value.

To find the total losses during a complete cycle of operation, it is only necessary to multiply the running losses by their duration in seconds and add the starting or plugging loss in joules. This gives the total joules loss over a complete cycle of operation and if divided by the total time for the complete cycle, it gives the average watts loss for continuous operation.

The value of secondary resistance to give minimum average loss for continuous operation will naturally depend on the time and variation of the load and the number of stops and starts or reversals.

Assuming that the torque T for any slip s is given by

$$T = \frac{7.04\, E^2\, r_2\, \phi\, s}{N\left[r_2^2\left(\frac{E}{E_g}\right)^2 + 2\, r_1\, r_2\, s + (r_1^2 + x^2)\left(\frac{E}{E_g}\right) s^2\right]} \qquad (3)$$

then the time taken to start from rest and reach a speed corresponding to a slip of S is given by

$$\text{Time (seconds)} = .01487\,\frac{(M\,I)\,N}{E^2\,\phi}\left[r_2\left(\frac{E}{E_g}\right)^2 \log_e\left(\frac{1}{S}\right) + 2\, r_1\,(1-s) + \left(\frac{E}{E_g}\right)\frac{(r_1^2 + X^2)(1-S^2)}{2\, r_2}\right] \qquad (4)$$

Where

$(M\,I)$ = moment of inertia of the whole system transferred to and including the rotor (lb-ft.).
N = synchronous speed (rev. per min.)
E = Primary volts per leg
E_g = $E - X_1 I_m$
$X_1 I_m$ = no-load reactance drop in primary
ϕ = number of phases
r_1 = primary resistance per leg (add external primary resistance if any)
r_2 = secondary resistance per leg in turns of primary
X = total reactance (add external primary reactance if any)
S = normal or final slip

Use .0149 for constant

Assuming that all the constants of the motor are fixed with the exception of the secondary resistance, then the value of secondary resistance to give minimum time to attain a given speed can be derived from the preceding equation and will be as follows:

$$r_2 = \sqrt{\frac{(X^2 + r_1^2)(1 - S^2)}{4.6\left(\frac{E}{E_g}\right)\log_{10}\left(\frac{1}{S}\right)}} \qquad (5)$$

This formula gives the value of r_2 which would speed the motor from rest to $N\,(1 - S)$ revolutions per minute in the least time.

Oscillograph records were taken of a squirrel-cage motor when starting up and when plugged in order to check the assumption that the dry bearings at start cause a delay which is small compared with the total time of start; they were also taken with a view to checking the time to establish the field.

Fig. 1A and B show the current in the primary building up when the motor is started and plugged. It can be seen from A that the current is normal after

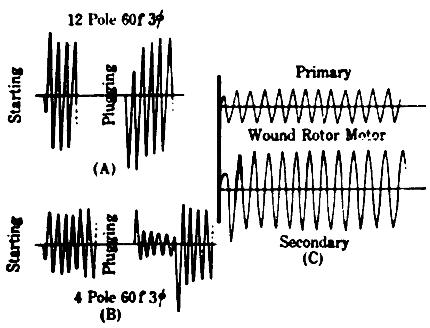


FIG. 1

about two cycles when the motor is started from rest and after four cycles when plugged. From B it can be seen that for start the current has about 90 per cent of its full value for about four cycles, and is then normal; when plugged there is some irregularity but after seven cycles the current is stable. This irregularity is probably due to one of the poles of the switch making bad

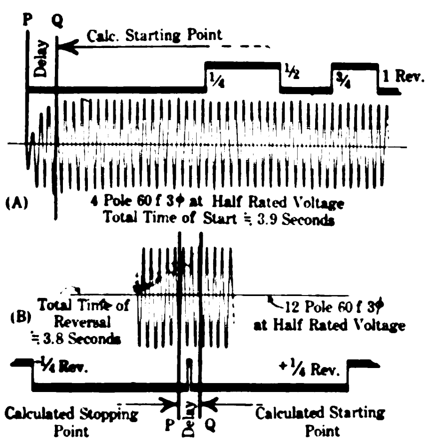


FIG. 2—(A) FOUR-POLE, 60-CYCLE, AT HALF RATED VOLTAGE, TOTAL TIME OF START = 3.9 SEC. (B) TWELVE-POLE, 60-CYCLE, AT HALF-RATED VOLTAGE, TOTAL TIME OF REVERSAL = 3.8 SEC.

contact. Later tests with a wound rotor showed that one of the contacts was poor as the primary current in this particular phase did not start till about one-tenth of a second after the secondary current had started up. This indicates that a faulty switch can cause excess loss in the motor because as soon as two poles make contact the motor will draw single-phase current which causes a loss in the stator and rotor but gives zero torque. It is only when the third pole makes contact that the motor starts up.

Fig. 1C shows the primary and secondary current of a wound rotor motor when started from rest. It can be seen that the secondary current builds up inside of two cycles.

From these tests it can be seen that it is not unreasonable to neglect the time taken to establish the field and the secondary current.

Fig. 2A shows the primary current waves of a squirrel-cage motor when starting up; and above it a line which is displaced after the rotor turns one quarter of a revolution and remains so for the next quarter revolution, etc. This line is obtained by mounting two contact strips diametrically opposite to each other on a paper pulley, each covering one quarter of the circumference of the pulley.

The pulley is mounted on the motor shaft so that every time a contact piece passes a stationary carbon brush a current is established which actuates the oscillograph. Working back from slips of 10 per cent, 50 per cent and 75 per cent to get the moment of inertia

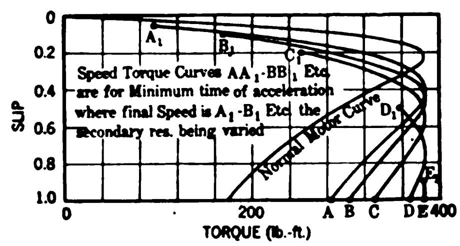


FIG. 3—SPEED TORQUE CURVES

A A-B B etc., are for min. time of accelerations where final speed is *A*, *B* etc., the final secondary resistance being varied

of the rotor and pulley and then using the result to get the instant of start, assuming there is no delay, the point *Q* is reached. Since the switch was thrown in at the instant *P* then the difference represents the delay. Fig. 2B represents the same thing when the motor is plugged. The delay in this case is for the excess friction when the rotor is changing direction of rotation. Both these delays are very small compared with the total time of start or plugging.

The usual value of friction and windage for a motor is such that it lowers the efficiency by only a few per cent so that it has the effect of reducing the torque exerted by the field on the rotor by only a few per cent at full load. For greater values of slip this reduction is less while the field torque is greater, which shows that it is justifiable to neglect it during the accelerating period, which has been done in the previous formulas.

Fig. 3 shows a series of curves each having the same maximum torque value, but which are for different values of secondary resistance. The various starting torques are obtained by using the value of secondary resistance obtained by formula (5) when the slips corresponding to A_1 B_1 etc., are used. These curves then give an idea of what shape the speed torque curve should have for the minimum time of acceleration to a

given speed (assuming that the only resistance to motion is in the form of inertia).

It should be noted that an erroneous conception is often held that the time of acceleration varies inversely as the average torque.

This would lead to the conclusion that a single-phase motor would start up since it has a definite average torque. The fact is that the time for any constant value of torque varies inversely as this torque, and this can be applied with reasonable accuracy for small changes in slip, but for the total accelerating period, it should be noted that the time of acceleration varies as the average of the inverse of the torque. This average being obtained by taking the inverse of the torques for equal increments of speed. From this it can be seen that the time can be abnormal if the torque for any speed whatever approaches zero and would be infinite if it did drop to zero, which means that the motor would never speed up beyond this point.

It is sometimes assumed that if the value of locked

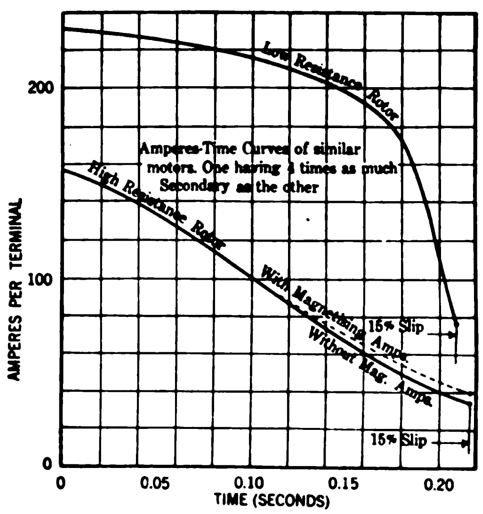


FIG. 4—AMPERE-TIME CURVES OF SIMILAR MOTORS

One having four times as much secondary resistance as the other

amperes is used for zero time and full-load amperes for the end of the accelerating period, then the current curve could be assumed to be a straight line joining these two points. This is not necessarily true, but happens that for some high resistance rotor motors it is nearly so. However, it is far from true of the average motor where the starting current tends to hang on, and in Fig. 4 is shown to be as high as 93 per cent of locked value after half the starting time is passed. This is the upper curve for the low resistance rotor. The lower curve is for a rotor with four times as much resistance, and it can be seen that the current falls off nearly as a straight line.

The torque curve for this latter motor would have nearly maximum torque at start.

It will be noted from these two curves how much the starting current is reduced for the high resistance rotor compared with the normal rotor, and also that the average current is still a lower ratio. The root mean square value of the two curves should have a ratio of nearly two because the time of start for each case is practically the same. The r. m. s. value of each current curve when multiplied by the time of start should have a ratio of exactly two, which, when squared and multiplied by the ratio of resistances gives unity; showing that the rotor loss is the same in either case as previously shown.

Since the stator winding is the same for either case, and noting that there is little difference in the time of start, it can readily be seen that the stator loss is much lower for the high resistance rotor than for the normal rotor.

TIME OF ACCELERATION USING TEST VALUES OF TORQUES

Taking the case of a normal resistance rotor motor when the duty cycle is known, it is true that in the majority of cases the motor which is finally selected has already been built and tested.

In such a case it is quicker to use these tested torques, than if a complete calculation were made of the machine.

The values required to find the time of acceleration from rest to a given speed are the slip at load torque equal to the starting torque, the maximum and starting torques, synchronous speed and moment of inertia of the rotor if starting light, and if loaded then the equivalent moment of inertia of the whole system, reduced to terms of the rotor.

Let

Maximum torque	$= T_m$
Starting torque	$= T_{st}$
Slip at load torque equal to T_{st}	$= s_1$
Synchronous speed	$= N$
Moment of Inertia (total)	$= (M\,I)$

$$T = \frac{a\,s}{b + c\,s + s^2} \qquad (4)$$

[Refer to formula (3)] where a, b and c are constants.

(a) $a = T_{st}\,(b + c + 1)$

(b) $b = s_1$

(c) $c = \dfrac{T_{st}\,(1 + s_1) - 2\sqrt{s_1}\,T_m}{T_m - T_{st}}$

From (a) (b) (c) the values of a, b and c can be found and can be substituted in a corresponding formula to (4), as follows:

Time of acceleration (sec.)

$$= \frac{\pi\,(MI)\,N}{30\,a}\left[2.3\,b\log_{10}\left(\frac{1}{S}\right) + c(1-S) + \frac{1-S^2}{2}\right] \qquad (6)$$

from rest to slip of S.

When the speed reaches 90 per cent to 95 per cent of synchronous speed, it can be assumed that it is near enough to be counted up to speed; then if 90 per cent is taken the log to the base ten becomes unity and for 95 per cent it becomes 1.301. It makes only a slight

difference in the time of start, whichever of the above final speeds is chosen.

Approximate Method Using only Maximum and Starting Torques

The preceding method can be simplified by assuming that the torque curve has a formula:

$$T = \frac{a\,s}{b + s^2} \qquad (\mathbf{8})$$

It should be noted that the value of a and b will be different in this formula than in formula (**6**) so that the part c plays is not entirely neglected.

Using only the maximum and starting torques, the

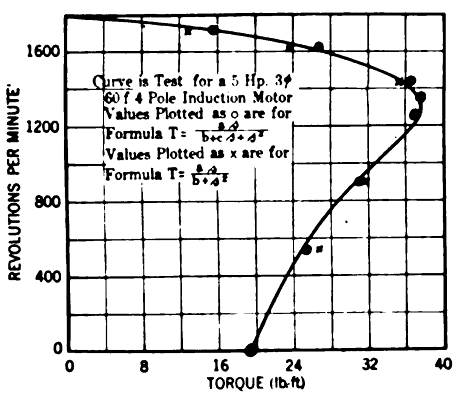


Fig. 5—Test Curve for 5-h. p., Three-Phase, 60-Cycle, Four-Pole, Induction Motor

Values plotted as O are for formula

$$T = \frac{a\,S}{b - c\,S - S^2}$$

Values plotted as X are for formula

$$T = \frac{a\,S}{b - S^2}$$

value of a and b for this formula are found in the following:

$a \;= 2\,S_m\,T_m$ or $= T_{st}\,(1 + b)$

$b \;= S_m^{\,2}$

where

$$S_m = \left(\frac{T_m}{T_{st}}\right) - \sqrt{\left(\frac{T_m}{T_{st}}\right)^2 - 1} = \text{Slip at maxi-}$$

mum torque as given by formula (**8**)

The curve plotted by using these values of a and b will have the same maximum and starting torque as test curve and will follow the test curve very closely.

The time equation then becomes:

$$\text{Time (seconds)} = \frac{\pi}{30} \times \frac{(M\,I)\,N}{a}$$

$$\left[\,2.3\,b\,\log_{10}\left(\frac{1}{S}\right) + \frac{1 - S^2}{2}\,\right] \qquad (\mathbf{9})$$

Fig. 5 shows a test speed torque curve and the calculated values for formula (**6**) plotted as (o) and those for formula (**8**) plotted as (x).

Speed Torque Equation for High-Resistance Rotor Motors

The two previous methods cannot be used for finding the equation of the speed torque curve of a motor which has approximately maximum torque at start. The following method should be employed: Find the ratio of torque to slip for a point infinitely close to the point torque = o, slip = o, by drawing a tangent to the curve at this point. Let this value be tangent θ.

Take the slip for some load torque, preferably of two-thirds the value of the starting torque. Let this slip be S_1 and the torque T_1. Let the starting torque $= T_{st}$

Then

$$a \;= b \tan\theta$$

$$b = \frac{1}{\dfrac{1}{S_1} - \dfrac{(T_{st} - T_1)\tan\theta}{(1 - S_1)\,T_{st}\,T_1}}$$

$$b = \frac{1}{\dfrac{1}{S_1} - \dfrac{\tan\theta}{2\,(1 - S_1)\,T_{st}}} \quad \text{if } T_1 = \frac{2}{3}\,T_{st} \qquad (\mathbf{10})$$

$$c = \frac{a}{T_{st}} - b - 1$$

and

$$\text{Torque} = T = \frac{a\,s}{b + c\,s + s^2}$$

Fig. 6 shows the test speed-torque curve in full,

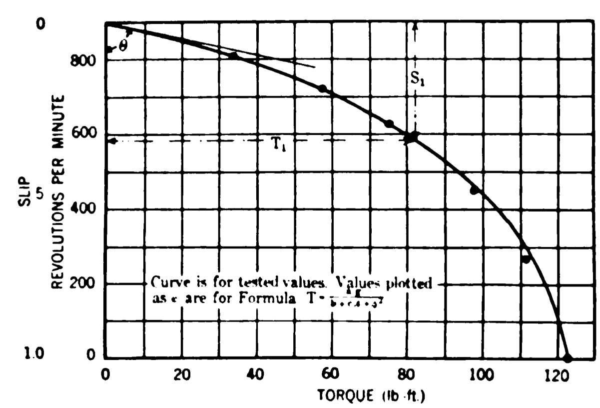


Fig. 6—Curve for Tested Values

Values plotted as O are for formula

$$T = \frac{a\,S}{b - c\,S - S^2}$$

and points calculated by this method plotted as ($\odot$).

Plugging Service

When a motor is plugged there are eddy currents in the rotor which are very pronounced at negative speeds. These eddy currents cause an increase in the rotor loss over what it would be if measures were taken to prevent eddy currents. This increase in the rotor loss makes the torque larger and since the eddy currents increase as the

slip increases it follows that the torques are affected more at negative speeds than at positive speeds. The increase in torque can be considerable and makes quite a difference in time of deceleration, and also in the joules loss in the primary.

When it is stated that there are eddy currents in the rotor it is meant that there are additional currents in the rotor bars besides a uniformly distributed current. These additional currents add in some places and subtract in others from the uniformly distributed current, and have the resultant effect of an uneven distribution.

Since the rotor copper loss is proportional to the average of the density squared of the current, then it can be shown that this loss is least when the density is uniform over the rotor bar. The loss must, therefore, be greater when the distribution is uneven, and this condition can be duplicated by a higher resistance rotor having no eddy currents.

The uneven distribution of current in the rotor bar is caused by variation of leakage flux linkages for different sections of the rotor bars, and is therefore more and more pronounced the higher the rotor frequency.

It is true that near standstill there is not a great deal of excess torque over what would be expected so that the equivalent secondary resistance can be assumed to be constant between rest and synchronous speed.

Since the derivation of formula (**2**) shows the secondary loss to be independent of the value of secondary resistance during acceleration or retardation, then it follows that it will be independent of a varying value of secondary resistance. But even though the primary resistance is constant the primary loss during this period depends on the variation of the secondary resistance.

For a high-resistance rotor motor, the major loss is in the secondary copper so that any variation in the primary loss as found by formula (**2**) when multiplied by the ratio of resistances can be neglected. Besides this latter consideration, it should be noted that a high resistance rotor will have less eddy currents than a low resistance rotor.

Therefore, when a high-resistance rotor motor is plugged the total loss during the total plugging time can be found by the following:

Joules loss in stator and rotor

$$= 0.00744 \frac{r_1 + r_2}{r_2} (M\ I)\ N^2 (4 - S^2) \qquad (\mathbf{11})$$

For high resistance rotor motors only and when motor is plugged.

When a low resistance rotor motor is plugged the primary loss is much less than the above formula would assume. The main difference being while the rotor is decelerating. The primary loss in joules during this time can be approximately found by assuming that the current is of constant value and equal to the current at the instant of plugging. This is very nearly true of a low resistance rotor motor but not so of a high resistance rotor motor in which case this current may be 30 per cent greater than the locked amperes.

The joules loss can be found by the following formula.

Joules loss in stator and rotor

$$= 0.00744 (MI) N^2 \left[\frac{r_1}{r_2} (1 - S^2) + 4 - S^2 \right] + \phi r_1 I_p^2 t_p \quad (\mathbf{12})$$

For low resistance rotor motors only and when rotor is plugged.

Where

I_p = amperes per leg of the winding at the instant of plugging.

and

t_p = time for rotor to come to rest.

The value of t_p can be approximately found as follows:

$$t_p \text{ (seconds)} = \frac{\pi}{60} (M\ I)\ N \frac{T_{plug} + T_{st}}{T_{plug} \times T_{st}}$$

where

T_{plug} = the torque at the instant of plugging.

Equivalent Moment of Inertia (In Terms of the Rotor)

It will be noticed that every time and loss formula includes the term ($M\ I$) which is the total inertia of the whole system reduced to terms of the rotor.

As this figure is the result of multiplying every small mass by its velocity squared and comparing it with that of the rotor, it can be seen that there are many cases where the rotor, due to its high speed, plays the major part in holding back the whole system from instantly coming up to speed.

The moment of inertia of the rotor should be known then if the preceding formulas are expected to give the correct losses and times.

The following method lends itself to great accuracy, due to the fact that the only measurement necessary is time. The other dimensions used are the journal sizes, which are very accurately ground to size, and are both of equal size and known beforehand.

The equipment is two rails accurately machined to a very large radius. These are placed parallel to each other and the rotor is placed on them so that each journal rides on a rail.

As the rails are circular the rotor naturally will swing back and forth with a harmonic motion.

Fig. 7 shows the scheme suggested.

Let

R = radius of gyration of the rotor (ft.)

P = period of rotor swing (sec.)

r = radius of rotor bearings (ft.)

l = radius of the circular rails (ft.)

g = gravity

Then

$$\text{Radius of gyration} = R = r \sqrt{\frac{P^2\, g\, (l - r)}{4\, \pi^2\, l^2} - 1}$$

When this formula is used it will be noticed that the

first term under the radical is very large compared with the second term, provided that l is very large. The accuracy with which R is obtained then approaches that of the period P.

The radius of the rails l should be made very large so that the period becomes very large and tends to eliminate windage, and also so that for a given amplitude of swing the angle of the rails will be small and so prevent slipping of the journals on the rails.

The accuracy of R is unaffected by the fact that the rotor might be placed on the rails slightly skewed so that when at rest the bearings would not be at the lowest point of the rails.

External Moving Parts

In transferring the inertia of external moving parts to terms of the rotor, the following rules are sufficient for most cases.

1. All parts that have only linear motion should be transferred according to the following law.

$$(M\ I) \text{ equivalent } = \frac{W}{g}\left(\frac{30\ V}{\pi\ (\text{r. p. m.})}\right)^2$$

Where

$(M\ I)$ equivalent = moment of inertia when transferred to the rotor.

W = external weight in lb.

V = velocity of W in ft. per sec.

g = gravity

(r. p. m.) = revolutions per min. of rotor

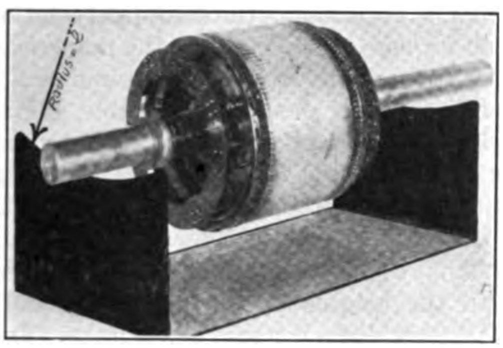


Fig. 7—Curve for Tested Valves

Valves plotted O are for formula

$$T = \frac{a\ S}{b - c\ S - S}$$

2. All parts that have a rotary motion only should be transferred by having their moment of inertia multiplied by the square of the ratio of their speed compared with the speed of the rotor.

All previous formulas pertaining to loss or time have been evolved with the assumption that the only resistance to motion is inertia. This is approximately so in a great many cases, but if any particular application should have a large friction or hauling load to overcome then these formula cannot be used. Any friction or hauling load should be applied as a reduction in torque and not as some supposedly equivalent inertia.

If the complete current torque curve be not available then it can be built up from the speed-torque curve by the following:

$$I_1 = I_2 = \sqrt{\frac{N\ s\ T}{7.04\ \phi\ r_2}} = \sqrt{s\ T} \times \text{constant}$$

where s and T are the values of slip and torque corresponding to the current.

Conclusion

For all cases worked out the primary loss has been found so that if some type of control be in the circuit, the loss can be found for it during a complete cycle of operation. The proper size controller can then be applied which will not have an excessive factor of safety.

When a motor is to be used for either starting and stopping or reversing service, the total losses of the motor during a complete cycle can be found by the preceding formulas. Knowing from test the amount of loss that the motor can dissipate for a definite rise of temperature, and knowing the loss it will be required to dissipate, the temperature rise of the motor can be predicted.

This estimated rise indicates whether or not the proper size motor has been selected.

THE DISTANCE RANGE OF RADIO TELEPHONE BROADCASTING STATIONS

As is well known, the conditions affecting radio transmission are too complex to permit a simple analysis. A direct method of studying such conditions and their variations is the analysis of a large number of similar observations taken by an organized group of observers of receiving conditions. The Bureau of Standards has made such an investigation, and part of the results are described in a paper just issued, Technologic Paper No. 297, A Statistical Study of Conditions Affecting the Distance Range of Radio Telephone Broadcasting Stations, by C. M. Jansky, Jr. This paper describes one year's work on the investigation of conditions affecting distance range of broadcasting stations by the Bureau of Standards with the aid of about 100 voluntary observers. The observations were made for a year in the period 1922-23 on transmitting station KDKA of the Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. The observers were scattered over all distances up to 400 miles from the transmitting station. The data obtained were analyzed on automatic machines. The paper gives charts showing (1) variation of strength of atmospherics, (2) variation of fading, (3) relative magnitude of obstacles to reception, (4) variation of interference from receiving sets, (5) relative magnitude of obstacles to reception grouped in bimonthly periods, and (6) mean reliability of reception as a function of distance. A copy of this paper may be obtained for 5 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Cross-Field Theory of Alternating-Current Machines

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Synopsis.—*It is the purpose of this paper to show how analysis by the cross-field theory may be used to obtain accurate, purely numerical methods of calculating performance characteristics of alternating-current machines. Methods of calculation are derived and sample calculations are given for the single-phase induction motor and the repulsion motor.*

ALTERNATING-current machines may be analyzed according to either the revolving-field or the cross-field theory. Each of these theories has its own individual merits, depending more or less on the type of machine under consideration. Some phenomena are more easily understood by a study following the revolving-field theory, and other phenomena are made more clear by use of the cross-field theory.

For routine calculation of performance characteristics of alternating-current machines, many graphical and analytical methods have been developed. These different methods also have their own individual merits and the choice of a method of calculation should depend partly on what is most desired; *e. g.*, speed, accuracy, or aid to visualization.

Therefore, we may say that, in general, neither the revolving-field nor the cross-field method of analysis, and no one method of calculation, graphical or analytical, should be used exclusively. Although this paper deals only with a general analytical method of studying some types of a-c. machines using the cross-field theory, it is not by any means intended as a plea for the exclusive use of this general method, for it is recognized that whatever usefulness it may have will be found in rather limited fields.

In the following, the attempt is made to show how a general method of analysis, following the cross-field theory, may be applied to alternating-current motors to obtain simple and accurate, purely numerical methods for routine calculations of performance characteristics. The fundamental principles of the analysis of motors by the cross-field method are, of course, very well known. The general method given below is fundamentally the same as that outlined by Steinmetz in his "Theory and Calculation of Electrical Apparatus," but differs from it in the treatment of the leakage reactance, and in the arrangement of the results.

Briefly stated, the general method as applied to a motor is as follows: Kirchoff's voltage equations are set up for the different circuits of the motor and are solved to obtain equations for the currents in each of the circuits in terms of the applied voltage, the design constants of the motor and the speed. From these equations, other equations for the fluxes linking or cut by the rotor conductors are obtained. The torque corresponding to any one of the rotor circuits is obtained by multiplying the in-phase components of the current and the fluxes cut by the conductors of that circuit. Adding the components of torque corresponding to each of the rotor circuits, we obtain an expression for the total torque developed, which, multiplied by the speed, gives the power generated. Subtracting from this the friction losses gives the power output. The power input is, of course, given by the product of the applied voltage and the in-phase component of the line current.

In this paper, the angle of hysteretic lag between flux and m. m. f. is neglected in the analytical solutions, and correction for core loss is made in the numerical calculations by treating the core loss the same as if it were a friction loss. If it should be desirable, the angle of hysteretic lag can be taken into account by using the complex quantity $Z_m = R_m + j\,X_m$ for the magnetizing impedance in place of the pure reactance $j\,X_m$ which is used in the equations in the following part of this paper. This would complicate matters slightly by adding to the lengths of the equations, and would yield but a very slight increase in accuracy. In almost all cases, the slight increase in accuracy would not justify the extra labor and chances for numerical errors.

Sine wave distributions of m. m. f., and uniform air-gap permeance are assumed in all cases.

The details and application of the method can best be shown by means of examples, as follows:

THE SINGLE-PHASE INDUCTION MOTOR

According to the cross-field theory, the components of the main flux of the motor and the rotor currents are considered separately in two axes at right angles to each other. The axis of the stator winding may be called the transformer axis, and the axis at right angles to it the field axis. A squirrel cage is considered as equivalent to a commutated winding with brushes bearing on the commutator short circuited on themselves in the transformer and field axes. The motor can then be represented diagrammatically as in Fig. 1.

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The following symbols will apply:

E = applied voltage
I_1 = line current
I_{1a} = power component of line current
I_{1b} = reactive component of line current
I_{2t} = rotor current in the transformer axis
I_{2f} = rotor current in the field axis
r_1 = resistance of the stator winding
r_2 = resistance of each of the rotor circuits
X_m = mutual inductive reactance of the stator and rotor windings
x_1 = leakage reactance of the stator winding
x_2 = leakage reactance of each of the rotor circuits
N = effective number of turns in each of the circuits
f = frequency of applied voltage
S = speed as a fraction of synchronism

The symbols for voltage and current all represent r. m. s. values of time vector quantities. The positive senses of the currents are indicated by the arrows in Fig. 2.

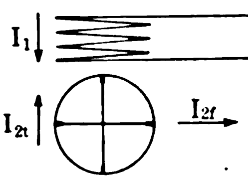
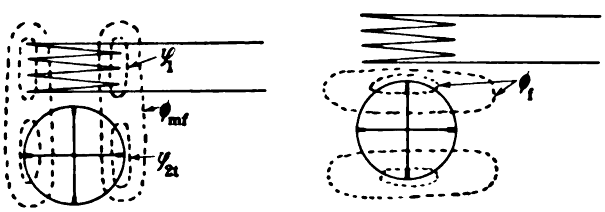


FIG. I

The motor flux is resolved into the following four components: (1) the "transformer" flux Φ_{mt} which is the flux that is mutual to the stator winding and the rotor circuit in the transformer axis; (2) the "field flux Φ_f which is the flux produced by the m. m. f. of the current I_{2f} in the field axis of the rotor; (3) the leakage flux φ_1 of the primary, and (4) the leakage flux φ_{2t} of the rotor circuit in the transformer axis.



A B

FIG. 2—FLUX COMPONENT IN SINGLE-PHASE INDUCTION MOTOR

(a) In transformer axis
(b) In field axis

In terms of the currents and the motor reactances, the equations for the above flux components are:

$$\Phi_{mt} = \frac{X_m (I_1 - I_{2t})}{2 \pi f N} \tag{1}$$

$$\Phi_f = \frac{(X_m + x_2) I_{2f}}{2 \pi f N} \tag{2}$$

$$\varphi_1 = \frac{x_1 I_1}{2 \pi f N} \tag{3}$$

$$\varphi_{2t} = \frac{x_2 I_{2t}}{2 \pi f N} \tag{4}$$

Voltage applied to the stator terminals must overcome the resistance drop and the mutual and leakage reactance drops due to alternation of Φ_{mt} and φ_1. The equation is

$$E = r_1 I_1 + j x_1 I_1 + j X_m (I_1 - I_{2t}) \tag{5}$$

In the transformer axis of the rotor, the sum of the voltages induced by transformer action of Φ_{mt} and φ_{2t}, and by rotation through the flux φ_f plus the resistance drop $r_2 I_{2t}$ must equal zero. The equation is, for counter clockwise rotation of the rotor,

$$0 = -j X_m (I_1 - I_{2t}) - S (X_m + x_2) I_{2f} + r_2 I_{2t} + j x_2 I_{2t} \tag{6}$$

Similarly for the field axis of the rotor,

$$0 = j (X_m + x_2) I_{2f} - S X_m (I_1 - I_{2t}) + S x_2 I_{2t} + r_2 I_{2f} \tag{7}$$

Solving these three voltage equations for I_1, I_{2t}, and I_{2f} we get,

$$I_1 = E \frac{[-r_2^2 + (1 - S^2)(X_m + x_2)^2 - j\, 2\, r_2 (X_m + x_2)]}{U_1' + j W_1'} \tag{8}$$

$$I_{2t} = E X_m \frac{(1 - S^2)(X_m + x_2) - j r_2}{U_1' + j W_1'} \tag{9}$$

$$I_{2f} = - \frac{S E X_m r_2}{U_1' + j W_1'} \tag{10}$$

Where

$$U_1' = - r_1 r_2^2 + 2 r_2 x_1 (X_m + x_2) + r_2 X_m (X_m + 2 x_2) + (1 - S^2) r_1 (X_m + x_2)^2 \tag{11}$$

$$W_1' = - r_2^2 x_1 - 2 r_1 r_2 (X_m + x_2) - r_2^2 X_m + (1 - S^2) [x_1 (X_m + x_2)^2 + x_2 X_m (X_m + x_2)] \tag{12}$$

Substituting the above values of I_1, I_{2t}, and I_{2f} in equations (1), (2) and (4), we get

$$\Phi_{mt} + \varphi_{2t} = \frac{- E X_m [r_2^2 + j r_2 (X_m + x_2)]}{2 \pi f N (U_1' + j W_1')} \tag{13}$$

and

$$\Phi_f = - \frac{S E X_m (X_m + x_2) r_2}{2 \pi f N (U_1' + j W_1')} \tag{14}$$

The torque developed by the motor consists of two components, one component T_1 due to the interaction of the current I_{2t} and the flux Φ_f, and another component T_2 due to the interaction of I_{2f} and the flux $\Phi_t = \Phi_{mt} - \varphi_{2t}$. These torque components in synchronous watts are equal to the products of the in-phase components of the currents and the fluxes with which they interact multiplied by $2 \pi f N$; that is, from equations (9) and (14).

$$T_1 = \frac{E^2 X_m^2 (X + x_2)^2 r_2 S (1 - S^2)}{U_1'^2 + W_1'^2} \tag{15}$$

and from equations (10) and (13)

$$T_2 = \frac{-E^2 X_m^2 r_2^3 S}{U_1^{1\,2} + W_1^{1\,2}} \tag{16}$$

and the total torque developed by the motor is

$$T = T_1 + T_2 = \frac{E^2 X_m^2 r_2 S\,[(1 - S^2)(X_m + x_2)^2 - r_2^2]}{U_1^{1\,2} + W_1^{1\,2}} \tag{17}$$

This equation shows that the torque developed by the motor is zero when

$$1 - S^2 = \frac{r_2^2}{(X_m + x_2)^2}$$

or the ideal no-load speed is

$$S_0 = \sqrt{1 - \frac{r_2^2}{(X_m + x_2)^2}} \tag{18}$$

Substituting the above value for the no-load speed in equation (7), we obtain for the no-load current,

$$I_0 = \frac{2\,E\,(X_m + x_2)}{2\,r_1(X_m + x_2) + \dfrac{r_2\,X_m^2}{X_m + x_2} + j\,X_m\,[X_m + 2\,(x_1 + x_2)]}$$

For all usual relative values of the design constants, this is very closely,

$$I_0 \simeq -j\,\frac{2\,E}{X_m}\left[\frac{X_m + x_2}{X_m + 2\,(x_1 + x_2)}\right]$$

$$\simeq -j\,\frac{2\,E}{X_m}\left[1 - \frac{2\,x_1 + x_2}{X_m + 2\,(x_1 + x_2)}\right] \tag{19}$$

It is obvious that by means of this equation, the value of the magnetizing reactance X_m can be calculated with any desired degree of accuracy from the values of the short-circuit and no-load currents.

The performance characteristics of a motor of given design constants can be calculated completely by means of equations (8) and (17). The solution of these equations can be reduced to a simple matter of arithmetic by means of a suitable printed form, arranged for carrying out the calculations for a number of different speeds simultaneously. The use of very large numbers will be avoided and the calculations for motors of different sizes will be more nearly alike if the numerators and denominators are divided by $(X_m + x_2)^2$ and $(X_m + x_2)^4$ in equations (8) and (17) respectively. This gives

$$I_1 = \frac{M_1 + j\,N_1}{U_1 + j\,W_1} \tag{8'}$$

$$T = \frac{S\,F_8 + S\,(1 - S^2)\,F_9}{U_1^2 + W_1^2} \tag{17'}$$

Where

$M_1 = F_1 + (1 - S^2)\,F_2$
$N_1 = F_3$
$U_1 = F_4 + (1 - S^2)\,F_5$
$W_1 = F_6 + (1 - S^2)\,F_7$

The complete expressions for F_1 to F_9 inclusive are given in the following sample calculation.

Performance Calculation of Single-Phase Induction Motor

Motor design constants:

$E = 220$
$r_1 = 0.12$
$r_2 = 0.3$
$x_1 = 0.4$
$x_2 = 0.4$
$X_m = 15$

Core loss and friction = 600

$F_1 = -E\dfrac{r_2^2}{(X_m + x_2)^2} = -0.0835$

$F_2 = E = 220$

$F_3 = -2\,E\dfrac{r_2}{X_m + x_2} = -8.57$

$F_4 = r_2\left[\dfrac{x_2\,X_m - r_1\,r_2}{(X_m + x_2)^2} + \dfrac{X_m + 2\,x_1}{X_m + x_2}\right] = 0.315$

$F_5 = r_1 = 0.12$

$F_6 = -r_2\left[\dfrac{r_2\,(X_m + x_1)}{(X_m + x_2)^2} + \dfrac{2\,r_1}{X_m + x_2}\right] = -0.0105$

$F_7 = x_1 + x_2\dfrac{X_m}{X_m + x_2} = 0.789$

$F_8 = -E^2\,r_2^3\dfrac{X_m^2}{(X_m + x_2)^4} = -5.23$

$F_9 = E^2\,r_2\dfrac{X_m^2}{(X_m + x_2)^2} = 13{,}800.$

S	1.00	0.98	0.95	0.90	0.80
$1 - S^2$	0	0.0396	0.0975	0.19	0.36
$S(1 - S^2)$	0	0.0388	0.0927	0.171	0.288
(1) F_1	−0.0835	−.08	−0.08	−.08	−0.08
(2) $(1 - S^2) F_2$	0	8.70	21.4	41.7	79.2
(3) $M_1 = (1) + (2)$	−0.0835	8.62	21.3	41.6	79.1
(4) $N_1 = F$	−8.57	−8.57	−8.57	−8.57	−8.57
(5) F_4	0.315	0.315	0.315	0.315	0.315
(6) $(1 - S^2) F_5$	0	0.005	0.012	0.023	0.043
(7) $U_1 = (5) + (6)$	0.315	0.320	0.327	0.338	0.358
(8) F_6	−0.0105	−0.010	−0.010	−0.010	−0.010
(9) $(1 - S^2) F_7$	0	0.031	0.077	0.150	0.284
(10) $W_1 = (8) + (9)$	−0.0105	0.021	0.067	0.140	0.274
(11) $M_1 U_1$	−0.0263	2.76	6.98	14.05	28.3
(12) $N_1 W_1$	0.09	−0.18	−0.57	−1.20	−2.35
(13) $M_1 U_1 + N_1 W_1$	0.0637	2.58	6.41	12.85	25.95
(14) $N_1 U_1$	−2.70	−2.74	−2.80	−2.90	−3.06
(15) $- M_1 W_1$	−0.0009	−0.181	−1.43	−5.82	−21.66
(16) $N_1 U_1 - M_1 W_1$	−2.70	−2.92	−4.23	−8.72	−24.72
(17) U_1^2	0.0992	0.1025	0.107	.1143	0.1282
(18) W_1^2	0.0001	0.0004	0.0045	.0196	0.0751
(19) $U_1^2 + W_1^2$	0.0993	0.1029	0.1115	.1339	0.2033
(20) $I_{1a} = (13)/(19)$	0.642	25.1	57.5	95.8	127.5
(21) $I_{1b} = (16)/(19)$	−27.2	−28.4	−38.0	65.2	121.5
(22) $I_1 = \sqrt{I_{1a}^2 + I_{1b}^2}$	27.3	38.0	69.4	116	176
(23) Power factor = (20)/(22)		0.66	0.83	0.825	0.725
(24) Power input = E . (20)		5510	12660	21100	28000
(25) $S F_8$	−5.23	−5.1	−5	−5	−4
(26) $S(1 - S^2) F_9$	0	535	1280	2360	3970
(27) (25) + (26)	−5.23	530	1275	2355	3966
(28) $T = (27)/(19)$	−52.8	5150	11450	17600	19450
(29) Core loss and friction	600	600	600	600	600
(30) Net Torque = (28) − (29)	−653	4550	10850	17000	18850
(31) Power output = S . (30)	−653	4460	10300	15300	14700
(32) Efficiency = (31)/(24)		0.808	0.812	0.725	0.532

It will be noted that all the steps are indicated in the above. It is obvious that if a printed calculation form arranged as the above is used, the calculation of the complete performance characteristics of the single-phase induction motor is made comparable to a simple problem of bookkeeping, and can be done by a person without any technical training.

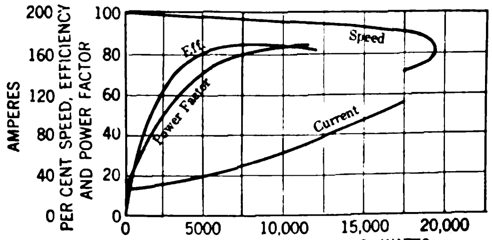


Fig. 3—Performance Characteristics of Single-Phase Induction Motor

The performance curves plotted from the above calculated values for current, torque, power factor, and efficiency are shown in Fig. 3.

As a further illustration, the method will be applied to the repulsion motor.

The Repulsion Motor

As usually built, the stator of a repulsion motor has a simple single-phase winding. This stator winding may be considered as made up of two windings, one which may be called the transformer winding and which is in inductive relation to the commutated winding, and

the other which may be called the field winding, which is at right angles to the axis of the commutated winding. According to the assumption of sine wave distributions of m. m. f., which is approximately realized in most cases, the transformer winding component will have $N \cos A$ effective turns, and the field winding component will have N sine A effective turns, where A is the angle in electrical degrees between the axis of the commutated winding as determined by the brush position and the transformer axis. The motor can be represented diagrammatically as in Fig. 4.

The same symbols that were used for the single-phase induction motor will apply for the repulsion motor and in addition we have,

I_3 = local short-circuit current in the coils short-circuited by the brushes.

r_3 = resistance of the local short circuits formed by the coils short-circuited by the brushes and the brush contacts.

The leakage reactance of the local short circuits is assumed the same as that of the rotor winding as a whole, viz., x_2.

We have, therefore, three circuits to consider in the repulsion motor, and three corresponding voltage equations. For the stator winding we have,

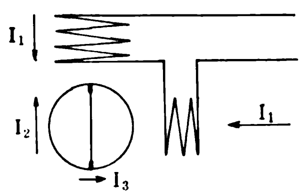


Fig. 4

$$E = j X_m (I_1 \cos^2 A - I_2 \cos A) + j X_m (I_1 \sin^2 A - I_3 \sin A) + (r_1 + j x_1) I_1 \qquad (20)$$

For the rotor winding proper,

$$O = - j X_m (I_1 \cos A - I_2) + (r_2 + j x_2) I_2 + S X_m I_1 \sin A - S (X_m + x_2) I_3 \qquad (21)$$

For the coils short circuited by the brushes,

$$O = - j X_m (I_1 \sin A - I_3) - S X_m (I_1 \cos A - I_2) + S x_2 I_2 + (r_3 + j x_2) I_3 \qquad (22)$$

Solving for I_1, I_2 and I_3, we get the equations,

$$I_1 = E \frac{[r_2 r_3 - (1 - S^2)(X_m + x_2)^2 + j (r_2 + r_3)(X_m + x_2)]}{U_2' + j W_2'} \qquad (23)$$

$$I_2 = E X_m \frac{[-S r_3 \sin A - (1 - S^2)(X_m + x_2) \cos A + j r_3 \cos A]}{U_2' + j W_2'} \qquad (24)$$

$$I_3 = E X_m \frac{[S r_2 \cos A - (1 - S^2)(X_m + x_2) \sin A + j r_2 \sin A]}{U_2' + j W_2'} \qquad (25)$$

Where

$$U_2 = - r_2 X_m^2 \cos^2 A - r_3 X_m^2 \sin^2 A - (r_2 + r_3)(x_1 + x_2) X_m - (r_2 + r_3) \; x_1 x_2 + r_1 r_2 r_3 - (1 - S^2) r_1 (X_m + x_2)^2$$

$$W_2' = r_1 (r_2 + r_3)(X_m + x_2) + r_2 r_3 (X_m + x_1) + S (r_3 - r_2) X_m^2 \sin A \cos A - (1 - S^2)(X_m + x_2) [X_m (x_1 + x_2) + x_1 x_2]$$

The components of the motor flux which react with the currents I_2 and I_3 to produce torque are the field flux Φ_f and the transformer flux Φ_t,

Where

$$\Phi_f = \frac{X_m I_1 \sin A - (X_m + x_2) I_3}{2 \pi f N} \qquad (26)$$

and

$$\Phi_t = \frac{X_m I_1 \cos A - (X_m + x_2) I_2}{2 \pi f N} \qquad (27)$$

The torque developed by the motor at any speed is, in synchronous watts,

$$T = 2 \pi f N [(I_2 \, . \, \Phi_f) - (I_3 \, . \, \Phi_t)]$$

where $(I_2 \, . \, \Phi_f)$ and $(I_3 \, . \, \Phi_t)$ represent the products of the in-phase components of I_2 and Φ_f, and I_3 and Φ_t, respectively. Substituting for the currents and fluxes their values from equations (**23**) to (**27**) and multiplying out, we get,

$$T = \frac{E^2 X_m^2}{U_2'^2 + W_2'^2} \left\{ \begin{array}{l} (r_3^2 - r_2^2)(X_m + x_2) \sin A \cos A \\ + (r_3 \sin^2 A + r_2 \cos^2 A) \\ [-S \; r_2 \; r_3 + S (1 - S^2)(X_m + x_2)^2] \end{array} \right\} \qquad (28)$$

The no-load speed is obtained by solving the cubic equation that is obtained by putting $T = 0$ in the above. An approximate solution is,

$$S_0 \simeq \sqrt[3]{1.5 + \frac{r_3}{X_m \left(\tan A + \frac{r_2}{r_3} \cot A\right)}}$$

This approximate equation is theoretically much more accurate than any calculated value of r_3 can be expected to be. Its chief value is to show how the no-load speed of a repulsion motor might be affected by changes in design.

Special simplified formulas for the current and torque at synchronous speed or at standstill can be obtained by putting $S = 1$ or $S = 0$ in equations (**23**) and (**28**). Slight approximations can then be made by which the equations are reduced to rather simple formulas which need not be given here.

The performance characteristics of the motor can be calculated completely from equations (**23**) and (**28**). For calculation purposes, it is advisable to divide the numerators and denominators of these equations by $(X_m + x_2)^2$ and $(X_m + x_2)^4$ as in the case of the single-phase induction motor. This gives,

$$I_1 = \frac{M_2 + j\,N_2}{U_2 + j\,W_2}$$

$$T = E^2\,\frac{G_9 + S\,G_{10} + (1 - S^2)\,G_{11}}{U_2^2 + W_2^2}$$

Where

$$M_2 = G_1 + (1 - S^2)\,G_2$$
$$N_2 = G_3$$
$$U_2 = G_4 + (1 - S^2)\,G_5$$
$$W_2 = G_6 + S\,G_7 + (1 - S^2)\,G_8$$

The complete expressions for G_1 to G_{11} inclusive are given in the following sample calculation.

PERFORMANCE CALCULATION OF REPULSION MOTOR

Motor design constants:

$r_1 = 1.1$
$r_2 = 3.5$
$r_3 = 100$
$x_1 = 2.8$
$x_2 = 2.8$
$X_m = 60$
$A = 15°$

Core loss and friction = 110 watts

$$G_1 = E\,\frac{r_2\,r_3}{(X_m + x_2)^2} = 19.5$$

$$G_2 = -\,E = -220$$

$$G_3 = E\,\frac{r_2 + r_3}{X_m + x_2} = 363$$

$$G_4 = -(r_3 \sin^2 A + r_2 \cos^2 A)\left(\frac{X_m}{X_m + x_2}\right)^2 - \left(\frac{r_2 + r_3}{X_m + x_2}\right)\left(x_1 + \frac{x_2\,X_m}{X_m + x_2}\right) + \frac{r_1\,r_2\,r_3}{(X_m + x_2)^2} = -17.98$$

$$G_5 = -\,r_1 = -\,1.1$$

$$G_6 = \frac{1}{X_m + x_2}\left(r_1\,r_2 + r_1\,r_3 + r_2\,r_3\,\frac{X_m + x_1}{X_m + x_2}\right) = 7.39$$

$$G_7 = (r_3 - r_2)\left(\frac{X_m}{X_m + x_2}\right)^2 \sin A \cos A = 22.0$$

$$G_8 = -\left(x_1 + \frac{x_2\,X_m}{X_m + x_2}\right) = -\,5.47$$

$$G_9 = +\,\frac{X_m^2\,(r_3^2 - r_2^2)\sin A \cos A}{(X_m + x_2)^3} = 36.3$$

$$G_{10} = -\,\frac{X_m^2\,r_2\,r_3}{(X_m + x_2)^4}\,(r_3 \sin^2 A + r_2 \cos^2 A) = -\,0.80$$

$$G_{11} = \left(\frac{X_m}{X_m\,x_2}\right)^2 (r_3 \sin^2 A + r_2 \cos^2 A) = 9.05$$

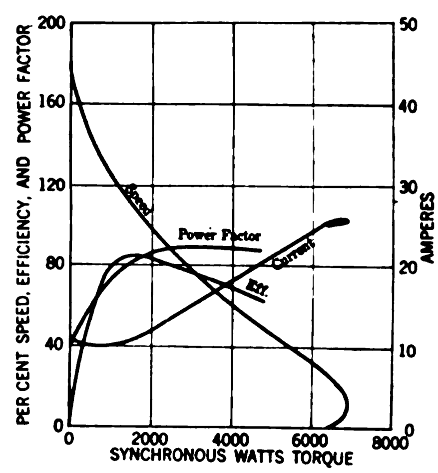


FIG. 5—PERFORMANCE CHARACTERISTICS OF REPULSION MOTOR.

The performance curves corresponding to the following calculated values are shown in Fig. 5.

It will be noted that this calculation form is, in general outline the same as that used for the single-phase induction motor, practically the only differences being in the expressions for the constants F_1, F_2, etc., and G_1, G_2, etc.

The single-phase induction motor and the repulsion motor have been chosen to illustrate the general method of analysis by the cross-field theory on account of their relative simplicity. The same general method might be applied to machines of more complicated types, such as those having four or more circuits to consider, but the method of procedure would be essentially the same, and the results would merely be somewhat more complicated. The analytical solution of such a motor by the same general method has been given in a previous paper. (TRANS. A. I. E. E., 1924, p. 1048.)

PERFORMANCE CALCULATION OF REPULSION MOTOR—(*Continued*)

	S	0	0.75	1.00	1.25	1.80
	$1 - S^2$	1	0.4375	0	−.5625	−2.24
	$S(1 - S^2)$	0	0.328	0	−.703	−4.03
(1)	G_1	19.5	19.5	19.5	19.5	19.5
(2)	$(1 - S^2) G_2$	−220	−96.3	0	123.8	493.
(3)	$M_2 = (1) + (2)$	−200.5	−76.8	19.5	143.3	512.5
(4)	$N_2 = G_3$	363	363	363	363	363
(5)	G_4	−17.98	−17.98	−17.98	−17.98	−17.98
(6)	$(1 - S^2) G_5$	−1.1	−0.48	0	.62	2.46
(7)	$U_2 = (5) + (6)$	−19.08	−18.46	−17.98	−17.36	−15.52
(8)	G_6	7.39	7.39	7.39	7.39	7.39
(9)	$S G_7$	0	16.50	22.0	27.50	39.6
(10)	$(1 - S^2) G_8$	−5.47	−2.39	0	3.08	12.26
(11)	$W_2 = (8) + (9) + (10)$	1.92	21.50	29.39	37.97	59.25
(12)	$M_2 U_2$	3820	1420	−350	−2490	−7950
(13)	$N_2 W_2$	696	7800	10680	13750	21500
(14)	(12) + (13)	4516	9220	10330	11260	13550
(15)	$N_2 U_2$	−6930	−6700	−6520	−6300	−5640
(16)	$- M_2 W_2$	380	1655	−570	−5450	−30400
(17)	= (15) + (16)	−6550	−5045	−7090	−11750	−36040
(18)	U_2^2	364	341	323	302	241
(19)	W_2^2	4	462	863	1440	3510
(20)	= (18) + (19)	368	803	1186	1742	3750
(21)	$I_{1a} = (14)/(20)$	12.28	11.5	8.75	6.45	3.62
(22)	$I_{1b} = (17)/(20)$	−17.8	−6.3	−5.98	−6.75	−9.6
(23)	$I_1 = \sqrt{I_{1a}^2 \, I_{1b}^2}$	21.6	13.15	10.55	9.35	10.25
(24)	Power factor = (21)/(23)		0.875	0.83	0.69	0.35
(25)	Power input = E . (21)		2530	1920	1420	796
(26)	G_9	36.3	36.3	36.3	36.3	36.3
(27)	$S G_{10}$	0	−0.6	−0.8	−1.0	−1.4
(28)	$S(1 - S^2) G_{11}$	0	3.0	0	−6.3	−36.4
(29)	= (26) + (27) + (28)	36.3	38.7	35.5	29	−1.5
(30)	$T = E^2 . (29)/(20)$	4790	2340	1450	805	−19
(31)	Core loss and friction	110	110	110	110	110
(32)	Net torque = (30) − (31)	4680	2230	1340	695	−129
(33)	Power output = S . (32)		1674	1340	868	−232
(34)	Efficiency = (33)/(25)		0.66	0.70	0.61	−0.29

The Calculation of Magnetic Attraction
By the Aid of Magnetic Figures

BY TH. LEHMANN[1]
Non-member

Synopsis.—*The present paper treats of the following matters:*

1. Simplification of the physical formula for magnetic attraction

2. Definition of magnetic reluctance when the magnetic field is bounded by non-equipotential surfaces

3. Calculation of the virtual variation in magnetic reluctance due to any displacement of the limiting surfaces

4. Demonstration of the theorem that the magnetic attraction between two ferromagnetic bodies depends only upon their common magnetic fluxes ϕ *and upon the virtual gradient of its air-reluctances* R_o, *and that the formula*

$$F_l = \frac{\phi^2}{8\pi} \frac{\delta R_o}{\delta_l}$$

which gives the attraction along any given direction l *is as general and as exact as the formulas of physics*

5. Direct deduction of magnetic attraction from the lines of magnetic flux depicted by a magnetic figure without resorting to the components of the magnetic field.

The method used is developed by the application of the well-known principles of the potential energy function to the magnetic flux in the air-gap. Paths for the magnetic flux are established across the air-gap between the two ferromagnetic surfaces bounding the air-gap, by decomposing the magnetic flux into elemental tubes of magnetic force, the envelopes of which enclose spaces in which the flux is constant. The element of boundary-surface intersected by each elemental tube at the two boundary-surfaces encloses an equal number lines of magnetic flux, irrespective of the magnetic density at these points. By replacing the element of boundary-surface by its geometrical projection on a plane normal to the axis of the elemental tube, an equivalent equipotential surface is obtained at each end of the elemental tube. Any non-equipotential surface bounding an air-gap can thus be replaced by an equivalent equipotential surface composed of an aggregation of elemental equipotential surfaces which produce denticulations in the contour of the boundary-surface. It becomes possible, in this way, to evaluate magnetic reluctance and magnetic attraction by reference to summations of elemental magnetic tubes and without the necessity of considering directly the magnetic density of the magnetic field at any point. The potential of each elemental tube of magnetic force depends only upon the potentials at its ends, at the boundary-surfaces, it being entirely independent of the path followed by the tube in traversing the air-gap.

* * * * *

I. Introduction

The resultant magnetic effort, F, which is experienced by a soft iron body in a medium whose permeability is independent of the field, H, can be calculated by means of the known formula

$$F = \frac{1}{8\pi} \int_s \{2H(B, N) - N(H, B)\}\, dS \qquad (1)$$

in which N is the external unit vector which is normal to the surface-element dS, H and B being the vectors of the magnetic field and induction at the same point.

By means of equation (**1**), the resultant force, F, can be calculated whenever the distribution of the magnetic field along the external surface of the magnetic body is known. When that body is surrounded by air or like medium, the formula (**1**) can be further simplified; but even in that case, there are no analytical solutions in the majority of the cases of magnetic field distribution met with in practise, so that, as a rule, all that can be done is to obtain the graphical integration of equation (**1**) by deducing the values of the magnetic field from a chart of its lines of magnetic flux. It is possible, now, to determine these values within one per cent[2].

This method of evaluation of the quantity indicated by equation (**1**) is not free from error, owing to the points of saturation which occur at the sharp angles and at the narrow portions of the ferromagnetic material enclosing the slots.

For these reasons it seems worth while to inquire whether magnetic attraction could not be deduced directly from the lines of force shown in a magnetic figure without the necessity of first obtaining the components of the magnetic field and then recombining them tensorially. It so happens that this is possible within the entire range of validity of equation (**1**).

In the present paper the only case considered will be that of the attraction between ferromagnetic bodies that are separated by a medium like air, this case being of more immediate interest.

II. Transformation of the Physical Formula for Attraction

In (1), let $\{2H(B, N) - N(H, B)\} = P$. This quantity is a linear vectorial function of the normal unit-vector N. By putting this expression in the form $aP + bH + cN = 0$, it is seen that $P, H,$ and N, and also B when $B \| H$, are situated in the same plane. Moreover, the vector H bisects the angle formed between P and N (Fig. 1)[3] as is seen at once by taking the scalar product of P and H, and observing that $P^2 = B^2 H^2$. This allows P to be written in simpler form.

Let us use the term "*directed algebraical product*" of two vectors, H and B, to designate the vector the length of which is equal to the algebraical product of the scalar values of H and B, and the angle of which, with the

1. Consulting Engineer, Urmatt, France.

2. See *Revue Générale de l'electricité*, 1923, Vol. XIV, pp. 347 and 395.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

3. See, for instance, A. Vaschy, "Théorie de l'Electricité," 1896, p. 64.

outward normal N, is equal to the sum of the angles, α, which H and B make with N; that is to say, 2α when $B \| N$. This vector, which is parallel to the same plane as N, H and B, will be symbolized by $(\overline{B\,H})_{2\alpha}$, so that for an iron body surrounded by air, formula (**1**) may be expressed in the following form:

$$F = \frac{1}{8\pi} \int_s B^2_{2\alpha}\, d\,S \tag{2}$$

Equation (**2**) may be considered a generalization of the ordinary formula of Maxwell, with which it becomes identical when $\alpha = 0$.

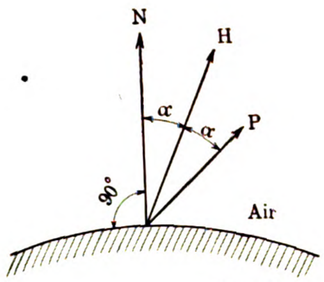


FIG. 1

It is seen at once that the algebraical value of the quantity to be integrated P, P is always equivalent to B^2 whatever may be the angle of incidence, α, of the magnetic field. In air, the tensorial ellipsoid consequently becomes a sphere. For the condition $\alpha = 0$, the integration is performed along a level surface, and $P = \overline{B_0{}^2}$ has the direction of N. For an angle of incidence $\alpha = 45$ deg., the elemental effort $P = \overline{B_{\pi/2}{}^2}$ is tangential to the surface. Finally, if the integration is performed along a surface generated by lines of magnetic flux, and more especially along a line of plane flux, we have

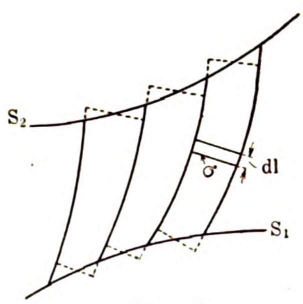


FIG. 2

$2\alpha = \pi$, and $P = \overline{B^{\,2}}$ is now directed in a direction contrary to that of N. Since the direction of P is obtained by simply reflecting N with respect to B, the application of formula (**2**) is a very simple matter.

III. Definition of the Reluctance Between two Non-Equipotential Surfaces which are Separated by an Air-Space

Let us subdivide the air-space between two non-equipotential surfaces, S_1 and S_2, (Fig. 2), into n very thin aliquot or subsidiary tubes having the reluctances $\rho_1, \rho_2, \rho_3, \ldots$, and let us replace the oblique bases of each tube by orthogonal bases having the same distance between centers. The elemental tubes being now limited by orthogonal bases, their reluctances can now be defined in the ordinary simple manner. It is known, moreover, that, in a medium of constant permeability, the magnetic energy of a Laplacian or vortex magnetic field is given by the volume-integral

$$W_m = \frac{1}{8\pi} \int B\,H\,d\,v$$

Integrating across the air-gap, along each tube, by tube-elements of sectional area σ and length $d\,l$, we will have

$$W_m = \frac{1}{8\pi} \sum_1^n \int B^2\,\sigma\,d\,l = \frac{1}{8\pi} \sum_1^n \phi_k{}^2 \int \frac{d\,l}{\sigma}$$

$$= \frac{1}{8\pi} \sum_1^n \phi_k{}^2\,\rho_k$$

But since the flux, ϕ_k, of each aliquot tube is equal to the nth part of the total flux Φ, we have

$$W_m = \frac{1}{8\pi} (\Phi_n)^2 \sum_1^n \rho_k = \frac{\Phi^2}{8\pi} R_0 \tag{3}$$

whence we deduce the total reluctance

$$R_0 = \frac{1}{n^2} \sum_1^n \rho_k \tag{3'}$$

or, more precisely,

$$R_0 = \underset{n\,=\,\infty}{\text{Limit}} \frac{1}{n^2} \sum_1^n \rho_k \tag{3''}$$

It is evident that, by defining the reluctance ρ_k of each tube in accordance with (3″), formulas (**3**) and (**3′**) will remain rigorously accurate, whatever may be the magnitude of the elemental tubes.

In principle, the reluctance R_0 between two non-equipotential surfaces may be defined by the aid of any drawing of magnetic tubes. If the fractional coefficients of the tubes be designated by $m_1 = \dfrac{\Phi}{\phi_1}$, $m_2 = \dfrac{\Phi}{\phi_3}$, ... we obtain, for R_0, the following more general expression:

$$R_0 = \sum_1^n \frac{\rho_k}{m_k{}^2} \tag{4}$$

The most frequent case is that where an arrangement of n tubes, conveying a total flux Φ, is composed of $n - 1$ aliquot tubes, each containing the flux $\phi_k = \dfrac{\Phi}{m}$ and a residual flux $\phi_n = \dfrac{\Phi}{m_n}$. The total reluctance then becomes equal to

$$R_0 = \frac{1}{m^2} \sum_{1}^{n-1} \rho_k + \frac{\rho_n}{m_n^{\,2}} \tag{5}$$

IV. Demonstration of the Equivalence of the Formula $F_l = \frac{\Phi^2}{8\pi}\,\frac{\delta R_0}{\delta l}$ to Formula (2)

Let us represent in cross-section (Fig. 3) the origin of a very thin tube, 2 - 3, and of the adjacent tubes, 1 - 2 and 3 - 4. Let us make the plane of the drawing parallel with the magnetic field in the air-gap B,

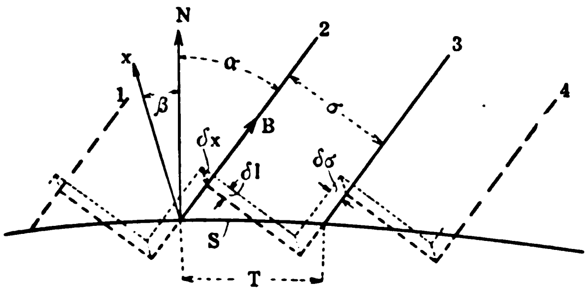


Fig. 3

and with the normal, N, with respect to the surface-element, S. The lines of magnetic flux being supposed to be very close to each other, no change will be caused in the reluctance of the tubes or in the external field if the oblique bases are replaced by orthogonal cross-sections through the same centers. Let us now displace the denticulated surface in a direction parallel to itself to the distance $d\,z$. All that need be considered is the projection $d\,x = d\,z \cos \eta$ of this displacement on the plane containing the vectors N and B, because any displacement of the surface-element S perpendicularly to that plane will have no influence on the reluctance of the tube under consideration. By taking any suitable unit of length for measuring the thickness of the tube in the direction perpendicular to the drawing, the width, σ, of the tube in the plane of the drawing can be made equal to its sectional area, and the intersections of its oblique base can be made equal to the surface-element, S.

Let (in Fig. 3) β designate the angle between $\delta\,x$ and the normal, N, and let α designate the angle of incidence of the vector, B. It will easily be seen that the displacement of the denticulated surface to the distance $d\,z$ causes in the tube of magnetic force a shortening equal to $d\,l = d\,x \cos(\alpha + \beta)$ in the direction of its length, and a decrease in its sectional area equal to $d\,\sigma = d\,x \sin(\alpha + \beta)$ over a length equal to $s \sin \alpha$. The result is that the reluctance of the portion of the tube thus modified is changed from $\rho = \frac{s \sin \alpha}{\sigma}$ to $\rho' = \frac{s \sin \alpha - \delta\,l}{\sigma - \delta\,\sigma}$, so that the variation in reluctance caused by the displacement of the surface-element, S, when $\sigma = s \cos \alpha$, and $s = S$, becomes equal to

$$\delta\,\rho = \frac{\delta\,x}{\sigma^2} \cos(2\,\alpha + \beta)\,S$$

$$= -\frac{\delta\,z}{\sigma^2} \cos \eta \cos(2\,\alpha + \beta)\,S \tag{6}$$

Now, let $\frac{\Phi}{m_k} = B\,\sigma$ represent the magnetic flux in any tube. The summation of the values $\frac{\Phi^2}{8\,\pi}\,\frac{1}{m_k^2}\,\frac{\delta\,\rho_k}{d\,z} = -\frac{1}{2\,\pi} B^2 \cos(2\,\alpha + \beta)\,S$ along the whole surface will then, with the aid of (**4**), give us

$$\frac{\Phi^2}{8\,\pi} \sum \frac{1}{m_k^2}\,\frac{\delta\,\rho_k}{\delta\,z} = \frac{\Phi^2}{8\,\pi}\,\frac{\delta\,R_0}{\delta\,z},$$

from which, by passing to the limit, we obtain

$$\frac{\Phi^2}{8\,\pi}\,\frac{\delta\,R_0}{\delta\,z} = -\frac{1}{8\,\pi} \int_s B^2 \cos(2\,\alpha + \beta) \cos \eta\, d\,S \tag{7}$$

It now becomes immediately apparent that the quantity under the integral sign is nothing more than the projection of the vector, $P = \overline{B_{2\alpha}}^{\,2}$ upon the direction of $\delta\,z$. Therefore, the formulas (**2**) and (**1**) lead to the same effort in any given direction δz, as the formula $\frac{F}{z} = \frac{\Phi^2}{8\,\pi}\,\frac{\delta\,R_0}{\delta\,z}$, and the three formulas are consequently equivalent to each other. This result can also be expressed vectorially as follows:

$$-\frac{\Phi^2}{8\,\pi} \times (\text{Virtual gradient of } R_0) = \frac{1}{8\,\pi} \int_s \overline{B_{2\alpha}^{\,2}}\, d\,S.$$

We shall now show that the attraction between two

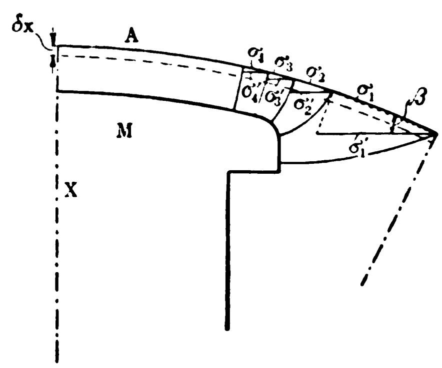


Fig. 4

bodies depends only upon the field that is common to both of them and that it can be evaluated without knowing the leakage-field.

V. Calculation of Magnetic Attraction by Means of the Common Field Only

A. *Unsaturated circuits.* Let us consider the attraction in a radial direction between a field-magnet M

with salient poles and the armature (or stator) A (Fig. 4), on the assumption that $\mu = \infty$ in the iron. For this purpose, let us suppose a virtual decrease equal to δx in the air-gap, as if the armature were brought closer in the direction of the axis (X) of the pole, and let us, for a moment, assume as being true, the physical figment that the external field is not disturbed in consequence of the displacement in question (δx). Under such conditions, the length of each tube of magnetic force will be decreased by an amount equal to $\delta x \cos \beta$, where β designates the angle between the normal to the surface S at the point under consideration and the direction of δx. Therefore, if σ is the sectional area of the tube as it emerges from the surface of A, the variation of its reluctance, ρ, will be $\delta \rho = -\frac{\delta x \cos \beta}{\sigma}$. The portion of the virtual energy pertaining to this tube, when ϕ is the flux, consequently becomes equal to $\delta T = \frac{\phi^2}{8\pi} \frac{\delta x \cos \beta}{\sigma} = \frac{B^2}{8\pi} \delta x \cos \beta \, \sigma$, and the elemental force along δx will be equal to

$$f_x = \frac{B^2}{8\pi} \sigma \cos \beta$$

which is evidently the projection upon δx of the force which is normal to σ, namely, $f = \frac{B^2 \sigma}{8\pi}$, in perfect accordance with formulas (**1**) and (**2**).

Inasmuch as the common flux ϕ, is generally the primary information available in practise, it is important to note that the total force of attraction F_x can be obtained without any integration, when the drawing shows m isometric tubes, by obtaining, along the armature, the value of the sum

$$F_x = -\frac{\Phi^2}{8\pi} \frac{\delta R_0}{\delta x} = \frac{\Phi^2}{8\pi} \frac{1}{m^2} \sum \frac{\cos \beta}{\sigma}$$

All that is necessary, therefore, is to obtain, at the place where the end-section, σ, of each tube emerges from the polar surface (A), the segments $\sigma' = \frac{\sigma}{\cos \beta}$, which are marked off by projection upon a line perpendicular to the direction of δx (see Fig. 4) by the normals to the chord of σ drawn (dotted in Fig. 4) between its two opposite edges. We thus obtain

$$F_x = \frac{\phi^2}{8\pi} \frac{1}{m^2} \sum \frac{1}{\sigma'} \qquad (8)$$

The degree of precision of F_x naturally depends upon the number of isometrical tubes into which the useful flux is subdivided. When the drawing comprises $n - 1$ tubes, each containing the flux $\phi = \frac{\Phi}{m}$, and a residual tube containing the flux $\phi' = \frac{\Phi}{m'}$, it is evident that we shall have

$$F_x = \frac{\Phi^2}{8\pi} \left\{ \frac{1}{m^2} \sum_{1}^{n-1} \frac{1}{\sigma_k - 1} \quad . \; . \; . \; . + \frac{1}{m'^2} \frac{1}{\sigma_n'} \right\} \qquad (8')$$

Let us now reverse the roles by bringing the field-magnet closer to the armature by the distance δx in a direction parallel to the axis of the pole. In order to make the physical figment plausible, we must now assume (Fig. 5) that the magnetic field is displaced bodily with its excitation-winding, which is assumed to have a fixed relation with respect to the pole (M). The line of flux 1 - 2 which starts from the neutral point, will be displaced upward by the distance δx in a direction parallel to itself, toward 1′ - 2′; and we now have to find the difference between the reluctances between the contours 1 - 2 - 3 - 4 and 1′ - 2′ - 3′ - 4′. But, instead of measuring these differences along the armature, we shall totalize them along the pole and the line 1 - 2. Along the polar surface, as far as the line 1′ - 2′, we shall obtain, as before, the segments $\sigma' = \frac{\sigma}{\cos \beta}$, where σ designates the sectional area of the tubes measured where they emerge from

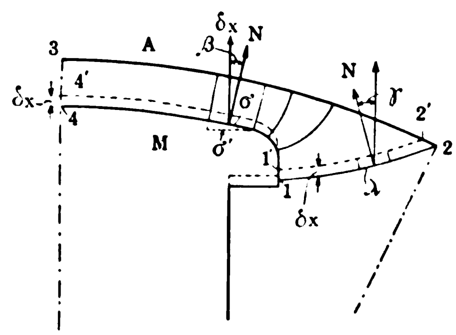


FIG. 5

the pole and β designates the angle between the normal N, to the chord of σ and the direction of δx. For the tube at the extreme right hand, there will be, in addition, a decrease in sectional area equal to $\delta x \cos \gamma$, where γ designates the angle between the direction of δx and the normal, N, to the line of flux at the point considered. The variation of reluctance per element of tube of length, λ, which results in the case of the last tube, in addition to the shortening, will be equal to

$$\delta \rho' = \frac{\lambda}{\sigma - \delta x \cos \gamma} - \frac{\lambda}{\sigma} = \frac{\lambda}{\sigma^2} \delta x \cos \gamma,$$

and the corresponding decrease of attractive force will be equal to

$$f_x' = -\frac{\phi^2}{8\pi} \frac{\delta \rho'}{\delta x} = \frac{B^2}{8\pi} \lambda \cos \gamma,$$

which is the geometrical projection on the pole-axis of a

force, $-\dfrac{B^2 \lambda'}{8\pi}$ which is normal to λ. The same term may also be obtained with equations (1) and (2), by making the surface-integral pass over the polar face and the line of flux $1-2$ which ends at the neutral point.

The tube of magnetic force that is contiguous with the line $1-2$ is composed (Fig. 6) of two squares, the mean sectional areas of which may be replaced approximately by the chords, λ_1 and λ_2, of their average lengths. The quantities $\lambda_1' = \dfrac{\lambda_1}{\cos\gamma_1}$ and $\lambda_2' = \dfrac{\lambda_2}{\cos\gamma_2}$ correspond to and can be obtained directly from segments cut off from a horizontal line (Fig. 6) by the perpendicular lines erected at their extremities in each case; and with the aid of these quantities, we finally have, in the case of m aliquot tubes of magnetic force,

$$F_x = -\frac{\phi^2}{8\pi}\,\frac{\delta R_n}{\delta x}$$

$$= \frac{\phi^2}{8\pi}\,\frac{1}{m^2}\left\{\sum\frac{1}{\sigma'} - \left(\frac{1}{\lambda_1'} + \frac{1}{\lambda_2'}\right)\right\} \quad (9)$$

It is therefore possible to evaluate the virtual derivative,

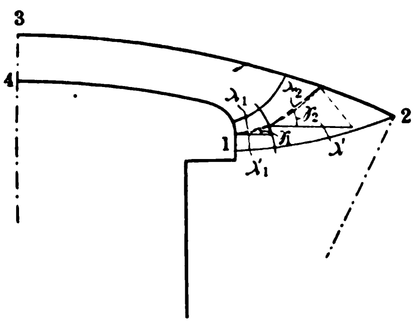


FIG. 6

$\dfrac{\delta R_n}{\delta x}$, *from the original drawing of the magnetic field, without representing the displacement δx and without introducing the components of the magnetic field.*

It should be noted that the virtual work is equal to the energy contained in the zone involved only when the armature is displaced. If, instead, the magnetic field-pole and its winding are displaced, the magnetic energy contained in the area embraced by the polar base of the useful flux, 1 - 4 (Fig. 5) should be reduced by an amount equal to the potential energy contained in the zone embraced by the extreme lines $1-2$ of the common flux.

Example. Let us take as an example, the magnetic figure (Fig. 7) reproduced from Fig. 19 in the "*Revue Generale de l'Electricite*," 1923, Vol. XIV, p. 397. After the fourth magnetic tube, counting from the neutral point, the lines of magnetic flux are radial, and they constitute, between that point and the polar axis, 6.4 unit tubes; so that the common flux, ϕ, per half pole consists of 10.4 unit-tubes. The air-gap being equal to 1.2 cm., and the polar half-pitch being equal to 9 cm., we have, for the sectional areas along the armature, reckoned from the neutral point:

2.85 cm.; 0.97 cm.; 0.71 cm.; 0.62 cm.; 6.4/0.6 cm.

The fractional coefficients are $m = 10.4$ for the first four tubes and $m' = 10.4/6.4$ for the last tube; so that, for the radial attraction per half polar pitch, we have:

$$F_x = \frac{\phi^2}{8\pi}\,\frac{1}{10.4^2}\left[\frac{1}{2.85}+\frac{1}{0.97}+\frac{1}{0.71}+\frac{1}{0.62}+\frac{6.4}{0.6}\right]$$

$$= \frac{\phi^2}{8\pi}\,\frac{1}{10.4^2}\,.\,15.06$$

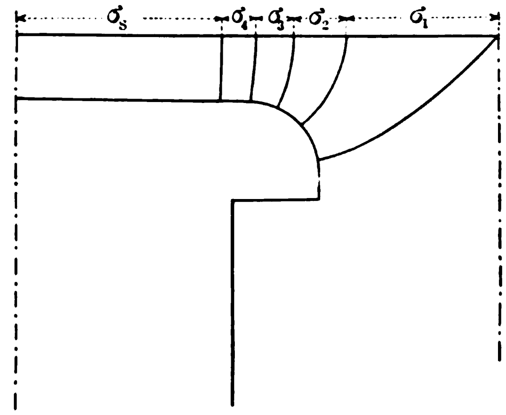


FIG. 7—DETERMINATION OF THE MAGNETIC ATTRACTION OF THE ARMATURE

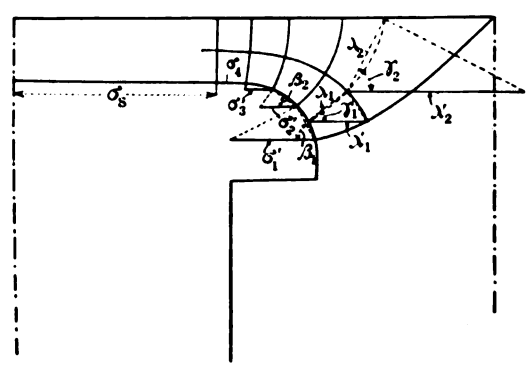


FIG. 7A—DETERMINATION OF THE MAGNETIC ATTRACTION OF THE FIELD

Let us now start from the field-pole. The bases of the first three tubes that emerge from the polar surface are no longer horizontal, and it is necessary to begin by erecting perpendicular lines on the chords of σ and to obtain in a horizontal direction (see Fig. 7A) the values of $\sigma' = \dfrac{\sigma}{\cos\beta}$; which gives us the following values; $\sigma_1' = 1.57$ cm.; $\sigma_2' = 0.70$ cm.; $\sigma_3' = 0.34$ cm.; and we can then point off directly the values $\sigma_4 = 0.55$ cm. and $\sigma_5 = 6.4/0.6$ cm. We still have to obtain,

on the line of median flux of the first tube (shown dotted), the segments $\lambda_1' = \dfrac{\lambda_1}{\cos \gamma_1}$ and $\lambda_2' = \dfrac{\lambda_2}{\cos \gamma_2}$, which may be cut off along any horizontal lines whatever by the lines perpendicular to the chords of the curvilinear elements λ_1 and λ_2 erected at their extremities. These values are found to be: $\lambda_1' = 1.10$ cm., and $\lambda_2' = 3.40$ cm.

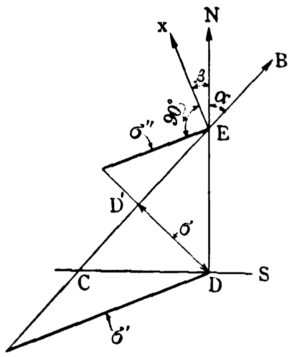


Fig. 8

The radial effort exerted per half pole pitch is thus found to be equal to

$$F_x = \frac{\phi^2}{8\pi}\,\frac{1}{10.4^2}$$

$$\left[\frac{1}{1.57}+\frac{1}{0.70}+\frac{1}{0.54}+\frac{1}{0.53}+\frac{6.4}{0.6}-\frac{1}{1.10}-\frac{1}{3.4}\right]$$

$$= \frac{\phi^2}{8\pi}\,\frac{1}{10.4^2}\cdot 15.20$$

The difference between this value and the preceding one is barely one per cent; which seems satisfactory if we bear in mind that for the whole of the half distance between the two poles only one tube of magnetic force has been assumed. The armature in Fig. 7, was assumed to be rectilinear, instead of curved, in order to simplify the comparison with the algebraical formula which can be established for that case. The inclination of the polar axes does not in any way modify the method of calculation, and the same results should always be obtained whether we start from the armature or from the field-pole.

B. Saturated Circuits. The physical figment that a displacement does not disturb the external field leads us immediately, by the aid of (**6**), to expressions for an armature in which there is no current,

$$F_x = \frac{\phi^2}{8\pi}\sum\frac{\cos(2\alpha+\beta)}{m^2\,\sigma\cos\alpha}, \qquad (\mathbf{10})$$

and for a field-pole which is driving its field without alteration,

$$F_x = \frac{\phi^2}{8\pi}$$

$$\left\{\sum\frac{\cos(2\alpha+\beta)}{m^2\,\sigma\cos\alpha}-\frac{1}{m_n^2}\left(\frac{\lambda_1}{\cos\gamma_1}-\frac{\lambda_2}{\cos\gamma_2}\right)\right\} \qquad (\mathbf{10'})$$

Let us consider (Fig. 8) the base $C\,D$ of a tube having the thickness $D\,D' = \sigma$, which emerges from an element $C\,D$ of the surface, S, of the iron, at an angle α with respect to the normal $D\,E$ to $C\,D$. We can then obtain the projection of the superficial force f_x, corresponding to this tube, in a direction x, forming an angle β with $D\,E$, by constructing directly

$$f_x = -\frac{\phi^2}{8\pi}\cdot\frac{\delta\rho}{\delta x} = \frac{\phi^2}{8\pi}\,\frac{\cos(2\alpha+\beta)}{\sigma\cos\alpha}.$$

But it is often easier to decompose

$$\frac{\delta\rho}{\delta x} = \frac{1}{\sigma'} - \frac{1}{\sigma''}$$

$$= \frac{\cos(\alpha+\beta)}{\sigma} - \frac{\tan\alpha\sin(\alpha+\beta)}{\sigma}$$

and to obtain σ' and σ'' from Fig. 8 by cutting off segments on the perpendiculars to x emerging from D and E through the mean vector of the field B passing through C on the one hand and through the normal to the vector, passing through D, on the other hand. In the case of the field-pole it is still necessary to add the terms $\dfrac{\lambda}{\cos\gamma}$ which come from the extreme tubes of the common flux and which are determined as before.

When the magnetic figure comprises one or more lines of equal potential, the calculation becomes simpler by making the summation along any contour whatever, such as $A\,B\,C\,D\,E$ (Fig. 9) composed of lines of flux and of lines of equal potential, ending at the neutral points of the armature, or, in more general manner,

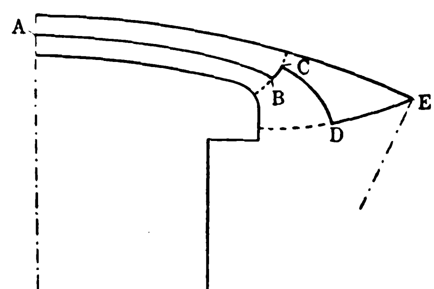


Fig. 9

ending at boundary points of the common field. The values of $\sigma' = \dfrac{\sigma}{\cos\beta}$ and of $\lambda' = \dfrac{\lambda}{\cos\gamma}$ may be obtained, as explained in paragraph A, from the sections σ on the equipotential lines and the segments λ on the isometric lines of flux, by noting that the terms

$\frac{1}{\sigma}$ are of the same sign as the areas swept over, whereas the terms $\frac{1}{\lambda'}$ are of contrary sign.

The equivalence of the process can be easily demonstrated by transforming, by means of the generalized form of Green's theorem, the surface-integral (**1**) into a volume-integral:

$$\int_s S\, P\, d\, S = \int \{2\, H \operatorname{div} B - H^2 \operatorname{grad} \mu - 2\,(B, \operatorname{rot} H)\}\, dv \qquad (\mathbf{11})$$

In the space in the air-gap which is traversed by the useful flux we have, inside any closed aerial surface, $\operatorname{div} B = 0$; $\operatorname{grad} \mu = 0$; $\operatorname{rot} H = 0$; therefore, we will have

$$\int_S P\, d\, S = 0 \qquad (\mathbf{12})$$

Let us now suppose that the air-gap is swept over once by the surface of the armature, for a distance equal to one polar division $0_1\, I\, 0_2$ (Fig. 10) and a second time by a string of any kind whatever, such as 0_1 II 0_2 which extends between the same points 0_1 and 0_2 of the armature. Multiplying (**12**) scalarly by the displacement $\overline{\delta\, x}$, and integrating along the closed contour 0_1 I 0_2 II 0_1, we have:

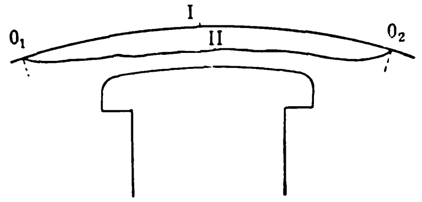


FIG. 10

$$\int_s (\overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S = 0; \text{ whence}$$

$$\int_{0_1 I\, 0_2} (\overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S = \int_{0_1 II\, 0} \overline{\delta\, x}, \overline{B_{2\alpha}{}^2})\, d\, S; \qquad (\mathbf{13})$$

or, on bringing (**13**) closer to the identity (**7**), we see that

$$(\delta\, R_0)_{\mathrm{I}} = (\delta\, R_0)_{\mathrm{II}}$$

It is, therefore, possible to determine the virtual variation of the reluctance, on the assumption that the air-gap is cut through by any contour whatever passing through the neutral points 0_1 and 0_2 of the armature. This manner of proceeding has advantages in the case of windings placed in slots (as in turbo generators).

The physical formulas for magnetic attraction are not much used in practise. Is this due to the hypotheses used in physics? It cannot be denied that, at first glance, our practical intuition, clarified by the idea of the magnetic circuit, finds it difficult to accept the figment which excludes any disturbance of the field during a virtual displacement. But this figment, although it may lead to a state of unbalance, is, in general, justified by observing that, in accordance with Thomson's theorem, one of the two neighboring states of distribution corresponds to a minimum of potential energy.

VI. APPLICABILITY OF THE DIFFERENT FORMULAS

Theoretically, formulas (**1**) and (**2**) enable the attraction to be evaluated whenever the magnetic field in the air-gap is known along the whole surface. But since no analytical solutions that are of interest in practise are available in the majority of cases the best we could hope to do would be to obtain the integration of these formulas graphically after the values of the magnetic flux have been deduced from a drawing of the lines of flux. And even this calculation becomes uncertain in the neighborhood of the slots for the windings, on account of the points of saturation found at the sharp corners and narrow parts of the cores that close around the slots. On that account the integration is rendered possible only when the surface of integration is situated at a suitable distance from the limiting surfaces. It is therefore necessary to have a complete survey of the magnetic field in the air-gap. Moreover, formulas (**1**) and (**2**) are no longer applicable when the surface of integration passes through a medium the magnetic permeability of which is a function of H.

The formula $F_1 = \frac{\phi^2}{8\,\pi}\,\frac{\delta\, R_0}{\delta\, l}$ makes it possible to evaluate the magnetic attraction in the case of any ferromagnetic body surrounded by a medium of constant permeability (air) without the necessity of taking into account the components of the field. The permeability of the body may or may not depend upon the field. In the form in which the formula is completed by the saturation-term[4], it can also be used when the permeability of the external medium depends upon the field. It is then possible, moreover, to do without the magnetic figures of the lines of flux, provided the reluctance, R_0, of the air-gap is known as a function of the extent l, of the air-gap, It is also more easy, by means of this formula, to note critical values of the effort of attraction near points of contact, where the attraction may become more than double, even when the flux is assumed to be maintained constant by means of equipotential connections.

VII. CONCLUSIONS

The magnetic effort exerted upon an assemblage of ferromagnetic bodies and of currents, surrounded by air as a medium, is determined by the corresponding fluxes, ϕ and by the virtual gradient of their air-reluctances, R_0.

The formula $F_1 = \frac{\phi^2}{8\,\pi}\,\frac{\delta\, R_0}{\delta\, l}$ is as exact and as

4. This case is treated in "*Revue Générale de l'Electricité*," Vol. XV.

general as the formulas of physics. It has the advantage over them that besides giving an algebraical solution, it renders possible the evaluation of magnetic attraction by the direct utilization of the lines of magnetic flux of a magnetic figure, without the necessity of first determining the components of the field and then recombining them tensorially.

In a general way, the attraction between two bodies depends only upon the field common to them both. That is still true when the two fields have nothing more in common than their lines of separation (the case of the ideal short-circuit); and the mutual magnetic effort is then determined entirely by the value of the field along these lines of separation.

Discussion at Pacific Coast Convention

APPLICATION OF ELECTRIC PROPULSION TO DOUBLE-ENDED FERRY-BOATS

(KENNEDY AND SMITH)

SEATTLE, WASHINGTON, SEPTEMBER 16, 1925

H. F. Harvey, Jr.: About the only comment which I have to offer is that sufficient emphasis has not been laid on the maneuvering feature. With direct control from each pilot house it is very evident that the one in charge can maneuver the boat more easily than by means of the ordinary signals to the engine room.

I believe that thus far most ferry-boats with electric drive are used on fairly long runs. Such runs do not show to advantage the speedier maneuvering, either when entering or leaving the slips. For short runs as between New York and Jersey City, or between Camden and Philadelphia, electric drive would show a decided advantage in this respect.

Ferry-boats are usually operated in congested waters where it is very necessary to have close control of the vessel in order to avoid accidents. Electric drive, I believe, affords quicker stopping and reversing than any other drive. Too much emphasis, therefore, cannot be placed upon the superior maneuvering qualties of electrically driven ferry-boats.

F. K. Kirsten: There has been no mention made in the paper as to the design of the propellers involved in ferry-boat propulsion. It seems that these boats are designed to travel in either direction with practically the same propeller showing. As a consequence, some design must be used on these particular ferry-boat propellers differing from that used in ordinary steamers. I would like to know if any particular statements could be made in that direction.

M. J. Whiteman: I should like to know if it is possible with a ferry-boat having four-propeller drive to rotate the boat on a center or pivot in order to make quick turns.

A. Kennedy Jr.: Mr. Whiteman asked if it is possible with an electrically-driven ferry-boat to pivot the boat in order to make quick turns, and also the number of electrically driven ferry-boats that are in operation. All electrically driven ferry-boats use the same method of steering as that used on reciprocating steam engine driven ferry-boats, that is, they use one rudder. I do not know of any way to make a ferry-boat pivot in order to make quick turns unless some change is made in the design of the boat.

At the present time there are eight electrically driven ferry-boats in operation, three in New York, four in San Francisco, and one at Poughkeepsie. These, I believe, are the only ones, but of course, others are being considered.

Professor Kirsten asked whether or not it was necessary to modify the design of the propellers for electrically driven ferry-boats. Normally, with steam engine driven ferry-boats, a compromised propeller design is used, as it is necessary to use the face and back of the blades. A good deal of work has been done trying to improve the over-all propulsive efficiency by decreasing the amount of power required to drive the forward propeller. As far as I know, no one has been able to improve the over-all propulsive efficiency by using this specially designed propeller, but they have reduced the power required to drive the forward propeller.

With electric drive it is possible to use a standard propeller for the simple reason that the bow propeller does not do any work. Only the face is used of the propeller for driving, whereas with the reciprocating steam engine connected to a through shaft a special design is made as the back of the blades is normally used on the forward propeller to assist in driving the ferry-boat.

A HIGH-VOLTAGE DISTRIBUTING SYSTEM[1]

(GLEN H. SMITH)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

M. T. Crawford: In Mr. Smith's paper he has referred to the use of a high-voltage primary distribution system, and some reference is also made in Mr. Kelley's paper, to the use of 12,000-volt primary system.

It occurs to me that in following a far-sighted policy, there would be some question as to whether such a high voltage should be used for primary distribution in a city area. There are several angles to the situation. Fundamentally high voltages are of value to cover distances. In distributing light and power in a large city, very large blocks of load can be obtained within short distances. In suburban areas around the large city, considerable distance has to be covered before any considerable amount of power is obtained. For that reason it has been the practise of the company with which I am connected to employ the high-voltage distribution primarily in the suburban area where one distributing substation can serve a radius of 10 to 15 mi., without having any unusually large load entrusted to its care.

In looking into the future of city distribution, we anticipate loads of such size and magnitude as to give load densities which would result in several hundred thousand kilowatts or more being supplied by one distributing substation. If 10,000 or 15,000 volts is used for primary purposes and if sufficient area is covered to make full economic use of such voltage, this would, it is felt, entrust more different consumers' services into the hands of this one substation than might be considered good policy, considering the importance of continuity of service to such a large number of people. The other angles to the use of the high voltage are, first, that it takes considerably more pole space, second, that transformers are more expensive, and third, that cable costs are higher. Such portions of the systems as have to be either submarine or underground will have to be handled by cables, and statistics collected by the National Electric Light Association indicate that in operating a large mileage cable failures increase rapidly in proportion to the voltage.

The high-voltage distribution system in the city of Seattle has worked out very satisfactorily and I think the engineers are to be commended for having secured such results. I would like to ask Mr. Smith, however, if the increase in railway load which has recently occurred and will continue will not result in fluctuating loads on his 26-kv. network, which will introduce

1. A. I. E. E. JOURNAL, October, 1925, p. 1104.

some difficulties in regulation and, may force a change in this policy. We have found where our load is largely lighting, we can use 13-kv. primary distribution very successfully, installing a 13-kv. automatic voltage regulator at the substation, to regulate the entire bus, serving an area within a 15 mi. radius with little or no supplementary regulation.

Where fluctuating power loads are to be handled together with a considerable amount of railway, this has not been possible, and it has been more economical, besides seeming to us better policy from the far-sighted point of view of future loads and service to the public, to install distributing stations and distribute at a lower primary voltage.

C. A. Heinze: There has been considerable discussion in these distribution papers on the matter of distribution at voltages of approximately 33 kv. Mr. Smith describes one at 26 kv. which is practically 33 kv. In Los Angeles, we have an area that is very lightly loaded, with the result that to place a network of low-voltage lines over that area would have called for considerable investment, not warranted by revenues. We were rather fortunate in this particular case to have two power houses, one on each side of the area. This permits us to carry straight line voltage on the 33-kv. lines between these two power houses.

Now, with a system plan, the system can be developed as follows: The first step to feed consumers from this 33-kv. line is to put a transformer on a pole, stepping down from 33 kv. to 4.4. kv., three-phase, three-wire delta. From this transformer we distribute a distance of from one to two miles each way, picking up the small consumers along the way. Now, as the load increases, the transformer becomes too big for the pole, the transformer is then mounted on the ground. This is the second step. With growth continuing, it is then necessary to split the 4.4-kv. line into feeders. As growth continues we go to regulated feeders. By the time we have two or more regulated feeders, it then becomes necessary to house the equipment and provide substation space. Having reached the substation period, the first step would be the use of automatic reclosing switching equipment. As the number of stations increase the automatic reclosing equipment is supplemented with supervisory control from one centrally located station.

I was very much interested to note in Mr. Kelley's paper on the Commonwealth Edison System of Chicago, that they are using a similar type of distribution.

A very important consideration in the design of substations is the proper provision for future growth and extensions. The most satisfactory way to accomplish this is to design the substation on the unit plan. Additions can be made to the initial unit by the addition of one or more similar units such that in the end the station building and interior design represent a balanced electrical and architectural design. Many of you have seen a substation, very beautiful in the beginning, at the end of five or ten years having several irregular additions built around—marring its original symmetry—in order to take care of the extensions and expansions required. This, because we didn't discover or take them into account at the beginning.

Glen H. Smith: I have to thank Mr. Crawford, in his reference to my closure, for bringing out some of the questions that we considered in deciding on our distributing system. I can only say that they are questions, and that we decided them one way though often they are decided the other way. The decision as to the voltage of a circuit depends probably more on the load than it does on the size of the district served.

We find that poles are more involved with lower-voltage circuits than they are with high-voltage circuits, because of the greater number of circuits, although high-voltage circuits take more pole space per circuit.

I can't answer the question as to the effect of fluctuating railway load on our voltage regulation as the railway stations are still connected by special 13,000-volt feeders direct from the station, nothing else being connected but those stations. We have, though, heavier loads than they represent connected to the high-voltage system without any trouble. We expect that the railway stations will help rather than hinder us, by furnishing synchronous capacity to hold the 26,000-volt busses to the proper voltage level in more than the original three points.

ON THE NATURE OF CORONA LOSS[1]

(HESSELMEYER AND KOSTKO)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

R. W. Sorensen: The peculiar curves for Fig. 1 of this paper have to be used in charting the results because a piece of tracing cloth, stretched over the end of the cathode-ray tube, must have lines, as shown, drawn on it to correct for the curvature of the tube and the distortion of the wave.

H. J. Ryan and J. S. Carroll: In the paper on The Hysteresis Character of Corona Formation, by Henline and Ryan,[2] presented a year ago at the Pasadena Convention of the Institute, the authors, in arriving at the existence of a space charge about a conductor in corona, worked at a disadvantage because they had not actually located the radial position of such space charge with respect to the conductor. During the past year two of our graduate students, Mr. Hesselmeyer and Mr. Kostko, proposed to study the radial location of the space charge by the simple plan of a concentric barrier that would limit the radial distance of the space charge from the conductor surface. They would use an isolated barrier cylinder mounted concentrically as specified in their paper; they would obtain the corresponding $E-Q$ relation and then change the radius of the barrier and obtain the $E-Q$ relation again. This plan would be continued over a wide range for the radius of the barrier in order to determine the manner in which the character of the $E-Q$ relation would change with the barrier radius. The purpose of this undertaking was to find out whether the character of the $E-Q$ relation, when barriers were used that bound the space charges to definite radial positions, would approach the character in form and area of the $E-Q$ relation as found for widely separated parallel conductors surrounded by no barriers.

When the work was completed and this paper was prepared by the authors and studied by us, the following point of view developed: The areas in units of energy, given by the Hesselmeyer-Kostko $E-Q$ diagrams, could be expressed in terms of the voltage and the capacitances of the conductor to the space charge and of the conductor to the grounded cylinder or neutral plane. The corresponding power would be the product of the energy by the frequency. Henline and Ryan, in their paper a year ago, had given the corresponding equation for the energy per cycle in terms of voltage and but one value of capacitance, viz., that of the conductor to the neutral plane. It was manifest that, by combining these equations, one could isolate the value of the capacitance of the conductor to the space charge.

Mr. Kostko then derived the equation for the power lost in corona using a barrier, as follows:

$$P = 4 f C (E E_0 - E_0^2) \frac{1}{\frac{C''}{C'} - 1} \tag{2a}$$

wherein

E, is the value of the crest voltage,
E_0, the value of the critical voltage,
C, the capacitance from conductor to neutral,
C'', the capacitance from conductor to the space charge, and
f, the frequency.

The corresponding equation given in the Pasadena paper a

1. A. I. E. E. JOURNAL, October, 1925, p. 1068.
2. A. I. E. E. JOURNAL September 1924, page 825.

year ago, wherein the term C'', capacitance of conductor to space charge was not used, was:

$$P = 4 f C (E^2 - E E_0) \quad (2)$$

By combining and reducing these equations the value of the capacitance of the conductor to the space charge was found to be:

$$C'' = C\left(\frac{E_0}{E} + 1\right) \quad (3)$$

If the radial distance from the conductor to the cylindrical space charge be D_r, and the radius of the conductor r, then the value of C'' will also be:

$$C'' = \frac{0.00368}{\log_{10}\left(\frac{D_r}{r}\right)} \quad (2d)$$

By combining equations (2c) and (2d)

$$\log\left(\frac{D_r}{r}\right) = \frac{0.00368}{C\left(\frac{E}{E_0} + 1\right)} \quad (2c)$$

and

$$\log D_r = \log r + \frac{0.00368}{C\left(\frac{E}{E_0} + 1\right)} \quad (2f)$$

wherein:

D_r and r are in inches

C and C'' in farads per 1000 feet of conductor.

Equation (2f) was applied to one of the corona loss-voltage curves[3] given by Professor Harding's Pasadena 1924 paper[4] the following locations of the space charge were obtained:

e Kv., r. m. s. swe. to neutral	D_r in inches	Kv. per inch, r. m. s.	
		Conductor to space charge	Between pointed electrodes*
140	9.5	14.8	10
165	12.0	13.8	10
220	18.9	11.6	9.9
260	24.1	10.8	9.8
300	29.8	10.	9.8

*A. I. E. E. Standardization Rules, 1912.

As a check upon this understanding of the distance of the space charge from a conductor in corona the following trial was made: In front of a pointed electrode at a distance of 9.5 inches a grid of fine wires was mounted. Alternate wires were electrically connected, thus forming two groups of wires each interlaced with the other. To the groups, a 20-volt, dry-cell battery was connected through a portable galvanometer; 60-cycle alternating voltage was then applied between the pointed conductor and grounded plate and the indications of the galvanometer noted as the value of the voltage was raised. The galvanometer indicated that no current was set up through the air between the two groups of wires in the grid until the voltage was raised to an effective value of 110 kv. Thereafter the current increased at the rate of 0.1 microampere per kilovolt until the value of three microamperes was attained at 140 kv. As a slight further increase of the voltage was made, the current through the air between the grid wires rose to eight microamperes. And then, as the voltage increase was continued, there was no corresponding continuation of increase of current. This is precisely the sort of thing that should happen if the foregoing understanding of the existence and position of a space charge about a conductor in corona is correct.

The matter was tried out by another plan: The space charge was reversed while the voltage increased from the critical value E_0 to the crest value, E, in a corresponding interval $\Delta t = t - t_0$. During such interval, Δt, electrons must travel from the conductor to the location of the space charge when the potential of the conductor is negative, and vice versa when positive. When the electrode in corona is the point of a conductor, the resulting luminosities produced by the migration of the electrons as just specified might be intense enough to be visible in full darkness to or near to the radial position of the space charge. On trial, such was found to be the case.

Another reasonable conjecture in regard to action due to the space charge was encountered: Voltage was applied between a pointed conductor and a grounded metal plate. As the voltage was raised corona filled a conical space that expands from the point toward the plate through distances in relation to voltages that correspond roughly to those given in the above table. As the voltage crests occur the space charges and point potentials have the same sign, while the signs of the space charges and bound charges induced in the grounded plate as opposing electrode are opposite. The consequence is that the intensity of the electric field between the space charge and the point has been reduced and that between the space charge and plate has been correspondingly increased. The outcome must be that, as the voltage is raised, critical electric stress will be encountered in the air between the space charge and the plate beyond which the intervening air must be ionized and rendered conductive. On trial, this too was found to be the case. As the voltage is raised, the faintly luminous cone develops, attached to the point with rounded base thrust forward. Then, as the rise of the voltage continues and the growth of the cone moved its base to a position whereat it was somewhat nearer the plate, a faint pillar of light suddenly extended from the cone to the plate; the air column connecting the point to plate had been ionized and spark-over and arcing followed with slight further increase of voltage.

And so, thus far every plan that has occurred for authenticating the existence and position of the alternating space charges established and maintained about a conductor in corona due to 60-cycle voltages when tried out, has resulted in corroboration of the understanding as given.

H. S. Bates: I should like to ask Mr. Hesselmeyer if there will be any means of accurately measuring corona loss? I wish to ask also what is the best method of preventing it?

C. T. Hesselmeyer and J. K. Kostko: The experiments of Prof. Ryan and Mr. Carroll are interesting not only because they prove the existence of a space charge, but also because they suggest experimental arrangements for a quantitative study of the distribution of the space charge and the field. It is easy to set up equations theoretically determining these two elements (Poisson's equation and equation of continuity); but numerical solutions could only be obtained by reducing these general equations to simpler types, based on the results of a preliminary experimental study of the problem.

In the author's opinion the most accurate method of measuring corona losses available at present is by means of the high-voltage wattmeter developed at Stanford University and described in several Institute papers by Mr. Carroll and others.[3] In Fig. 17 of the paper the losses measured with this wattmeter are compared with the losses obtained by a very different

3. In applying these equations it should be remembered that the voltage must be taken at a value sufficiently above the critical voltage to ensure that a fixed brush pattern has been formed and the value of C is a constant as presented in the Pasadena paper.

4. *Corona Losses between Wires at Extra High Voltages*, by C. F. Harding, A. I. E. E. JOURNAL, October, 1924, page 932.

3. *Power Measurements at High Voltages and Low Power Factors*, by J. S. Carroll, T. F. Peterson and G. R. Stray, JOURNAL A. I. E. E., Oct. 1924, page 941.

Some Features and Improvements on the High-Voltage Wattmeter, by J. S. Carroll, JOURNAL A. I. E. E., Sept. 1925, page 943.

method—integration of the E-Q cyclograms—and the agreement is remarkably good.

As indicated by the theory and confirmed by experiment (Fig. 8), it is possible to reduce corona loss by setting up a suitable space charge around the conductor, for instance by enclosing it in a cylinder of a small diameter; it does not seem, however, that this method is suitable for practical applications; at least in the case of a transmission line. A radical reduction of the transmission frequency would result in a reduction of corona loss (Fig. 17), in addition to many other advantages, such as better regulation, etc.

POWER DISTRIBUTION AND TELEPHONE CIRCUITS—INDUCTIVE AND PHYSICAL RELATIONS

(TRUEBLOOD AND CONE)

SEATTLE, WASHINGTON, SEPTEMBER 18, 1925

H. S. Phelps: Messrs. Trueblood and Cone have very ably and clearly pointed out the importance of the type of power-distribution system in the matter of inductive coordination. This importance is recognized, and as the problem is better understood, more and more attention is being given it. It seems to me, however, that they have not placed sufficient stress upon another equally important feature—namely, the characteristics of the telephone system.

The ideal arrangement, of course, would be, first, a power system without residual currents or voltages, with the conductors very close together. Such a system would be closely approached by using multi-conductor cable, where all the current was forced to return in the conductors; second, a telephone system without any impedance unbalance in the metallic circuit or admittance unbalance between the two sides of the circuit to ground. In this desirable telephone system the subscribers set should not require utilization of an unbalanced ground connection for ringing. Connecting such an instrument to the system by means of a well designed and carefully installed cable circuit to a well balanced central-office cord circuit would likewise materially improve the situation.

An ideal power system would not produce longitudinal voltage in neighboring telephone circuits, and therefore could not cause noise in the telephone system, regardless of telephone circuit unbalances. On the other hand, an ideal telephone plant would not be susceptible to induced longitudinal voltages, and therefore could not be affected by any distribution system during normal or abnormal conditions, unless the induced voltages were of a magnitude to constitute danger to life or property.

Since neither ideal system is necessary or practical, it remains to determine how far either system may depart from the ideal without placing serious limitations and burden on the other. In order to ascertain the technical facts underlying this problem, the joint Development and Research Committee of the National Electric Light Association and American Telephone and Telegraph Company has been carrying on work under one of its projects at Minneapolis for over a year.

Although many interesting and useful results have been obtained, it would be premature to attempt outlining any of these at this time. However, it is expected that an interim report will be issued in the early spring covering the major findings of this work.

The considerations outlined for coordination of the telephone circuits with a distribution system apply in the same manner to the problem of induction from a lighting system discussed in the paper by R. G. McCurdy.[1]

P. D. Jennings: I gather from reading this paper and from an informal talk with Mr. Cone that the residual higher harmonic currents are the ones that give the most trouble. I should like to ask why resonance shielding on substation ground circuits might not take care of most of this trouble. As an example, suppose in a particular substation, our oscillograph records show that the ninth and fifteenth harmonics are predominant. It occurred to me that a resonant shield might be used to resonate out the ninth and the fifteenth harmonics on the substation ground and in that way eliminate most of the trouble.

A. A. Williamson: Mr. Cone referred to the relatively greater freedom from inductive interference that is usually experienced when both the power and the telephone circuits are in cable. Cases sometimes arise, however, where interference is experienced between the two classes of circuits when they are both in cable, and such cases are usually of somewhat more than ordinary interest. A very brief reference is made to such a case in the paper and it seems to me that a few words of additional description of the conditions in that case would be interesting.

In this instance, power at 13,000 volts was supplied directly by a three-phase generator, connected in Y and with the neutral grounded, to two open-wire circuits, branching and each supplying 13,000-volt power to a substation. The power company decided to provide a tie between the two substations and concluded that in this case the tie should be of cable. The tie when installed was approximately 1.65 mi. in aerial cable, and about 0.7 mi. in underground cable. The sheath of the underground cable was, of course, well grounded, but was not connected in any way to the neutral of the generators. This cable tie paralleled in its aerial portion an aerial telephone cable.

As soon as the tie was energized, interference was noted in the telephone circuits. An investigation showed that the sheath of the aerial power cable was also grounded at intervals with driven grounds but that these grounds were of rather high resistance so that the residual charging current flowing into the cable sought ground and returned to the generating station through the low-resistance ground afforded by the sheath of the underground portion of the cable. Thus the charging current flowed through the parallel as residual current and produced interference. By installing a low-resistance ground on the sheath of the aerial portion of the power cable, at the end more remote from the underground portion, the induction was very greatly reduced. The reason for this was that with the additional ground in place, the charging current flowed through the capacity of the wires to the sheath and back over the sheath. Thus, in each part of the parallel, there was a return path for the charging current flowing out over the three-phase wires and instead of acting as a residual current, it became a balanced component. This case illustrates the effect of residual current in causing induction sometimes of serious magnitude even when both classes of circuit are in cable.

I should like also to cite very briefly a case with which I happen to have had intimate contact on the Atlantic Seaboard. This case illustrates the importance on the induction problem of unbalanced load current flowing in the ground. In this instance, a 4000-volt, three-phase, four-wire distribution system with the neutral grounded at the point of supply, paralleled in open-wire construction an aerial telephone cable. The parallel was about 8000 ft. in length; it was joint construction and at the end of the parallel more remote from the point of supply to the power system, the three-phase, four-wire circuit entered underground power cable. At that point, the neutral wire of the three-phase, four-wire system was connected to the underground cable sheath. As the sheath of the underground cable was well grounded, it could be seen that any current in the neutral due to unbalance of load between the three phases would return to the power station both by way of the neutral and by way of the ground, the division of current in the two paths being in approximately inverse proportion to the impedance of these two paths.

In this case, measurements were made of the interference on party line subscribers' circuits in the telephone cable, and approximately 900 standard noise units were found at the subscribers' receivers. Owing to the excellent cooperation of the

1. Induction from Street-Lighting Circuits, by R. G. McCurdy, A.I.E.E. JOURNAL, Vol. XLIV, October, 1925, p. 1088.

power company in this case, it was possible during the investigation to disconnect temporarily the power cable from the aerial portion. When this was done, the path for the unbalanced load current to return through the ground, no longer existed. Under this condition the induction was reduced to about one-third of its former value.

This case seems to illustrate very well the effect of unbalanced load current when it can return through the ground. The use of power cable with the sheath connected to the neutral wire is only one of the ways in which a path may be provided for unbalanced load current to return through the ground. Whenever the neutral wire of a three-phase four-wire system is grounded at several points, this same opportunity exists and experience has indicated that it is usually one of the most important features from an induction standpoint.

K. L. Wilkinson: In practically all cases telephone subscribers are users of electric light and power service. Therefore, the companies, in order to serve these customers in distribution areas, must of necessity have their overhead lines in close proximity to each other. The problems arising therefrom are mutual ones since they involve the rendering of both services to these common customers in a safe, adequate and economical manner. It seems to be now generally appreciated that these problems require cooperative consideration by the two utilities in order to be successfully solved. The advantages of this cooperative treatment have generally been recognized throughout the country, and the splendid cooperation between the operating utilities in the field is producing most satisfactory results.

Now, in order that these individual efforts in the field may be most successful, it is desirable that all parts of the country know what is going on in all other parts of the country and be in a position to have made available to them all of the data and information which would shed any useful light on the problem. To this end, some four years ago there was organized the Joint General Committee of the National Electric Light Association, and the Bell Telephone System. This Committee was to investigate the physical relations between electric supply lines and communication lines, and to develop principles and practises for the guidance of the operating companies in solving their day-by-day problems.

The Joint General Committee has at its disposal all the operating experience of the country and has, as you know, published *Principles and Practises for Inductive Coordination of Supply and Communication Systems.*

The principles which have been developed are nothing new; they are based on the operating experience in their day-by-day work in coordination of the two systems.

One of the most important, I think, is the principle of cooperation and the advance notice. I thought of that particularly when Mr. Heinze mentioned the growth and development of the power systems in the distribution areas, the increasing load density and of the fact that nearly everybody now has a telephone, and every telephone must be a part of a system that operates throughout the United States, so that any one telephone in any one part of the country can be connected with any other telephone in the system.

If we are going to have the best and most economical power system to supply the people with electric light and power, and if we are to achieve the ideal of universal communication throughout the country, it is absolutely essential that locally and nationally we establish and maintain the closest contact between the two utilities in order that the public may obtain the fullest benefits of all of our engineering knowledge and experience.

The Joint General Committee, in approaching the problem, established one thing clearly and that was that each party should be the judge of his own service requirements and what was necessary to serve his customers. Next to that was the duty of coordination; that is, each party should so conduct his business as to be less productive of adverse influence on the other system; and, the system should be as free as practicable from things which would make it capable of being adversely affected.

I think that if we bear these major thoughts in mind,—first, that each is the judge of his own service requirements, and second, that we have a mutual duty toward the public to see that they get safe, adequate and economical service,—then the necessity of planning well in advance so that the situation does not get out of hand will be fully appreciated and we shall be promoting the best interests of the public in getting these two necessary services.

F. O. McMillan: Would it not be advisable to include in this paper under the three-phase transformer connections, some reference to both the primary and secondary winding connections, because of the fact that the third-harmonic magnetizing current and all multiples of the third harmonic in Y-delta-connected transformers are very nicely cared for when the delta connection is used on either side of the transformer?

S. B. Hood: In the paper I note, in the tabulation of the relative ease of coordination of the different systems, that almost without exception, the power system which is easiest to coordinate is the very system which the power man does not want to use.

Now that means that we must have a cooperative spirit of give and take. At some place in the list is the system which is just as good for the telephone man as for the power man. Just where it is, I don't know. I don't think it has ever been discovered, but we certainly have to work in a true cooperative spirit toward that end.

M. T. Crawford: Mr. Cone refers to the possibility of a slight ground which persists for some length of time as being a very serious source of interference when it occurs on the primary system.

I believe that practical experience will bear me out that on a grounded-neutral primary system it is almost impossible for a slight ground to persist for any great length of time. The ground on the grounded-neutral system is a short circuit and very soon develops into something that will trip the switch out. That would be an argument in favor of the grounded-neutral system as being superior from the point of telephone interference.

I should like to ask Mr. Cone what he considers the principal objection to raising somewhat the 5000-volt limitation which is at present observed in connection with joint-pole construction of light-and-power and communication circuits. This, of course, is an old question, but it seems today to assume a new aspect inasmuch as there is here evident such a willingness to cooperate. Perhaps the difficulties of joint-pole construction on voltages over 5000 have been where the distribution work of the light and power companies was not planned far enough in advance to take into account the telephone company problem.

The Puget Sound Power and Light Company now operates on a part of its system a commercial telephone system, which was taken over in connection with the purchase of a smaller company. On this system we have 6600-volt primary distribution on our own poles in combination with our own telephone service lines. We have been able to live very well with ourselves under such conditions.

L. J. Corbett: I wish to second Mr. Hood's remarks in regard to cooperation in spite of the suggestion which has been made that a wave of propaganda is upon us.

I have observed that the telephone men have studied the theoretical part of power transmission and distribution rather thoroughly. But very few power men study the telephone problems thoroughly. If we did and suggested to the telephone companies how to operate their systems, it might be taken in the same spirit as that in which the power men receive suggestions from the telephone men as to how they might operate their systems.

The ideal manner of handling the inductive-coordination problem would be realized if the same interests owned both the communication system and the power system. If this were true

they would be compelled to get together and determine the accurate economic solution in each case.

In California we act under the California Railroad Commission. The order of the commission is a state law, and under that law we are "required to cooperate." We find that this cooperation really works both ways. It is not always merely doing that which is requested by the telephone company; we do a little telephone engineering ourselves, although not in a very aggressive way. When the telephone company suggests coordinating measures, as a rule we put them in when it is possible without unreasonable expense.

If, from our standpoint, they do not appear reasonable, or if some construction or operating difficulty is involved, or a higher unjustifiable expense is indicated, we raise the question as to whether or not the benefits to be gained by these measures are worth the expense and trouble involved. When such communications reach telephone company officials, the requests are usually modified or dropped.

The beauty of the California law is that public interest comes first, and the cost of any of these coordinating measures is reflected in the rate. In this manner the public is the final unifying agent or manager and the holder of the purse-strings.

F. H. Mayer: Mr. Cone raised some objection to the grounding of the neutral return on 4-kv. distribution systems. It is the practise of the Southern California Edison Company to ground the neutral at numerous points throughout the distribution system to enable the secondary voltage to remain somewhere near a safe value should the return cable become broken. The driven pipes will tend to span the gap and thus prevent the Y connection from straightening out to a straight delta connection. If the loads on the different phases are carefully balanced there ought not be any communication disturbances.

H. M. Trueblood: I am sure we can all endorse the attitude expressed in Mr. Phelps' discussion, namely, that the solution of the problem consists essentially in finding the degree to which ideal systems must be approximated.

Mr. Phelps' reference to the joint investigation at Minneapolis should, I feel, include mention of the Northern States Power Company and the Northwestern Bell Telephone Company as participants. The progress which has been made in that work is due in no small degree to the effective cooperation and assistance of these two companies.

As regards the suggestion that the paper does not lay sufficient stress on the characteristics of the telephone system, I wish to say that there is no desire to ignore this phase of the problem. The paper has been presented as one of a group dealing with various aspects of power distribution and, as such, it does not purport to discuss telephone-system characteristics, except incidentally.

With reference to Mr. Jennings' inquiry, I know of at least one case in which the measure which I believe he has in mind was applied successfully. In this instance, there were two harmonics to be taken care of, the 15th and the 33rd, and two antiresonant elements, each consisting of a condenser and an inductance in parallel, tuned respectively to the frequencies of these two harmonics. They were connected in series between the neutral of a 13,000-volt generator and a grid resistance of low value, the other terminal of which was grounded. The exposure involved was about 3 mi. long at a separation of some 30 ft. I have been informed that effective reductions were obtained in the noise, previously quite severe, and that the arrangement has proved satisfactory from a power-operating standpoint.

Mr. McMillan refers to the omission of reference to the effects of delta windings. Because of the rather extensive ground covered in Table I, it was necessary to simplify the table and to make some selection among the different features that might be included. Of course, delta windings on transformers do affect the magnitudes of the triple-harmonic voltages and currents that appear on the lines; but this effect may be either to increase or to diminish the magnitudes of the line residuals of these frequencies, depending upon the locations of the transformers concerned and the conditions of grounding. Of the systems summarized in the table, those presenting the greatest difficulties in coordination are ones in which the load currents are more important than excitation currents, and, of course, the transformer connections are immaterial, so far as load currents are concerned.

Mr. Hood and others have remarked that the distribution systems classified in the paper as presenting the greatest facility of coordination are not those which a power company would ordinarily adopt if nothing more than the distribution of power were involved. Without attempting to pass judgment on the relative merits of different systems from the latter standpoint, I believe we should not be surprised that a conflict of this character is found to exist. This is an essential feature of the situation with which we are confronted at the present time. In fact, we have an inductive-coordination problem largely because types of systems which are deemed advantageous from one standpoint may not be so from the other. Mr. Hood's inference from the situation to which he refers is substantially the same as that arrived at by Mr. Phelps, and I find no difficulty in concurring in it.

Mr. Hood has referred to the use of multiple grounds on the neutral as a stabilization proposition. While stabilization may be the principal purpose in using the multiple-grounded neutral, it is unfortunately true that this does not prevent the setting up of residual load currents.

In his remarks applying to Mr. McCurdy's paper, as well as to that by Mr. Cone and myself, Mr. Heinze refers to the question of cooperation between the telephone company and the other electric utilities. It is true that most telephone engineers who have had to do with the inductive-coordination problem keep prominently before them the idea of cooperation. That is because it appears to us that no other method of approach can be successful. While this is more nearly self-evident now than it was some years ago, it is so important that one feels justified in laying stress upon the idea. The same thought has been expressed more than once by power engineers in the discussion of these papers.

Mr. Heinze asks how far the telephone company will go in this cooperative endeavor. As to the general spirit and attitude of the Bell System, I will merely remind you that for a number of years it has gone to considerable trouble and expense to adapt itself to circumstances which have arisen because of situations of proximity between its circuits and power circuits. That this willingness to cooperate in the fullest way will be maintained in the future seems to be sufficiently evidenced by the adoption of principles and practises by the Bell System and the N. E. L. A., under which cases are now being handled generally throughout the country, and by the undertaking of a joint research investigation to determine the fundamental physical and engineering factors which enter into the inductive-coordination problem. The work at Minneapolis is one project in this general research program, and other projects are under way in different parts of the country. As to division of cost, it must be recognized that after the correct engineering solution of a given case has been found, the question of an equitable division of the expenditure necessary to put it into effect will arise. This phase of the problem has so many ramifications that any attempt to summarize it here might be misleading, and a comprehensive discussion would carry us much beyond the field with which the paper is concerned.

In conclusion, I wish to make it clear that Mr. Cone and myself have attempted nothing more than to analyze the problem in a preliminary way without going into detail, and to bring out the technical facts known to us as we see them. Mr. McCurdy, I am sure, would agree with this attitude.

D. I. Cone: Mr. Crawford spoke of the interference that arises from accidental grounding of one phase wire. On a three-wire system normally isolated from ground, such conditions may

persist for days at a time, or longer. This can be prevented by suitable maintenance measures. On the other hand with the grounded-neutral system the tendency is for such accidental contacts to develop into short circuits and to operate the circuit breakers. From the discussion by Messrs. Crawford and Cunningham it is evident that the local conditions immediately surrounding an accidental ground contact cause great variations in contact resistance and resulting ground current.

Mr. Crawford has raised the question of joint use at higher voltages than has been customary in the past. Many of you are doubtless aware that the subject of conditions of joint use is under active study by the Joint General Committee of the N. E. L. A. and the Bell Telephone System. We do, of course, recognize that there are some special cases where joint use of poles at higher voltages is the best engineering solution to meet the conditions of a particular problem and in such cases joint use is being approved.

Mr. Crawford also stated that his company had lately acquired a combination power and telephone distribution system with the power lines operating at 6600 volts. Our experience has not been encouraging as to the conditions of noise and hazard that obtain in such circumstances.

There are, of course, differences of opinion in respect to the question of protection from the hazards of power distribution. I wish to suggest, first, that higher voltages are ordinarily employed in distribution for longer distances and larger loads and, second, that this inevitably means either extraordinary measures to prevent hazard and impairment of service or else lowered standards. It is our view that advance planning will enable us to avoid to a great extent the necessity of joint use at the higher voltages. Meanwhile, any specific situation that arises we are more than ready to consider.

Mr. Corbett has described the working out of cooperative consideration of specific cases in California. As he states, the best results are obtained when the reactions of proposed measures are thoroughly considered by both parties. Suggestions arising from the study of these problems by the power engineers are cordially welcomed. I think it fair to say that the working together in California is not merely a matter of compliance with regulations but a realization that it is the rational way for the power and communication utilities to solve these problems. Mr. Mayer's discussion brings out the fact that there are conflicts to be adjusted between the requirements of the communication and power distributions and that the degree of detriment from multiple grounding depends upon several factors in the layout of the systems. Mr. Mayer's point about the use of multiple grounds on the primary neutral for stabilization has also been brought out by Mr. Hood. While recognizing that accurate balance of loads might prevent detrimental induction in communication circuits so long as all phases are present, we must not overlook the facts that setting up and continuously maintaining such close balance is not a simple matter and that exposures often occur where only one- or two-phase wires are involved.

OPPORTUNITIES AND PROBLEMS IN THE ELECTRIC DISTRIBUTION SYSTEM[1]

(Blake)

Seattle, Washington, September 18, 1925

C. E. Carey: I wish to discuss one or two details in Mr. Blake's paper. He mentions primarily the single-pole protective unit. He goes into detail and attempts to establish the justification of the multiplicity of parts. However, the question of single-phase or single-pole units cannot be separated from the whole network. Personally, I believe that the multiple unit is the real solution. We have seen that there are certain state laws requiring that we open the entire circuit, rather than allow an unbalance on the networks and produce inductive interference. It is much better, I believe, to clear the entire trouble as quickly as possible rather than take out one phase at a time. The three-pole unit will not occupy as much space in the manhole as three single-pole units. The automatic a-c. network protector is a device which does everything you can expect it to do. It is designed to go into the standard 35-in. manhole cover. The covers of the units are of aluminum, are light and can be handled by one man. Furthermore, if inspection is to be made of these devices the time consumed will be less with three-pole units than with three single-pole units.

In regard to the translator, I believe, that anything we put in to complicate the network is defeating the purpose of the a-c. system. The whole thing resolves itself back into continuity of service, simplicity and low cost, and the only way we can arrive at that service with a reasonable cost is to trim it down to just the bare necessities.

Practically everyone will agree that if we had it to do over again, we would never put in a d-c. network. We have it, but what are we going to do with it? If we attempt to change to an a-c. network we are confronted with the cost of changing over the customer's equipment, which will be so high in some cases that the interest and other fixed charges on that additional cost will more than carry the high losses in the d-c. network. However, one solution is being used to bring the economics of the d-c. very close to those of the a-c. network, the use of the automatic substation. The automatic substation gives primarily the same type of distribution as the a-c. system; that is, high voltages to the converting stations and low-voltage for distribution. The automatic substation is reliable and economical. A real analysis of the problem will often show that it is better to hold to the d-c. network, remove the concentrated manually operated stations, and distribute that conversion power over a network to a large number of small conversion stations, approaching extremely close to the transformers on the a-c. network in losses and other factors which come into the distribution problem.

Henry Richter: In considering a-c. secondary networks, it is well to recognize that the network systems mentioned by the United Electric Light and Power Co. as used in New York City—and also those in New Orleans—use triple-pole automatic network units exclusively, and that similar systems and network units will shortly be in operation in Dallas, Memphis, Knoxville, and Atlanta. Minneapolis will install these units as the load grows, preparatory to forming a network. These comprise all the companies that have completed or started to construct a network like that of Fig. 2, using automatic network units.

In practically none of the installations in these cities, where space might permit single-pole units to be installed, has it been necessary to add to the dimensions of new manholes in order to accommodate the triple-pole network unit; or to construct new manholes, or enlarge old ones, due to any extra space required because single-pole units were not available; or even to take up space in an existing vault that could be ill spared. These networks are considered justifiable only in heavily loaded areas where the loads are too great to be supplied in the single-phase manner. Three-phase transformer banks are therefore the rule, ranging in size from three 25-kv-a. single-phase transformers up to three 100-kv-a. transformers. The manholes and building vaults to accommodate such banks, to allow for growth of load, to ensure no excessive temperatures, and to permit proper racking and maintenance of cables, must be of such size that there is no lack of wall space for a triple-pole network unit. It is customary to locate this unit on the wall opposite that along which the three transformers are placed, and close to a corner of the manhole. In existing manholes having three-phase banks formerly part of a radial primary and secondary system, the triple-pole network units can usually

1. Abridged in A. I. E. E. Journal, December, 1925, p. 1355. Complete copies in pamphlet form only.

be put into the space formerly occupied by the large secondary junction boxes. In most cases, this space is not otherwise useful, for the network systems employing these automatic network units are so simple that nothing else is necessary in the manhole besides the transformers with or without small reactors, the cables and the network unit. Further, it is an erroneous idea that single-pole network units, particularly in a submersible housing, can be made so tiny that they can be installed in any odd corners of a manhole. The desirability of giving them proper maintenance makes such procedure far from advisable even if they were so small.

If it is desired to have the leads to the secondary mains leave the triple-pole network unit horizontally, to either side, it is extremely simple to provide a small terminal box where the outgoing leads emerge from the top of the submersible housing. This small box can have wiping nipples mounted horizontally at either side. The extra bend in the cable is thus eliminated. However, in none of the cities enumerated has this been necessary. Seven and a half feet is an average height for these transformer manholes as determined by good subway construction practise and even with a triple-pole network unit for a bank of three 100-kv-a. transformers there is no cramping of cables entering and leaving the housing.

When the triple-pole network unit was being designed, it was recognized that the submersible housing must pass through a certain minimum-size manhole opening. A country-wide survey was made and it was learned that the great majority of companies have adopted 35-in. diameter round as the smallest opening for transformer manholes in existing or contemplated construction. Apparently this minimum was governed by the dimensions of 100-kv-a. single-phase subway transformers. Accordingly the triple-pole units of all sizes were designed to pass through a 35 in. diameter round opening. In none of the six network cities mentioned, and together they are typical of all other cities, will it be necessary to rebuild the opening of any manhole to permit the unit to pass through; and careful investigation shows that in none of the cities where three-phase networks are being considered for the future will there be any difficulty in this regard.

If it becomes necessary to rack cables along the wall back of the network unit, it is just as easy to mount the triple-pole unit on a pipe framework braced to the wall as for the single-pole unit, since the two types are not very different in depth. However, just as with junction boxes, subway oil-circuit breakers and such apparatus, electric service companies do not consider this good practise in manholes. In only one case has a company mounted on a transformer tank a piece of auxiliary apparatus of such size as a single-pole network unit might be, and there the conditions are unlike those anywhere else in the country. In general, the place for such equipment is against a wall.

Where subsurface conditions make it impossible to build a manhole for three transformers at any particular location in the street on a main thoroughfare, three solutions have been found to be applicable: (1) obtain a vault in the basement of a building; (2) install a manhole under the sidewalk, or (3) locate the manhole in the street as close to the desired location as possible. In almost no case has it been impossible to use one of these methods. Where the third method must be employed, the distance from the most desirable location is usually so short that the cost of the extra length of duct line is small compared with the extra cost of three smaller manholes over one larger one. It is also doubtful whether city authorities will permit subsurface obstruction at three neighboring points.

The triple-pole network unit for manholes is constructed with a window of heavy, wired glass, amply strong, in the cover; this makes inspection of the principle parts easier than by taking off the cover of a single-pole unit. If it is necessary to get at the parts inside, the time to remove the few extra bolts or lugs holding the cover on the triple-pole unit is negligible. The aluminum cover of the triple pole unit can be handled by one man without difficulty.

The design of the single-pole unit to permit easy removal of the panel from the housing when it is desired to make repairs at the shop follows the identical idea that is incorporated in the triple-pole network unit design. Similarly, right from the start, fuses have been installed on the panel of the triple-pole unit, in series with the outgoing leads, to make a separate fuse box unnecessary. These last two points, therefore, do not apply exclusively to single-pole units.

The paper claims that the single-pole unit conforms with the method of single-pole switching inherited from the radial system of distribution. In a properly designed three-phase network system single-pole switching is no longer necessary and may be abandoned. In a radial system it is better to have some light than no light, when trouble occurs on a feeder, and hence the value of single-pole switching. Networks are designed so that in no case will trouble on any feeder cause interruption of any service fed from the secondary network. Among such troubles there must always be included the putting out of service of all three conductors of a feeder, either by phase-to-phase short circuit in a three-conductor cable, or, where three single-conductor primary cables are in the same duct, by the melting down of all the conductors by a severe fault to ground on one of them. It may even be necessary to provide for the possibility of a manhole fire taking two feeders out of service simultaneously. Thus, there is no necessity in complicating the system to get the insurance that goes with keeping two of the phases in service when the third goes out. One large company even plans to use three-phase regulators on three-phase feeders serving an important network, and some are thinking of using triple-pole oil-circuit breakers at the station and three-phase distribution transformers where these can be passed through the existing manhole openings.

The paper overemphasizes the importance of manhole installations. While the difficult conditions encountered in manholes must be met and are being met, it should be remembered that of a total of over 600 triple-pole network units that will be in operation by the end of this year, less than one third will be in manholes.

Three single-pole units have three operating mechanisms in place of one for the triple-pole unit, and this means more parts to maintain. Three units together have more surface to gasket than a triple-pole unit, which gives more chance for water to leak in with any given type of construction. Three units also occupy a greater total space in the manhole, and every cubic foot is valuable. When the design of automatic network units was first under consideration, all these factors were weighed and the single-pole type was abandoned as inferior to the triple-pole type.

The simplest method of ensuring stable operation of regulators on feeders operating in parallel on a network[2] does not require any extra apparatus such as the transformers T and reactors X of Fig. 3. It employs only a transfer switch, corresponding to switch S for each feeder. This scheme was given a thorough test on the network system of the United Electric Light and Power Company, where it originated, and was shown to be entirely satisfactory.

One of the greatest problems in connection with secondary networks is the type of combined light and power secondary system to employ. Mr. Parker has blazed the trail in an effort to devise some scheme whereby the advantages of the combined system may be obtained and the disadvantages of the star connection avoided. It cannot be too strongly urged that others follow in his steps. However, it must be pointed out that the translator scheme may introduce disadvantages that outweigh those of the simple four-wire, star system, and these

2. Described in the *Electric Journal*, July, 1925.

disadvantages may so handicap the development of the network idea as to result in a loss to all concerned.

In the star system of Fig. 4 the only voltage unbalance at the motor terminals is caused by unbalance of load in the secondary mains due to varying sizes of the loads as encountered along the street. This unbalance may be reduced to a negligible amount by care in connecting two-wire and three-wire services on alternate phases. From the analysis of the translator scheme it is evident that it may easily result in voltage unbalances of at least 10 per cent at the motor terminals. For the same per cent voltage unbalance on a motor as per cent voltage reduction, both the heating and starting torque are affected to a worse degree in the case of the unbalance. Hence the effect on motors would be worse with the translator scheme than by operating them at 199 volts on a 115/199-volt star-connected secondary.

Adding extra transformers on other phases to obtain a better balance of voltage where power loads are frequent not only increases the number of transformers on the system, but also calls for larger or more manholes to house them. This would materially cut down the savings in transformer capacity gained by the diversity that networking makes possible.

Where the 115/199-volt star-connected secondary system is employed it has been necessary to use auto-transformers on not more than 15 to 20 per cent of the motors connected to the system in order to supply satisfactory voltage. On the basis of power load equal to half the lighting load these auto-transformers represent less than 7 per cent of the capacity of the secondary system. If the translators, equivalent in capacity to the total capacity of the secondary system, cause an increase of investment averaging 10 per cent of the entire distribution system cost, the auto-transformers necessary to ensure satisfactory operation of motors on a star system involve an increase in investment of less than 0.7 per cent.

The unbalance of current for the case of power load half the lighting load requires that the wire carrying the maximum current in the translator system use about 60 per cent more copper than for the star system. It would be highly inadvisable to proportion the size of the three-phase wires in the translator scheme according to the loads in those wires, because the sizes would have to be changed from block to block all over the system, and this would complicate the system even more than by adding the translators. Hence all secondary wires would be as heavy as the largest one, and this might mean a 60 per cent increase in the total amount of secondary copper required. Where 500,000-cir. mil copper is taken as the largest size, the extra copper would in many cases require a second main and duct. To these extra costs must be added those of the translators, value of manhole space they would occupy, and losses in secondaries and translators. Even the seven-wire, separate-light-and-power secondary system would not cost more and would be simpler. The increase in cost due to all these items might easily overcome any saving gained by combining power and light mains and defeat the very purpose of the translator scheme.

If the electric service companies want to inconvenience the fewest number of customers using a star-connected system, they will adopt the 115/199-volt three-phase system, as only the polyphase motor users will be affected. In the few cases where tests show insufficient voltage, the simple auto-transformers can be employed to boost the voltage. In Memphis, a 115/199-volt system of this kind has been in operation for over ten years and the customers are entirely satisfied. In Rochester, for several years, light and power loads in large buildings downtown have been supplied by 120/208-volt transformer banks in the basements and, even though motors up to 40 h. p. are connected at the end of long risers and no auto-transformers are employed, the customers praise the service.

It must be recognized that for most systems an a-c. network system, even though fed at 13,200 volts is just a little less than half the annual cost of a d-c. system and hardly less than 80 per cent of the cost of an a-c. radial system. These ratios have been checked independently by the engineers of five large systems. Hence, we would be deceiving ourselves as to the economic value of the translator scheme for it introduces such elements of additional cost as would wipe out the balance now in favor of a-c. networks.

The control of multiple street lamps or pole-mounting, constant-current transformers supplying series street lamps, by means of carrier current over the primary feeders, will represent a great step ahead. One company has tried out such a system, but the operation has been faulty and the relay units on the poles are of such nature as to be relatively expensive. The sender at the substation is also complicated. Another company has developed a simpler form of relay unit, and tests of a number of these, equivalent to at least a full year's service, have proved them satisfactory. This relay unit is compact, substantial and inexpensive. The sender unit is also simple and strongly built.

M. T. Crawford: Mr. Blake's paper refers to a method shown in Fig. 5 of which the title is "New Connection of Induction Regulator Circuits to Eliminate Circulating Currents." I think I am correct in stating this connection has been used recently by our company in our new Union Street substation and has proved very successful in regulating 4500-volt feeders in a multiple-feed network. One practical point in connection with it has been that some means has been found desirable to automatically disconnect the regulator control circuit on low voltage, so that regulators will not assume, during system trouble, different positions after fluctuations. I mean by that if a short circuit comes on the transmission network, and the voltage of the system as a whole oscillates back and forth, perhaps reaching very low values for brief moments, there is a tendency for the regulators to attempt to follow these voltage variations up and down. By the time matters have settled down again, some of the regulators are in one position and some in another, due to their slightly different characteristics. That has resulted at times in tripping out of network switches on the underground distribution system due to reverse flow of power for brief periods from one feeder into another where the voltage conditions were slightly different. By the simple expedient of providing a low-voltage release on the regulator control circuit, this trouble has been eliminated. The operator at the substation can reset the control circuit after the system has quieted down to normal.

The translator referred to is a very clever development. The Puget Sound Power and Light Company's underground distribution system employs single-phase, three-wire mains for lighting and alternate blocks with longitudinal alleys are placed on alternate phases, so the first alley is on one phase, the second alley on another, and so on. By that method the phases are relatively well balanced at the substation. In places, we have recently installed a fourth wire paralleling the single-phase, three-phase mains to provide small polyphase service. The result has been three-phase, four-wire mains in each alley similar to the ones referred to by Mr. Blake, and the respective alleys in the same phase relation as those shown in his diagram.

The translator, therefore, in our case offers something to look forward to as a possibility of permitting interconnection of the three sets of secondary mains for purposes of phase balancing or load protection if it should be found desirable. However, the addition of apparatus is always to be very closely scrutinized, and its necessity must be proven before it is added, as the simpler a system is, the better the service will always be.

A. H. Kehoe (communicated after adjournment): Regarding Mr. Blake's discussion of single-pole versus three-pole a-c. subway network switches I consider the proper switch to use is the one which will give minimum cost over an extended period. The cost of revising a few existing locations will be negligible on the total installation cost. Tripping and closing

elements in these switches represent a major item of cost and single-pole units will nearly triple this cost for each installation. Space, that is, cubical contents, naturally will be less in a three-pole unit than in three single units. These conditions seem to make the three-pole unit the one to be adopted generally. However, I do not favor certain of the existing three-pole switches of the so-called "battleship" construction. If the principal installation advantages set up by Mr. Blake for single-pole switches be used as specifications for three-pole switches, none of the latter's many advantages need be considered except the greatly reduced cost.

Under operating advantages there are several references to separating the phases either in the physical location or for operation of the transformers. I believe this is a case of confusing what *can* be done with what *is likely* to be done. It is possible to separate phases in three transformer vaults but it is probable that one vault three times as long will be cheaper and better if polyphase load is to be supplied. The system of polyphase secondary distribution is primarily for better universal utilization of electric service, as methods of balancing are now successful without it. However, that balanced polyphase loads are desirable at all points on a system, is a design axiom. All progress up to this time points to polyphase rather than single-phase distribution transformers for ultimate use. If the standard three-wire, single-phase system is taken as analogous to the polyphase system, it is evident that two single-phase, two-wire transformers could be placed in separate transformer vaults supplying a three-wire system. This is not likely to be found, however, in standard practise as all the capacity is found in one unit and a vault is built to take this larger unit, as this design gives minimum cost. I believe similar conditions will hold as the polyphase system develops.

Concerning the operating situation with radial distribution, the single-pole substation switches had economical advantages which could be charged to reliability. Since, in network distribution, there must be, and is always, sufficient reserve on each phase to allow for a failure of that phase, in each locality where it exists it is certain that the remaining phases will have sufficient reserve capacity to be eliminated in case of fault. Such operation does not have any effect upon service which can be equated against the increased cost, when the money, if necessary, could be expended to obtain an increased reserve upon all phases so that the particular phase in trouble would benefit by having a greater reserve. I doubt whether single-pole network switches are proper even with those systems already operating with three single-pole switches on four-wire, 4000-volt service, as new load will cause a higher voltage supply to be used than 4000 volts. It is possible to superimpose the new load on to the existing system and avoid the double transformation which is otherwise required.

Mr. Blake describes a method of cross-current compensation as the "most promising." It is, however, neither simpler nor easier of installation than others now in use. The several such connections should be given consideration before applying a definite arrangement to a particular system. The method described makes constant current and power factor the major considerations, while constant service voltage becomes a secondary one. Constant and correct service voltage is one of the most important elements in the business. While the network insures reliability and better voltage regulation than on radial systems yet this latter should not be compromised unnecessarily. It seems to me to be preferable to design the system for proper balance of load and have the regulating equipment give proper voltage under all conditions. The connection proposed does the opposite. Applying such a connection to a number of long feeders on an extended network makes other connections preferable due to the voltage variation under the ordinary load shifting.

It should be noted that a distribution network does not simulate a bus in respect to voltage or to concentration of load as indicated in Fig. 3 of the paper.

I fail to find in the translator description any reference to the use of this connection on certain distribution transformer secondaries to join and supply the different mains. If such a device ever has a practical application I believe it will be necessary to make it up in such a form, rather than as an auto-transformer, owing to cost and losses involved. Mr. Blake's statement that each section of secondary mains on a Y-connected system is not likely to be well balanced is not in accord with the purpose of adopting polyphase distribution. In some existing installations a certain amount of unbalance may exist due to the utilization having been designed for three-wire, single-phase service, but new installations are easily balanced and it is only in districts where growth of loads occur that any considerable amount of three-phase, four-wire mains are likely to be installed.

D. K. Blake: Mr. Carey questions the application of the single-pole switch. Mr. Richter's discussion also differed as to the application of the single-pole switch. It is recognized that the objection to the multiplicity of units for maintenance is valid. It is also recognized that a number of large companies will be able to utilize building and sidewalk space and, therefore, for these places the triple-pole switch is preferable. In the synopsis of the paper is this statement: "The circumstances which make single-pole switching preferable are outlined." It was my impression that there was a similar statement in the text, but on reading it over I notice there is not, and, therefore, some wrong conclusions might be drawn because of this omission. In his discussion Mr. Richter seemed to deny that these circumstances exist at all. He mentioned the cities where the large switches are being used. I agree with him that the triple-pole switch is preferable in these cities with one exception. Mr. Richter's references to the design of the switches indicates he misunderstood the paper. No exclusive features are claimed. To include all of these features in a triple-pole switch presents serious difficulties which are expensive to overcome. The operating advantages of single-pole switching may be questionable. Some engineers believe it desirable.

Mr. Richter mentions that the transfer switch shown in the *Electric Journal*, July 1925, corresponds to switch *S* shown in Fig. 3 of my paper. Switch *S* is a single-pole auxiliary switch whereas the transfer switch consists of four auxiliary switches or else one auxiliary switch to control an electrically operated double-pole double-throw switch. The cross-connected scheme is not as simple in its operation. All regulators are not adjusted at the same time according to the amount of circulating current passing through them but adjustment is obtained in a sequence. Mr. Kehoe's statement that the proposed connection does not "give proper voltage under all conditions" is not clear to the author. The line-drop compensator in each feeder maintains constant voltage at the load center with varying load. The impedances of the feeders may be different, some feeders may be long and some short. The proposed connection, by substituting a phase shifter at *T*, can also be used with three-phase regulators which is not true of other connections now in use.

I want to thank Mr. Crawford for telling us of his experience with the new regulator connection. We shall have to learn something about the operation of this connection on the systems where we use the sensitive reverse-power relay. I am glad to learn that Mr. Crawford has found a simple way of correcting the trouble.

It is not evident to the author why the translator system "may easily result in voltage unbalances of at least 10 per cent at the motor terminals." The translator system is simply the tying together of four-wire combined light-and-power mains which are supplied by delta-connected transformers. The unbalance on these mains is due to the lighting load on one phase and since this is limited to 3 per cent regulation that is also the extent of the unbalance on a 230-volt circuit. Heavy power loads are usually supplied with individual transformer banks and, there-

fore, it is not evident why larger or more manholes are necessary for this purpose on the translator system.

The translator system may be used with single-conductor cable with two of the phase wires larger than the third—just as is done in radial practise. These sizes would not have to be changed from block to block but would be uniform over the system. The case of power load equaling half the lighting load required that the wire carrying the maximum current in the translator system use about 34 per cent more copper than for the star system instead of 60 per cent as given by Mr. Richter.

Mr. Kehoe refers to a scheme using transformer secondaries. Such a connection is shown in Fig. 1, herewith, utilizing four

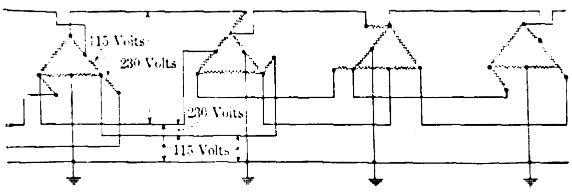


FIG. 1

standard distribution transformers. The main objection to this system is that it is tied up with the primary feeder making it necessary to provide two triple-pole network switches for protection. The translator is independent of the primary voltage. The fourth transformer is greater in kv-a. rating than the translator and very much more expensive in case of 13,200-volt or 11,000-volt primaries. The fourth transformer should be located in the same manhole with the other three while the translator may be located where convenient. Part of the lighting load is supplied from open-delta connections.

DISTRIBUTION TO SUPPLY INCREASING LOAD DENSITIES[1]

(CRAWFORD)

SEATTLE, WASHINGTON, SEPTEMBER 18, 1925

C. A. Heinze: Mr. Crawford assumes as an ultimate load density in his residential areas approximately 6250 kw. per sq. mi. He has used some figures that apply apparently to Seattle, which possibly may not apply to other cities. The number of houses per block, and the number of blocks per square mile—those are local conditions. The ratio of apartment houses and flats to single residences determines the load density for residential consumers. Studies of the conditions as they exist in Los Angeles show that it is reasonable to expect future load densities of 2500 kw. per sq. mi. for single residences, 6000 kw. per sq. mi. for flats and 19,000 kw. per sq. mi. for apartment houses. The actual load density in any square mile will be determined by the ratio between the different classes.

A few years ago the Commonwealth Edison Company of Chicago had already experienced in the Loop district a load density of 75,000 kw. per sq. mi., and was preparing for a future load density in this same area of 200,000 kw. per sq. mi.

The great majority of papers presented at this convention have to do with Y-connecting the present 2300-volt systems in order to get a higher feeder voltage. Personally I think that we are wrong in stopping at this voltage. We should go higher. While some authors have intimated in their papers that if they were to start over they would probably adopt higher voltages, it seems to me the sooner we adopt the highest practical voltage considering future load densities, the easier our future distribution problems are going to be. Certainly we do not want our systems growing larger and larger with the lower voltages, and then reach a time when we have to change to a higher voltage. Why not do the changing at the time when the system is small?

One thought that seemed to run through all the papers is that each of the authors in turn said he has a system plan. Certainly that is a big step in the right direction. The trouble in the old days was that we did not have a system plan.

Having a system plan, and realizing the enormous load densities of the future, we should build today that proportion of the ultimate plan which will give us maximum economies.

It should be realized that when a 2300-volt delta-connected system is Y-connected, we have then reached the ultimate change that can be made in that particular system. On the other hand, by adopting a higher delta voltage for the time being, we may then ultimately, when our load densities become heavier, Y-connect that and have a voltage suitable for the densities of that time.

R. E. Cunningham: I want to ask Mr. Crawford what happens when their primary phase wire falls on the ground. We have had some very serious and expensive accidents; our primary wires have fallen on the ground and lain there some time before we discovered them, and in the meantime caused troubles. To us, taking care of that feature and fully protecting the public is more important than possibly saving a little copper by using a common ground return.

Our state law requires that where the higher voltage lines such as 11-kv. and 15-kv. circuits are paralleling telephone toll lines and become grounded, we must discontinue the service until the ground is cleared. From the hazard to the public it has become a practise with us, even though it does not parallel a toll line, to pull off the circuit until the ground is cleared. On a delta-connected system we have ground detectors which will show us when our circuit is on the ground, but with a Y-connected system such as the 4-kv. we are still hunting for the answer. If Mr. Crawford could, I wish he would give us what his experience has been and what is the accepted practise of taking care of cases where the primary wire falls on the ground.

We have only recently begun the use of automatic reclosing switches having installed two smaller substations with such equipment on the 4-kv. outgoing lines. We arbitrarily adopted the practise of reclosing the first time after 2-sec. interval, the second time, 15 sec. and the third time 30 sec. If the short circuit still remains on the circuit, the switch then locks out. I would like to know what Mr. Crawford's practise is in that regard.

L. R. Gamble: I note that Mr. Crawford has planned his system somewhat in the way the telephone engineers have been planning their systems for the past several years. It always seemed to me that it was a very good scheme. However, very few companies today are doing that thing, planning for the future.

Regarding the matter of diversity in load, on distribution circuits, I note Mr. Crawford has arrived at 1600 watts per residence. In accordance with tests now being made by the National Electric Light Association, on the Electric Range Committee of which I am the engineer in charge of collecting all the data and making the reports, we have arrived at a similar figure on our more or less superficial tests. The 1600 watts per residence is on the basis of about 150 residences, and takes into account the diversity so that in considering a distribution network such as Mr. Crawford has considered here, the figure is probably fairly close. However, in radio systems, that figure is going to be somewhat higher as the diversity factor will be smaller for a smaller number of residences.

I have been more or less a dyed-in-the-wool radial fan. I have not particularly liked the network system. As time goes on, however, it seems that due to improvements in apparatus, and varied schemes in working out different problems in practise, the network system for the higher-density loads is the coming system. No doubt it is in underground systems, but in overhead systems, there seems to me to have been some sort of question.

There is one question I wanted to ask Mr. Crawford. In laying out his system for the future, he figures that he will not have

1. A. I. E. E. JOURNAL, October, 1925, p. 1063.

to rebuild or make any very material changes as the load grows. Considering this, does he use the butt-treated pole? Of course, I realize in asking this that not only does the butt of the pole decay in certain localities, but sometimes the top is also subject to rot.

There is one other point, and that is regarding trees. By the extension of the primaries to a considerable length and interlacing them as Mr. Crawford does, he is subjecting his line to tree interference which is very considerable. All distribution engineers and power men realize the disadvantage of trees, and, so long as we are going to have the "city-beautiful" idea, which luckily a great many cities have not yet adopted, our troubles will be ever increasing.

Digressing a little from Mr. Crawford's paper, there is one subject which should be of interest to distribution engineers and that is the painting of poles. An engineer is an artist to a certain extent; probably in the negative sense. The idea is that he should be able to put these poles in the streets and paint them such a color as to paint them out of the picture instead of into it. Of course, we don't all paint our poles. In some places it is required by ordinance. But I think we ought never to paint a pole a pea-green color.

F. H. Mayer: It has been found in designating electrical grounds for substations and power houses that it is more practical to ground non-current-carrying structures by means of a network, supplemented by one or two ground electrodes, than to ground the various structures by numerous electrodes.

A well designed grounding system must serve two general functions—

1. It must be designed so that its operator can come in contact with any non-current-carrying structure with safety at any time, and
2. It must permit of continuity of service.

The safety feature is accomplished by the metallic network, because a condition is approached similar to that of a station that is constructed on an immense metallic plate, thus tending to keep the potential gradient at the time of an electric failure to practically zero. The control of the potential gradient permits of the grounding of 220-kv. transformer neutrals and cases to the network with absolute safety to the operators.

The continuity of service is brought about by a more reliable relay performance and due to the fact that there is a low-resistance path from any part of the structure there is no tendency for high-voltage current to pass through the control board or other vital parts of the station.

So far as local failures are concerned the network suffices. However, if failures occur foreign to the station, the ground current returns to the station transformer neutrals through the earth and finally is picked up by the electrode that supplements the network, or if an overhead ground wire is used some of the current will return over it.

The overhead ground wire may not be essential where it is possible to extend the ground electrode into a stratum of permanent moisture and it is reasonably sure that the same stratum is again cut at the other stations. This is not always practical in rough areas, and in such cases the overhead ground wire serves a very good purpose, in that it furnishes a lower-resistance path than what is possible through the earth and ground electrode. Most of our power houses are located in mountainous country and such is our experience.

The point that can be gained, I think, is that on distribution systems feeding consumers in a hilly section, for the safety of human life, it is of prime importance, to furnish some reliable metallic return. This can be accomplished by grounding all transformer cases and neutrals to the water pipe or by conductors as outlined by Mr. Crawford.

It has been found that water pipes are not always reliable. Our experience showed in one instance that the pipe supplying the operator's cottage with gas was of lower resistance than the water system. In this particular case, the water system was connected to the transformer cases through the transformer-cooling system. The gas main was connected to the water main through the automatic water heater and at the time of an electrical failure on the 60-kv. switching rack the ground current that flowed through the water heater was sufficient to destroy the heater coil.

It may be possible that this water system also had insulated sections. At any rate, it only goes to show that water-pipe grounds are not always reliable.

M. T. Crawford: I have been very much pleased at the evident appreciation of the policy of looking into the future as far as possible. I believe it is a fundamental responsibility for us, as engineers, to do this, inasmuch as the managements of our respective companies rely on us to a large extent in connection with making heavy investments which are not readily changed.

Mr. Gamble raised a question in regard to the use of networks as a general principle. That seems to me one of the fundamental necessities if we are to build for the future. Five years ago the Puget Sound Power and Light Company installed an a-c. low-voltage network in the Seattle underground district, which was the first one in the country to employ the principle of power-directional relay protection for interconnecting transformers on different feeders on the same system of mains. After these years of operation, we have felt that it is justified, and therefore, the network principle was considered in connection with future plans for the residential areas.

We had in mind building a distribution network something similar in principle to a fishnet, which might be suspended at a certain elevation above the floor. As various articles were thrown on this fishnet, tending to sag it down at certain points, supports in the form of wire or rope from the ceiling could be installed near those points, which would bring it back to level. They correspond to feeders from the substation, running out to tap the network where the load is heavy, bringing the voltage of the network up to the normal value.

Mr. Heinze referred to Dr. Ryan's prediction of one kilowatt per capita and interpreted that to result in approximately 19,000 kw. per sq. mi., and compared it with the 6250 kw. per sq. mi. load density mentioned in this paper as presently to be anticipated load.

I think that it should be borne in mind that the one kilowatt per capita or 19,000 kw. per sq. mi. includes downtown commercial loads, industrial power, and other loads in the city, whereas the figure of 6250 kw. in the paper refers solely to the residential-lighting and domestic load. In the same areas 13,000-volt loop feeders are run for large industrial power customers and as stated in the paper, their loads are not included in this load-density figure. Data are being collected now by the a-c. low-voltage network subcommittee of the National Electric Light Association, and I have in my hands for the report of that committee load-density figures from various sections of the country in the larger cities and the figures of 19,000 kw. per sq. mi. would be very low indeed unless it was an average of both light and heavy load densities, inasmuch as in the central part of cities like Chicago and New York the load densities aggregate 190,000 to 200,000 kw. per sq. mi. The area immediately surrounding this hotel in Seattle now has a load density of over 100,000 kw. per sq. mi.

Mr. Cunningham asked about our experience with one wire on the ground during trouble. We have had both experience with the delta system, ungrounded, and more recently with the grounded neutral in this respect. We find that grounded-neutral system is very much more apt to trip out the feeder at the station, in case of a feeder on the ground. In fact, with the delta system, we have had partial grounds persist three or four days at a time, which we could not locate, which were not apparently causing any dangerous condition, and sometimes cleared themselves up;

but on the grounded-neutral system, if we get a ground at all, it is very apt to build up into a serious one in a short time, causing the feeder to trip out.

Mr. Cunningham also asked about the re-closing features in our automatic substations on these grounded-neutral 4500-volt feeders. At the present time we have the feeder switches set to reclose after 30 sec. when they trip out from overload and after reclosing three times they lock out. Then, of course, we have to find the trouble on the feeder before it can be put back in service. In a considerable proportion of the cases, however, before the third trip-out occurs, the short circuit either burns itself entirely clear, or for some other reason is broken, so the feeder stays in after the first or second reclosure.

Mr. Gamble asked about butt-treatment and painting of poles. We have not gone into butt treatment to any considerable extent as yet, although a good deal of investigation has been under way, and we have had sample carloads of poles treated several ways, not only with butt-treatment, but with full pressure treatment of the pole as a whole. On Puget Sound, however, conditions are probably the least favorable for economy in connection with the butt-treatment or other treatment of poles, inasmuch as the cedar grows locally and is always obtainable at a lower price than in most other parts of the country; furthermore, we have found that where cedar is reset as a pole in the same soil in which its native growth occurred, it lasts very much longer, and we have thousands of poles which are now 20 years old which were not treated at all originally, and which still have sufficient strength, although the average life will probably not exceed 18 years. Where poles will live 18 to 20 years without treatment, it is a grave question as to whether a large increase in initial investment is to be incurred from which no return will be obtained until at least 18 to 20 years later. As other changes occur, such as the building up of the country, perhaps underground requirements may necessitate the removal of a considerable number of the poles within 20 years.

We paint all poles set in the city a very dark green except the 6 ft. next to the ground, which is painted black. With this arrangement, poles set up through shade trees are very unobtrusive. The tree-interference problem with us is a serious one, as with Mr. Gamble and others, but we have an arrangement whereby once each year we organize a tree-trimming crew which works under the supervision of a representative from the city park board, and the city ordinance permits us to trim trees in parking strips; in fact, requires that it be done by the power company. The trimming work done in this way tends to keep the trees at least out of the primaries.

Mr. Mayer pointed out in the discussion an instance of a water-pipe ground which did not prove reliable. But I think that this is something which it is quite important to emphasize here, and it is not so much the reliability of any one water-pipe ground as it is the reliability in the aggregate of a large number of such grounds. The grounding is done on the 4500-volt grounded-neutral system, primarily as a safety precaution, not as a means of returning neutral current, and in any construction or design for the purposes of safety precaution, a multiplicity of small precautions are more reliable than one single large one. There was a case not long ago in Victoria of a fatal injury where the court, after hearing considerable expert testimony, was of the opinion that the injury was primarily the result of water-pipe grounds not having been made. The local light and power company had made as good grounds as they could, but the soil being very rocky these grounds were entirely inadequate. The local authorities would not permit them to make water-pipe grounds on individual services. After collecting considerable data and testimony, it was the opinion of the court that such grounds should have been provided as a precaution for the safety of the public.

SPANS HAVING SUPPORTS AT UNEQUAL ELEVATION[1]

(Smith)

Seattle, Washington, September 15, 1925

F. K. Kirsten: I wish to congratulate Mr. Smith on his courage in using the catenary equations for the analysis of spans supported from points at unequal elevations, and I would also like to make some supplementary comments.

We know that the more closely we wish to describe a physical phenomenon by means of mathematical formulas, the more involved and unwieldy these formulas become. As an illustration, we might use the simple equation of a circle to express the location in space of a suspended cable, and describe actual conditions with sufficient accuracy although the assumptions involve considerable error. By a closer analysis of the forces in action we find, however, that the parabola describes actual conditions better than the circle and hence the application of the parabola yields greater accuracy, although the mathematical operations are more involved. But still a considerable error is made in the assumption that the weight per unit projected length of the span is uniform along the span. The demand for greater accuracy forces us to base our mathematical formulas upon the assumption that the weight per unit length of span, measured along the span, is constant. This assumption leads us to the catenary, a rather involved mathematical stratagem. This mathematical form is rather difficult to handle, especially if temperature changes accompanied by stress changes must be covered by its use. And still the catenary equation does not describe conditions with absolute accuracy. Since the tension changes along the span, the weight per unit length of cable cannot be uniform. But an attempt to involve this actual condition in the modification of the catenary form would lead to unmanageable expressions.

It will be apparent from a perusal of Mr. Smith's work that the chief difficulty in applying the catenary equation to spans of unequal elevations resides in the introduction of the slope of the suspension points into equations which are already complex enough for ready manipulation. Especially do we feel a naturally increasing reluctance to use the catenary analysis if changes of wind and ice loading together with temperature variations over a considerable range must be accounted for by proper mathematical operations with the catenary form. It is, therefore, in my opinion, a step in the right direction to adhere to the simple catenary forms which Mr. Smith ingeniously introduces into his second method instead of using the first method supported by equations **12, 14** and **15**.

We now have, thanks to Mr. Smith's work, a simple catenary analysis of spans of unequal elevation, and there cannot be any excuse for the use of parabolic forms in the future. It must be remembered, that the catenary method is independent of fixed mass and space units, hence all span conditions which may occur in practise may be expressed by a series of curves from which by interpolation any span, at any slope, for any size or material of cable or any temperature range, may be read at once. This set of curves is as readily applied, without modifications by constants, in continental Europe where the metric system is used as in the lands of inches, pounds and quarts.

Another important finding in Mr. Smith's paper I believe is the discovery that the point of maximum deviation from a straight line connecting any two points of unequal elevation of the cable in suspension occurs midway between the points of support in the middle of the span. This naturally facilitates a check upon the strain of a cable from points of unequal elevation by dropping targets from point B_2 to point A, of predetermined length, the line of vision touching the point of maximum deflection from the line joining these two points.

R. J. C. Wood: Our engineering department has done

1. A. I. E. E. Journal, December, 1925, p. 1352.

a good deal of work in calculating sags and we went into this question of catenary versus parabola quite fully and find that up to about a 1000-ft. span, the parabola is practically a satisfactory curve to use. It must be remembered that after the mathematician has figured out the sag of the line, some fellow in overalls is going to pull that line up as near as he can to the predetermined either sag or tension.

We have been a little undecided as to whether to use the sag or the tension in the line as the criterion. At one time we have used one and at another time the other. We have finally decided to use a dynamometer to measure the tension in the new line. The maximum tension under worst conditions will be about 12,000 lb. and under ordinary stringing conditions may be 6000 or 7000 lb. The dynamometer will probably read within 200 lb. so that any extreme refinement of calculation as to the desired tension is not necessary.

I do not wish to detract in any way from the fine work of mathematicians who calculate these things because, while we may be able to use the laws of a parabola up to a certain point, yet we depend upon the mathematician to tell us where that point is and from where on we should use the more accurate formula. We have ourselves used the catenary formula in all long-span work.

Our spans run up to about 3000 ft. and for that length of span the catenary is necessary. We have had to go a little further than indicated in Mr. Smith's paper, because we have found it quite necessary to calculate clearances to ground under wind conditions. In building the line on a hillside it is not only necessary to know the vertical clearance in still air, but it is quite essential to know that the line will not blow onto the ground when the wind is crosswise, so we have to calculate those conditions of load applied side-ways.

It leads to some very interesting mathematics when there are, for instance, two spans which are dead-ended at the outer ends and hanging on a string of suspension insulators at the middle support, and the wind blows side-ways, because the two spans then no longer remain in a plane but becomes a warped figure and the catenary calculations become quite involved.

C. E. Magnusson: Reference to the parabola by Mr. Wood leads me to bring out a point on the use of hyperbolic functions. Many engineers seem to think that using hyperbolic functions in connection with engineering problems is throwing out a smoke screen to prevent the reader from following the argument. They do not appreciate that for certain types of problems hyperbolic functions become a very convenient means for obtaining accurate solutions. A few years ago while discussing a problem with a nationally prominent engineer, one who has presented many papers before the Institute, I suggested that for an accurate solution hyperbolic functions should be used, and was astounded to find that he had no idea as to what type of problems would require hyperbolic functions. As there may be others in the same predicament let me state that the basis for using circular or hyperbolic functions is simply this: A rotating vector of constant magnitude can be fully represented by circular functions but if the radius vector varies in length while changing in phase position hyperbolic functions fit the case. For example the voltage and current functions along a transmission line vary in magnitude as well as in time-phase position and hence require hyperbolic functions as they cannot be correctly expressed by circular functions.

R. W. Sorensen: I want to second the motion on hyperbolic functions. Dr. Kennelly of Harvard has been trying for years to get us to use them. I have been trying for about fifteen years to get engineering classes to use them, and they use them just as readily as they use trigonometric functions, if you once start them off.

L. J. Corbett: The paper given by Mr. Kirsten[2] a number of years ago is I think a classic in its field of the application of hyperbolic functions to catenaries and long spans. I think Mr. Smith's paper is a very creditable companion paper to that one.

I like particularly Fig. 4 in which the common point A is used as a basis instead of the usual method, although I have not had time to check it and see whether there are particular advantages to be gained over the old method of calculating sag from the inclined line between A and B.

Mr. Smith, in his discussion, brought up also a point in which we were very much interested in the re-insulation of the Carquinez crossing of the Pacific Gas & Electric Company, and that is the difference in expansion between a long span and a contiguous short span. If you can, visualize that crossing. On the south side the anchors are an average of probably 80 ft. from what is called South Tower. Then comes the long span of 4427 ft., then a span of 1350 ft. and then a final span of 335 ft. to the other set of anchors. On the high tower between the 4427-ft. span and the 1350-ft span, was placed a saddle with a sliding top. This was to allow for a difference in expansion between the two spans and to insure a vertical reaction on the tower. We calculated by a number of methods, but chiefly we went back to the original hyperbolic functions, and we thought that, taking all things into consideration we might expect a possible travel of 5 in. We allowed for a travel of somewhat more than that, 8 in. being the final figure allowed,—4 in. in each direction.

The saddle was placed on roller bearings which were immersed in grease so as to offer the very freest possible travel for the cable. The operating department tells me that in the past year according to the marks on the saddle, there has been a travel of only 1 in. so it is questionable how successful our calculations were. There is still room for improvement in our methods of calculation for long and important spans.

M. T. Crawford: I find Mr. Smith's paper very interesting in that he has gone into unequal supports, something which seems to have been more or less avoided in considerations of span problems. I would ask if he could suggest a method of approach toward the solution of a problem that we have. At one previous Pacific Coast Convention, a paper[2] was presented describing transmission-line construction in crossing Stampede Pass in the Cascade Range, where the loading conditions were very extreme at certains times of the winter, and where it was found advisable on account of the unequal loading which would come alternately on successive spans to change all dead-ends to a suspension form of conductor support, doubling up the insulator springs with yoked attachment at the suspension point.

The changes described in the previous paper have proved eminently successful in eliminating the operating troubles we had of jerking insulator strings in two. In trying to calculate the sags which would result from unequal loading in successive spans, we found a complication came into the matter where an entirely suspension form of construction was used, and where the towers were at different elevations, in that heavier loading in one span would pull the suspension strings out of the vertical position. This would make a change in the length of conductor in the span, location of points of support, and other factors, which are assumed constant in most of the ordinary methods of approaching the subject.

We worked it out fairly closely by making assumptions and trials, but found that the extreme condition which we might assume would occur when the insulator string was pulled out to a position approximately tangent to the catenary. This would result in the wire being down in the snow in winter conditions, but we have never found in practise that it went that far, because there was always some tension in the adjoining spans which would prevent the strings from pulling that far out.

I would like to have Mr. Smith add some discussion or suggestions as to how we might approach the problem of calculating the result of extremely unequal loading in the successive spans where the suspension form of construction is used.

2. Trans. A. I. E. E., 1917, p. 735.

2. Transmission-Line Construction in Crossing Mountain Ranges, by M. T. Crawford, A. I. E. E. Transactions, 1923, page 970.

G. S. Smith: I would like to thank Mr. Wood for mentioning a point I did not have time to bring up in the presentation and perhaps did not make clear in the paper; that is, that the method presented was intended primarily for long spans or special problems. It would usually prove too laborious for a single short span. However, where the Kirsten method is applied to the various symmetrical spans encountered in the usual line, it requires only a small amount of additional work to compute, by the method presented here, the remaining spans whose supports are not at the same elevation, since the cable used is commonly uniform throughout.

In discussions by Dr. Magnusson, Professors Kirsten and Sorensen, a more general use of hyperbolic functions was advocated. My experience has been somewhat similar to the instances mentioned. While most of us are more or less reluctant to use hyperbolic functions freely, I believe it is largely because of two reasons: first, we have never become accustomed to think in terms of such functions; and second, in attempting to use them we find it difficult because so few good tables of hyperbolic functions are available. In some previous work in connection with transmission-line design, I found it necessary to compute sufficient tables for this particular use. These tables will be found in one of the University of Washington Experiment Station bulletins referred to in the paper.

Messrs. Corbett and Crawford pointed out some very interesting problems in this same connection: problems which might be termed those of "variable spans." A similar problem was encountered in the design of "The Narrows" span of the Tacoma Lake Cushman Project mentioned in this paper. It was in an attempt to apply the Kirsten method to such problems that I found it desirable to first work out the problem of spans with supports at unequal elevations. Thus far I have found no direct method of attacking such problems, but the possibility of finding such a method seems entirely feasible.

DISTRIBUTION LINE PRACTISE OF THE SAN JOAQUIN LIGHT AND POWER CORPORATION[1]

(Moore and Minor)

Seattle, Washington, September 17, 1925

R. E. Cunningham: I wish to refer to the described methods of voltage regulation in the commercial district at Fresno using regulated circuits, tied in with circuits feeding directly from the bus. It would seen that this would cause considerable circulating current.

L. J. Moore: Referring to Mr. Cunningham's comments, I am submitting herewith actual readings taken on the feeders in the City of Fresno, which are shown in Fig. 16 of the original paper. Readings *A* and *C* were taken with the two regulated feeders carrying the load, and then the switches were closed on the three alley feeders which are unregulated and readings *B* and *D* were taken. Ammeters were installed in current-transformer secondaries on two phases of each circuit and readings taken. Where no ammeter readings are shown for the alley feeders, the switches at the substation were open.

It is noted from the readings that circulating current is set up when the substation bus voltage fluctuates to an extreme degree, and as indicated in the original paper, no attempt is made to keep the switches in when the substation voltage is extremely low. As a matter of fact, the San Joaquin system is not fully regulated and to some extent the system voltage is varied by increased feeders on generators so as to raise the entire system at time of peak loads. This naturally tends to keep up the bus voltage in Fresno at the time of system peak and reduces the amount of regulation required, and this, of course, naturally limits the circulating current. For that reason it has been possible to operate all of these lines tied together to good advantage on numerous occasions.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

DEPRECIATION OF THE REFLECTING PROPERTIES OF WHITE PAINTS

The illuminating engineer of today has made much progress in a study of the various factors which are involved in the installation and maintenance of an efficient and effective lighting system. He knows full well the influence that the type of luminaire, its spacing and mounting height and the color of the surroundings have on the character of the illumination produced. He is also quick to realize the uselessness and ineffectiveness of even the best of lighting systems if they are allowed to depreciate because of an accumulation of dust and dirt. He knows, too, that the majority of lighting systems are largely dependent for their effectiveness upon the general lightness in color of the surroundings. The illuminating engineer is not alone in his interest in these factors, however, for the architect, the plant executive and the building manager should be concerned equally as much, if not actually more, in the adequacy of the lighting system.

In view of the fact that light colored ceilings and side walls play an important part in the effectiveness of lighting, and also that pure white paint is generally conceded to be the most desirable for these surfaces—at least from an illumination standpoint—a series of tests* have recently been conducted on the reflecting properties of various kinds of white oil paints. The object of these tests was to determine the kind of white paint having the highest initial reflecting power when applied to various surfaces and also to determine the rate of depreciation of the various paints under different conditions. Twenty-six samples of paints were selected and applied to the test surfaces in accordance with the recommendations of the various paint manufacturers.

*"The Reflecting Properties of White Interior Paints of Varying Compositions," a paper presented by A. L. Powell and R. B. Kellogg, before the New York Section of the Illuminating Engineering Society on Nov. 12, 1925.

Kw. Total	Volts Bus	Current in Feeders											
		Kern		Tuolumne		Fulton Van Ness		Broadway Fulton		H Broadway		Total	
(*A*) 2800	121	280	260	220	240	—	—	—	—	—	—	570	500
(*B*) 2800	122	50	60	40	60	160	160	170	160	120	120	540	560
(*C*) 3300	116	310	350	340	360	—	—	—	—	—	—	700	710
(*D*) 3200	116	290	330	330	300	60	110	100	148	80	128	860	1016

1. A. I. E. E. Journal, November, 1925, p. 1201.

Three different kinds of surfaces were used in order to determine whether or not the type of surface had any effect on the reflecting properties and rate of depreciation of the paint. These test surfaces of wood (white pine), finishing concrete, and galvanized sheet iron were made into the convenient test size of 5 by 7 inches. The concrete samples were aged for eight weeks before they were used in order to lessen the possibility of destructive chemical action.

Two sets of specimens were prepared with each of the 26 paints on each of the three different surfaces. One of these sets were sealed up in a dust proof cabinet with a glass front, and exposed to direct north skylight so as to determine the depreciation of the paint due to light alone.

The other set of specimens was suspended close to the ceiling in a factory interior in which a certain amount of very small metallic and graphic particles were suspended in the atmosphere. In addition to these, the atmosphere contained a fairly high percentage of the products of combustion as produced by the many gas burners used in the drawing of tungsten wire. The test on these specimens would show the acquired depreciation which a paint would have under conditions which might be considered slightly more severe than normal industrial service.

The entire test covered a period of about 20 months and photometric readings were taken of each sample at intervals of 16, 31, 49, 71 and 88 weeks. It can be readily seen that this involved a considerable amount of photometric work and for this reason a rather inexpensive modified sphere or icosahedron was constructed for the purpose. In addition to this modified sphere, a small photometer and projection lantern were required.

In the actual determination of the reflection factor of a sample which has been placed in the sphere, the sight tube of the photometer is first directed upon the walls of the sphere and a reading of apparent foot-candles is made. This is considered to be the illumination incident upon the sample. The photometer is then directed toward the sample and a second reading is taken. This is considered the light reflected from the sample. The ratio of those two readings is, of course, the reflection factor of the sample. In order to maintain the accuracy of the results obtained a freshly scraped block of commercial magnesium carbonate was used as a standard at regular intervals.

The results of the test as a whole, disclosed some interesting facts. It was found that the initial reflection factor of the 26 types of white paint tested showed an average value of 81.1 per cent. The maximum value found was 87.6 per cent for a flat paint with titanox lead and free zinc as pigment material. While the minimum reflection factor was 75.5 per cent for a flat paint with lithophone as a pigment material.

The average results as obtained from all the specimens in the two sets of tests reveal the fact that with the specimens in the glass covered cabinet, the character of the material to which the paint is applied has practically no effect on the rate of depreciation, while with the set of specimens exposed to factory conditions the metal and concrete samples drop off somewhat more rapidly than the wood specimens. The curve of Fig. 1 shows this clearly.

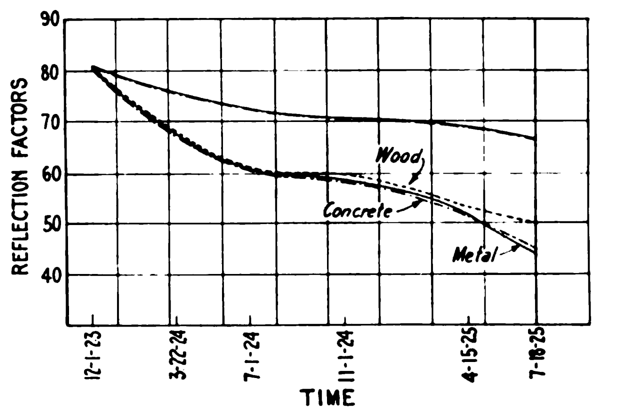


FIG. 1—AVERAGE DEPRECIATION CURVES OF ALL SPECIMENS BASED ON THE MATERIAL TO WHICH THE PAINT IS APPLIED
Upper curve —Cabinet set
Lower curve —Factory set

The curve in Fig. 2 was obtained by grouping all specimens having the same type of finish (gloss, egg-shell or flat) regardless of composition, and averaging the test values. Initially the flat white group shows the highest reflection factor and, contrary to common opinion, the average rate of depreciation is about the same for all types of finishes. This may be explained by the particular character of the dirt which accumulated in the factory test. It was of a slightly greasy

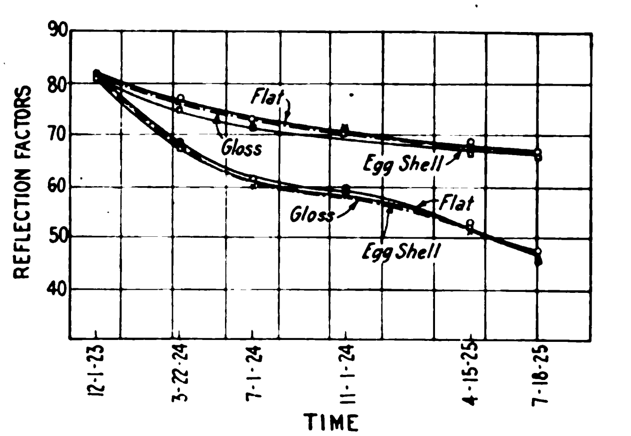


FIG. 2—AVERAGE DEPRECIATION CURVES OF ALL SPECIMENS BASED ON TYPE OF PAINT FINISH
Upper curve —Cabinet set
Lower curve Factory set

carbon nature which would cling with equal tenacity to flat or glossy surfaces.

By grouping specimens of the same pigment together and averaging values regardless of the character of finish, the results obtained seemed to indicate that the paint having titanox as a part of the pigment had the

TABLE I
THE REFLECTING PROPERTIES OF WHITE PAINTS

Specimen No.	Basic Pigment	Type of finish	Initial reflection factor	Average reflection factor during 20 months: Cabinet Specimens	Average reflection factor during 20 months: Factory Specimens	Appearance at end of test
1	Lth and Zn O	Undercoat Semi-Gloss	81.9	73.1	64.7	Grayish
2	Zn O and Lth	Eggshell	82.5	71.3	62.0	White
3	Titanox Pb and Zn	Flat White	86.9	76.3	65.7	White
4	Lth Pb and Zn	Gloss	86.6	75.3	63.5	Bluish
5	Lth Titanox Pb and Zn	Eggshell	84.3	75.3	63.2	White
6	Zn O and Lth	Flat White	85.2	76.4	64.3	White
7	Zn O and Lth	Gloss	83.7	74.8	57.6	Bluish
10	Lth	Enamel	80.4	73.75	57.9	White
11	Lth	Flat White	82.7	75.9	61.8	Cream
12	Lth and Zn O	Gloss	81.1	74.5	59.15	White
13	Lth	Eggshell	81.7	74.4	61.8	Cream
15	Lth	Flat White	81.7	74.8	60.9	White
16	Lth and Zn O	Gloss	82.2	74.8	61.1	White
17	Lth	Semi-Gloss	78.5	72.8	60.6	Cream
18	Zn O	Semi-Gloss	75.8	68.8	57.2	White
20	Lth	Flat-White	76.3	68.0	59.2	White
21	Lth	Eggshell	79.75	69.4	58.3	White
22	Lth	Gloss	77.4	68.7	52.9	Cream
24	White Pb	Flat White	77.25	68.5	59.8	White
27	Zn O	Enamel	83.5	65.8	59.65	White
29	Pb and Zn O	Eggshell	75.1	68.3	55.5	Cream
30	Lth and Mgsi Silicate	Eggshell	80.0	70.7	60.7	White
32	Lth and Zn O	Gloss	80.1	73.8	61.5	White
33	Lth and Mgsi Silicate	Flat White	80.0	72.5	62.2	White
34	Lth	Eggshell	81.4	73.5	61.7	White
35	Lth	Gloss	82.1	73.6	63.2	Grayish

highest initial reflection factor, with those of lithophone, lead, and zinc following in the order named. The rate of depreciation of the different groups is in this order also. These results, however, do not tell the whole story, for there may not be enough varieties of certain types to give good average figures, whereas with other types there may be instances of high values grouped with exceptional low values.

The question naturally arises as to whether a distinct chemical action took place with those specimens exposed to factory conditions. At the conclusion of the test all samples which had been hanging in the workroom were removed and carefully cleaned with a fine grade of soap and hot water. This was more carefully done than would have been the case if an ordinary workman was called upon to clean a paint surface. Readings were then taken of each specimen and it was found, in general, regardless of finish or composition, that the reflection factor of the cleaned specimen was very close to that corresponding specimen which had been kept in the glass cabinet.

The grand general average showed the factory specimens after cleaning to be about 2 per cent below those of the control set. The maximum departure was 5.7 per cent less, and on the other extreme, one specimen showed 1.8 per cent higher reflecting power. These deviations are so relatively small as to be well within the limits of error of such measurements.

The question naturally arises as to what is the best type of paint for different conditions, and one must stop to analyze what is required of the paint. The initial reflection factor certainly does not tell the whole story. One paint may have a very high initial value and its rate of depreciation may be quite rapid; another may have a lower initial reflection factor and yet over a period of time actually reflect more light—in other words, it depreciates at a lower rate.

DIELECTRIC CONSTANT, POWER FACTOR AND RESISTIVITY OF RUBBER AND GUTTA-PERCHA

Technologic Paper, No. 299, of the Bureau of Standards, by H. L. Curtis and A. T. McPherson, comprises a careful study of the dilectric constant, power factor, and resistivity of rubber and its compounds, and of gutta-percha. Crude rubber has a lower dielectric constant than either gutta-percha or vulcanized rubber, the value of the latter depending on the conditions of vulcanization. Vulcanization by sulphur alone produces a higher dielectric constant than vulcanization with the aid of an accelerator. The addition of a filler generally increases the dielectric constant, sometimes by as much as 200 or even 300 per cent. Dried samples of both rubber and gutta-percha have a lower dielectric constant than those which contain absorbed water. Vulcanized rubber may have a lower dielectric constant than gutta-percha.

The power factor of crude rubber is about the same as that of gutta, the hydrocarbon of gutta-percha. Crude rubber, vulcanized rubber, and gutta-percha all have about the same resistivity. The incorporation of some substances in vulcanized rubber increases the resistivity.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Midwinter Convention February 8-11

All is ready for the opening of the Midwinter Convention in New York, February 8-11, with headquarters at the Engineering Societies Building. The advance indications show that there will be a large attendance. An unusually large number of requests for advance copies of the technical papers proves that the topics to be presented are of wide interest. The social events also will be of such quality that they will be thoroughly enjoyed.

Among the technical subjects to be presented are transmission power limits, protection, control systems, electrical machinery, measurements, insulation and dielectric absorption, electromagnetism, electrophysics, communication and sound reproduction, and furnace-resistor design. In the list below the titles of all papers are given.

An informal smoker at which entertainment will be furnished by some high-grade talent will be held at the Hotel Astor on the evening of Tuesday, February 9th. A delightful evening is assured on the evening of Wednesday in the dinner-dance which will be held at the Hotel Astor. Paul Whiteman's Piccadilly Players will furnish the music. A prominent speaker will be heard in an address of general interest on Thursday evening in the Engineering Societies Building.

Inspection trips will be made to a number of interesting places including the following: The new Holland Tunnel (the vehicular tunnel under the Hudson River), Broadcasting Station W.E.A.F. of the American Telephone and Telegraph Company, The Edison Lighting Institute of the Edison Lamp Works, the Loening Airplane Factory, Kearny Power Station of the Public Service Electric Power Company, Hudson Avenue Station of the Brooklyn Edison Company, Hell Gate and Sherman Creek Stations of the United Electric Light and Power Company, the Bell Telephone Laboratories and a machine-switching central telephone office. The regularly scheduled trips will be made on Wednesday afternoon though small parties may visit some of the places at other times.

Two intensely interesting lectures, on topics which engineers do not often have the chance to hear presented by foremost authorities, will be delivered on Thursday evening, in the Engineering Auditorium beginning at 8:15 P. M.

Dr. Alexis Carrel will talk on some developments of modern biological research. A motion-picture demonstration will illustrate the points of the address. Dr. Carrel is a member of the Rockefeller Institute for Medical Research and a winner of the Nobel Prize. He is widely known for his accomplishments in the field of medical and biological research and, in addition, is a magnetic speaker.

Dr. Carrel will deal particularly with the life of tissues outside of the organism. The motion pictures will show the actual growth of living cells outside of the living organisms from which they were taken. Some strains of cells in Dr. Carrel's laboratory have been living and growing under artificial conditions since 1912.

Major Allen Carpe, of the American Alpine Club, will describe "The Ascent of Mount Logan." This mountain is 19,850 ft. high, and was the highest unclimbed mountain in North America when the ascent was made last summer. This also will be illustrated with motion pictures.

Mount Logan, in Yukon territory, is probably the largest mountain mass in the world, in the center of the largest glacial area outside of the polar region. On this expedition, Major Carpe obtained some most remarkable motion pictures covering the work of approach and ascent of this mountain, including packing and hand-sledding over the lower glaciers, establishment of the higher camps and pictures taken on the actual summit of the mountain.

All local arrangements have been made by the Convention Committee and subcommittees. The general committee is as follows: H. A. Kidder, Chairman, H. H. Barnes, Jr., G. L. Knight, E. B. Meyer and L. F. Morehouse. Chairmen in charge of features are as follows: Entertainment, H. H. Barnes; Smoker, G. W. Alder; Inspection Trips, H. Y. Hall; Dinner-Dance, J. B. Bassett, Special Meeting, H. S. Sheppard and Finance, G. L. Knight.

PROGRAM OF THE MIDWINTER CONVENTION

MONDAY MORNING

Registration
Committee Meetings

MONDAY AFTERNOON

TRANSMISSION SESSION

1. *An Investigation of Transmission-System Power Limits*, C. A. Nickle, and F. L. Lawton.
2. *Calculation of Steady-State Stability in Transmission Lines*, Edith Clarke.
3. *Practical Aspects of System Stability*, Roy Wilkins.
4. *Further Studies of Transmission Stability*, R. D. Evans and C. F. Wagner.
5. *Transmission Systems with Over-Compounded Voltages*, H. B. Dwight.

MONDAY EVENING

DIELECTRICS AND INSULATION

6. *Dielectric Absorption and Theories of Dielectric Behavior*, J. B. Whitehead.
7. *Theory of Absorption in Solid Dielectrics*, V. Karapetoff.
8. *Ionization Studies in Paper-Insulated Cables*, C. L. Dawes and P. L. Hoover.

TUESDAY MORNING

PROTECTION, CONTROL AND BUS CONSTRUCTION

9. *Operating Performance of a Petersen Earth Coil-II*, J. M. Oliver and W. W. Eberhardt.
10. *Theory of the Auto-Valve Lightning Arrester*, Joseph Slepian.
11. *Current-Limiting Reactors with Fire-Proof Insulation on the Conductor*, F. H. Kierstead.
12. *Temperature Rise and Losses in Structural-Steel Members Exposed to the Fields from A-C. Conductors*, O. R. Schurig and H. P. Keuhni.
13. *Carrying Capacity of Sixty-Cycle Busses for Heavy Currents*, Titus G. LeClair.
14. *Supervisory Systems for Electric Power Apparatus*, Chester Lichtenberg.

TUESDAY AFTERNOON

TWO PARALLEL SESSIONS, A AND B

(A) ELECTRICAL MACHINERY

15. *Experimental Determination of Losses in Alternators*, Edouard Roth.
16. *No-Load Copper Eddy-Current Losses*, Thomas Spooner.
17. *Mechanical Force Between Electric Circuits*, R. E. Doherty and R. H. Park.
18. *Concluding Study of Ventilation of Turbo-Alternators*, C. J. Fechheimer and G. W. Penney.

(B) COMMUNICATION AND SOUND REPRODUCTION

19. *The Development and Application of Loading for Telephone Circuits*, Thomas Shaw and William Fondiller.
20. *Cipher Printing-Telegraph Systems*, G. S. Vernam.
21. *Refraction of Short Radio Waves in the Upper Atmosphere*, W. G. Baker and C. W. Rice.
22. *High-Quality Recording and Reproducing of Music and Speech*, J. P. Maxfield and H. C. Harrison.

TUESDAY EVENING

Smoker

WEDNESDAY MORNING

ELECTRICAL MACHINERY

23. *Parameters of Heating Curves of Electrical Machinery*, V. Karapetoff.
24. *Rating of Electrical Machinery as Affected by Altitude*, C. J. Fechheimer.
25. *Motor Band Losses*, Thomas Spooner.
26. *Starting Characteristics of Polyphase Squirrel-Cage Induction Motors and Their Control*, H. M. Norman.

WEDNESDAY AFTERNOON

Inspection Trips

WEDNESDAY EVENING

Dinner-Dance, (Hotel Astor)

THURSDAY MORNING

ELECTROMAGNETISM AND PHYSICS

27. *Calculation of Magnetic Attraction*, Th. Lehmann.
28. *The Magnetic Hysteresis Curve*, Hans Lippelt.
29. *Properties of the Single Conductor*, Carl Hering.
30. *Heaviside's Proof of His Expansion Theorem*, M. S. Vallarata.

THURSDAY AFTERNOON

MEASUREMENTS, MACHINERY AND INDUSTRIAL

31. *A New Wave-Shape Factor and Meter*, L. A. Doggett, J. W. Heim and M. W. White.
32. *Practical Application of Vibration Instruments to Rotating Electrical Machines*, J. Ormondroyd.
33. *A High-Frequency Voltage Test for Insulation of Rotating Electrical Machinery*, J. L. Rylander.
34. *The Cross-Field Theory of Alternating-Current Machines*, H. R. West.
35. *Rating of Heating Elements for Electric Furnaces*, A. D. Keene and G. E. Luke.

THURSDAY EVENING

Some Modern Developments of Biological Research, by Dr. Alexis Carrel, Member Rockefeller Institute for Medical Research.

The Ascent of Mount Logan, by Major Allen Carpe, of the American Alpine Club.

Regional Meeting at Cleveland

MARCH 18-19

Plans are practically completed for the Regional Meeting which will be held in Cleveland on March 18-19 with headquarters at the Hotel Cleveland. This will be a two-day meeting and papers will be devoted to the subjects of sectionalized electric drive and electric refrigeration. There will be addresses by prominent men, a dinner, a meeting of Branch Counsellors of the Second District and inspection trips.

SECTIONALIZED ELECTRIC DRIVE

In recent years no more interesting problem has been presented to the electrical engineer than the interlocking of individual motor drives into a controlled group drive. The problem has been so successfully solved that it is possible to control the speed of the group over a wide range and still maintain no variation between the relative speeds of the individual motors of the group. Furthermore, at the will of the operator the fixed relation may be adjusted over a considerable range.

This subject will be presented and discussed before the Institute for the first time at the Cleveland Meeting in the sessions on Thursday, March 18. The various systems will be described by S. A. Staege of the Westinghouse Electric and Mfg. Company, R. N. Norris of the Harland Engineering Company and H. W. Rogers of the General Electric Company.

Plans are being successfully carried out to have present a large number of paper-mill engineers and executives to enter into the discussion of these papers. It was in the paper-mill field that the demand for such a synchronized group drive originated. There it has been so successfully applied that paper has been manufactured at speeds higher than 1000 ft. per min.

It is probable that in many other lines of industry there exist fields for such a drive. Wherever it is necessary to provide for a variation in the speed of the group as a whole and still maintain synchronism between the individual motors of the group a possible field of application exists provided the investment is justified by the advantage secured.

FRIDAY SESSIONS

Two unusual speakers of national reputation have been secured for the second day of the meeting. C. F. Kettering, President of The General Motors Research Corporation, will speak on "Electrical Refrigeration," a subject in which every householder as well as every engineer in interested.

Past-President Farley Osgood, will deliver an address under the heading "Engineering and Humanity."

A dinner will be held at the Hotel Cleveland on Thursday evening, at which a message of welcome will be given by Manager Hopkins of the City of Cleveland and an address will be made by a well-known speaker.

A special inspection trip will be made on Friday evening to the National Lamp Works of the General Electric Company at Nela Park. A number of other interesting trips also may be taken by those at the meeting.

Thorough arrangement of plans and details is in the hands of an able general committee and subcommittees. The general committee consists of: Chairman, A. M. MacCutcheon; Secretary, C. S. Ripley; A. G. Pierce, Vice-President of Second District; C. L. Dows, Ralph Higgins, A. F. E. Horn and Nathan Shute. The chairmen in charge of the subcommittees are: L. D. Bale, Transportation; H. B. Dates, Program; C. L. Dows, Reception; H. L. Grant, Publicity; G. A. Kositzky, Finance; A. M. Lloyd, Registration; E. H. Martindale, Attendance; C. W. Rakestraw, Dinner, and I. M. Van Horn, Trips.

Niagara Falls and Madison, Wis., Regional Meetings in May

Two regional meetings are planned for the coming May, a meeting at Madison, Wis., being scheduled for May 6 and 7 and one at Niagara Falls, N. Y., for May 26-28.

The meeting at Madison will be held under the auspices of Geographical District No. 5. A two-day program is planned and the papers will cover the subjects of rural electrification, power transmission and distribution, cooperative research relations between colleges and industries, and radio.

The committee in charge of the Madison meeting is as follows: Edward Bennett, Vice-President of District No. 5, J. B. Baily, A. J. Deward, H. R. Huntley, L. E. A. Kelso, Carl Lee and R. G. Walter.

The Niagara Falls meeting which will be held by District No. 1 will be a three-day affair. The technical papers will cover methods of dielectric power-factor measurement, transmission, power plants and other subjects. Arrangements are being made for a special illumination of the Falls, a trip down the Gorge, visits to generating and manufacturing plants and entertainment features.

The general committee in charge of the Niagara meeting consists of H. B. Smith, Vice-President of District No. 1; A. C. Stevens, Secretary; J. R. Craighead, E. D. Dickinson, J. A. Johnson, A. E. Soderholm and A. W. Underhill. J. A. Johnson is chairman of the local committee on arrangements.

Student Convention at Cambridge

Plans are under way for a Northeastern District A. I. E. E. Student Convention to be held in Cambridge, Mass., in the Spring. Arrangements are being made by a student committee headed by the Chairman of the Massachusetts Institute of Technology Branch acting with the advice and assistance of the Executive Committee of the Boston Section.

Tentatively, it is proposed to hold a morning session at which two or three student papers will be presented and a banquet in the evening to be held jointly with the Boston Section. The afternoon will be devoted to a number of inspection trips to points in and about Boston. Included in these trips will be the well-known Edgar Station of the Edison Electric Illuminating Company of Boston and the laboratories of the electrical Engineering Department of Massachusetts Institute of Technology.

Future Section Meetings

Baltimore

Mercury-Arc Rectifiers as Applied to Power Development, by H. D. Brown, General Electric Co., Johns Hopkins University. February 19, 8:15 P. M.

Mechanical Power and Trend of Civilization, by C. E. Skinner, Westinghouse Electric & Mfg. Co., Engineers' Club. March 19, 8:15 P. M.

Boston

High-Tension Cable Testing, by F. M. Farmer, Electrical Testing Laboratories. Meeting to be held in the new 750,000-volt testing laboratory of the Simplex Wire & Cable Co., Boston, Mass. February 19.

Connecticut

The Value of Patents. Stamford. February 16.

Power Production. Hartford. March 9.

Lehigh Valley

Automatic Control of Centrifugal Pumps, by Otto Haentjens, Barrett Haentjens & Co., and

Wallenpaupack Hydro-Electric Development, by N. G. Reinecker, Pennsylvania Power & Light Co., Wilkes-Barre. March 26.

Pittsfield

Lightning. Round-Table Discussion, Leader, F. W. Peek, Jr., General Electric Co. February 23.

Earthquakes and Volcanoes, by B. R. Baumgardt, Scientist and Explorer. Illustrated. February 16.

Artificial Refrigeration, by A. R. Stevenson, Jr., General Electric Co. Illustrated. March 2.

Round-Table Discussion. March 9.

St. Louis

Development of Electric Power Generation and Distribution, by Col. Peter Junkersfeld, President, McClellan & Junkersfeld. March 17.

American Engineering Council

ANNUAL MEETING, WASHINGTON, D. C., JANUARY 13-15, 1926

The Annual Meeting of the Amerian Engineering Council was held in Washington, D. C., at the Mayflower Hotel, January 13-15, 1926. About one-hundred delegates and interested visitors were in attendance. The official delegates came from all parts of the country and represented the various national, state and regional engineering societies composing the membership of the Council. In the absence of President James Hartness, of Vermont, who is recovering from a long illness, the meeting was presided over by Vice-President Gardner S. Williams.

The sessions of the Assembly were marked by keen interest, abiding confidence, and constructive action. Those in attendance were gratified with the work accomplished and were inspired with the great sphere of usefulness immediately at hand.

The meetings of the Executive Committee and the Administrative Board of the Council were held on Wednesday, January 13th, at which various matters were considered and recommendations formulated for the consideration of the Assembly of the Council on the following day. These matters are included in the following summary of the principal topics discussed and actions taken by the Assembly on January 14th and 15th.

Department of Public Works and Domain

A conference on Public Works was attended by official representatives from sixty-three engineering and allied technical associations. The Conference approved the draft of a bill providing that the Department of Interior be named the Department of Public Works and Domain. The drafted bill calls for the following four assistant secretaries: an Assistant Secretary having administrative jurisdiction over the Design and Supervision of Architectural Works; an Assistant Secretary having administrative jurisdiction over the Design and Supervision of Engineering Works; and Assistant Secretary having administrative jurisdiction over the administration and execution of the Construction Work of the Department of Public Works and Domain; and an Assistant Secretary having administrative jurisdiction over the Public Domain. Under the provisions of the bill all subdivisions of the Federal Government of an architectural, engineering and construction character would be transferred to the Department of Public Works and Domain.

The Bill will be introduced in the Senate by Senator Jones, of Washington, and in the House of Representatives by Congressman Wyant, of Pennsylvania.

Government in Industry

The Council had been invited to become an affiliated member of the Conference on Government in Industry. This it declined to do. However, it voted to lend its moral support to the purposes of the Conference. This it did by declaring it to be the sense of American Engineering Council that the Government should not trespass upon the field of industry unless it was satisfactorily shown that the Government could better engage in a particular business than private enterprises.

Federal Water Power Commission

In view of the fact that bills have been introduced into Congress proposing to remove the Tennessee and Colorado Rivers from the jurisdiction of the Federal Power Commission, and since other legislation is pending which, if passed, will undermine the Commission, the Assembly approved a resolution of disapproval of all such legislation. The Assembly instructed its Water Power Committee and officers to use all possible means to defeat any legislation that tends to impair the usefulness of the Commission or to destroy the functions thereof as provided for in the enabling act.

Salaries of Federal Judges

The Assembly unanimously endorsed House Bill 3831, "A bill to increase the salaries of Federal Judges," and instructed its Patents Committee to exert its efforts to secure the passage thereof.

Patents

The Assembly passed a resolution authorizing its officers to endeavor aggressively to secure a new building for the Patent Office. They were instructed to enlist the active support of all interested groups. The urgent need for a new building and modern equipment was clearly set forth by the Executive Secretary, who has been serving on a Committee on Patent Office Procedure, appointed by the Secretary of Interior and continued by the Secretary of Commerce.

Street and Highway Safety

Mr. W. B. Powell, Chairman of the Committee on Street and Highway Safety, submitted a most suggestive report. The committee recommended that American Engineering Council alone or in cooperation with other organizations have a study made of:

A. Traffic control signals.

B. Directional and general traffic signs for city streets.

C. Analysis of the physical factors entering into the efficient operation of street intersections.

D. Analysis of the most efficient methods of turns at intersections.

The Assembly approved the report and referred it to the Administrative Board for consideration of ways and means to having the study made.

Reclamation

Chairman H. B. Walker, speaking for the Committee on Reclamation, said the future policy of Federal reclamation should embody the principle that previous to inaugurating any project, there shall be ascertained:

A. The producing capacity of the land.

B. The ability of the land and the project to meet the cost of construction, operation and maintenance.

C. The practical occupation of the land by responsible settlers.

The Committee recommended that American Engineering Council have made under its direction a thorough and an important study of:

A. The fundamental principles involved in a reasonably fixed policy of Federal Reclamation.

B. An administrative plan looking toward the creation of a Federal corporation, controlled by a small board of directors, authorized to administer and enforce congressional acts relating to reclamation.

C. Development of a land settlement plan which may be practical under such corporate administration.

The Assembly adopted the report of the committee and referred it to the Administrative Board with power to have such a study made if means for financing it can be obtained.

Program of Research

Dr. H. E. Howe, Chairman of the Committee on a Five-Year-Program of Research, presented a progress report which was enthusiastically adopted. This program proposes the following studies:

Waste in Agriculture, with special reference to the engineering phases thereof.

Survey of Waste in Industries using Agricultural Products as Raw Materials.

Waste of Power, in the realm of generation, transmission and use of power obtained from coal, oil and gas.

Reclamation of Material Wastes, such as metals, forest products, city refuse and garbage.

The Engineering Approach to the Problem of Labor Supply.

Training and Employment of the Partially Incapacitated.

Industrial Fatigue.

Integration of Industry.

This program contemplates the expenditure of approximately $350,000 during the next five years.

On the basis of past experience and a known source of interest, it is believed the necessary funds can be secured.

Civil Aviation

Announcement was made that the report on Civil Aviation had been completed and issued in book form. This report, made jointly by the Department of Commerce and American Engineering Council, has been most favorably received and will undoubtedly serve a useful purpose during this session of Congress.

Survey for 1926

The Council has secured $25,000 with which to defray the expense of its survey for 1926. This survey will have to do with safety in industry. The details are being developed and a further announcement concerning it will be made in the near future.

Meeting of Washington Sections.

On the evening of January 13th, the delegates in attendance were the guests of the Washington Sections of the A. S. M. E. and the A. I. E. E., at a dinner at the Cosmos Club. Messrs. A. F. Horn, Chairman of the A. I. E. E. Section, and Arthur Adelman, Chairman of the A. S. M. E. Section, acted as "alternating" toastmasters. The following officers and Past Presidents of the A. S. M. E. and A. I. E. E. were called upon and made brief addresses:

William L. Abbott, A. W. Berresford, M. E. Cooley, Ira M. Hollis, F. L. Hutchinson, Dexter S. Kimball, F. R. Low, Farley Osgood, Calvin W. Rice, E. W. Rice, Jr., and Charles F. Scott.

The principal speaker of the evening was Dr. Harold G. Moulton, Director of the Institute of Economics, Washington, D. C., who gave an exceedingly interesting and instructive talk on "The French Debt Problem."

Banquet

The Council sessions concluded with a Banquet at the Chevy Chase Club, Friday evening, January 15th. Mr. Gardner S. Williams, Acting President, presided at the Banquet. A short address was given by President-elect Dexter S. Kimball. The principal speakers were Honorable Hubert Work, Secretary of the Interior, and Honorable D. R. Crissinger, Governor of the Federal Reserve Board. Many prominent members of Congress and government officials attended.

Officers Elected

The officers elected at this Annual Meeting are:

President, Dexter S. Kimball, Dean of Engineering, Cornell University, Ithaca, New York.

Vice Presidents, Gardner S. Williams, Ann Arbor, Michigan, (re-elected) and I. E. Moultrop, Boston, Massachusetts.

Treasurer, Dr. H. E. Howe, Washington, D. C. (re-elected)

Executive Secretary, L. W. Wallace, Washington, D. C., (re-elected by the Administrative Board)

Hold-Over Officers are:

Vice Presidents, O. H. Koch, Dallas, Texas; and A. W. Berresford, New York, N. Y.

The representatives of the A. I. E. E. present were:

A. W. Berresford, John H. Finney, M. M. Fowler, H. M. Hobart, F. L. Hutchinson, William McClellan, Farley Osgood, E. W. Rice, Jr., C. F. Scott, and C. E. Skinner.

Announcement was made of the names of the representatives who will constitute the Administrative Board for the year 1926, consisting of the President, the four Vice Presidents, the Treasurer and representatives of the national societies and the regional districts; the delegation to represent the A. I. E. E., in addition to Vice-President Berresford is composed of:

John H. Finney, Washington, D. C.; D. C. Jackson, Boston, Massachusetts; Farley Osgood, Newark, New Jersey; E. W. Rice, Jr., Schenectady, New York; Charles F. Scott, New Haven, Connecticut, and C. E. Skinner, Pittsburgh, Pennsylvania.

Four alternates were also designated namely:

M. M. Fowler, Chicago, Illinois; William McClellan, New York, N. Y.; A. G. Pierce, Cleveland, Ohio; and E. C. Stone, Pittsburgh, Pennsylvania.

John Fritz Medal Awarded to Edward Dean Adams

The John Fritz medal, established in 1902 in honor of John Fritz, one of the great pioneers in the iron and steel industry to be awarded annually for notable scientific and industrial achievement—the highest honor bestowed by the engineering profession of this country—was on January 15, awarded by the John Fritz Medal Board to Edward Dean Adams, for achievement as "an Engineer, Financier, Scientist, whose vision, courage and industry made possible the birth at Niagara Falls of hydroelectric power." The presentation will be made at a later date.

Born in Boston Mr. Adams has resided in New York since 1878. He was graduated as a bachelor of science from Norwich University in 1864 continuing the pursuit of his engineering studies at Massachusetts Institute of Technology. Mr. Adams has been a fellow of American Society of Civil Engineers since 1891, an associate of American Institute of Electrical Engineers since 1910, Vice-Chairman of Engineering Foundation since its inception, and, for years, an active member and officer of Engineering Societies Library.

It was by his decision that alternating current was chosen for the epoch-making plant of The Niagara Falls Power Company in 1891 as well as the transmission of the power by wire to Buffalo. He personally made extensive studies of the latest forms of electric generators and water turbines in Europe and America. In spite of contrary opinions he adhered to his momentous decision with regard to the kind of electric current and equipment to be used emphatically expressed by Edison and Sir William Thomson (later Lord Kelvin) and now alternating current and direct-connected hydroelectric units are almost universally employed for power development and transmission.

Mr. Adams has been a patron of many expeditions for observing total eclipses of the sun and of other scientific investigations personally participating in some of them. He is a member of the National Research Council, the American Museum of Natural History, for many years a trustee of the Metropolitan Museum of Art, and a patron of the fine arts in this and other countries.

On April 9 last year, a host of friends, men of national and international reputation in many fields of human endeavor, entertained Mr. Adams at a dinner at the Waldorf-Astoria Hotel in celebration of his seventy-ninth birthday.

Most of his long and intensely active business life has been devoted to important enterprises combining engineering and finance. He took a leading part in the organization and reorganization of the numerous railroads, including the West Shore, Central of New Jersey, Western Maryland and the Northern Pacific. Out of innumerable small companies he created the American Cotton Oil Company, led in establishing the All-America Cables, and has had no unimportant share in many another industrial undertaking. For fifteen years he was a member of the banking firm of Winslow, Lanier & Company, and for twenty-one years American representative of the Deutsche Bank, of Berlin.

Relation of Diesel Electric Locomotive to Electrification

A meeting of great interest in these days of acute transportation problems is to be held jointly by the four Founder Societies, the A. S. C. E., A. I. M. E., A. S. M. E. and A. I. E. E. on Thursday, February 18, 1926, 8 p. m., Engineering Societies Building, 33 West 39th St., New York, N. Y. The subject "The Relation of the Diesel-Electric Locomotive to Electrification" will be developed by three speakers: C. H. Stein, General Manager, Central Railroad of New Jersey; Hart Cooke, McIntosh and Seymour Company; and N. W. Storer, Westinghouse Electric and Manufacturing Company.

Mr. Stein will speak of heavy electrification problems as seen by the operating officials with relation to short haul, switching and terminals, showing how single units with their own power plants might fit, and also supplement trunk line electrification. Mr. Hart Cooke will describe the characteristics of the Diesel-Electric Locomotive and give some results of operation. He will show why and in what way it will as a prime mover meet requirements. Mr. Storer will deal with the electrical characteristics of the Diesel and cover the problem from the standpoint of the electrical engineer and electrical equipment. The meeting will be presided over by H. A. Kidder, Supt. of Motive Power, I. R. T., Chairman, New York Section A. I. E. E. and George J. Ray, Chief Engineer, D. L. & W. R. R., Chairman, New York Section A. S. C. E.

ENGINEERING FOUNDATION

A PLATFORM FOR ENGINEERING FOUNDATION
An Announcement

Engineering advances by continual gain and diffusion of new knowledge. Organizing for effective conduct of research under the auspices of the four national American Societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers, has, however, not been a simple task. Nevertheless, important progress has been made recently.

Technical investigations have been conducted by these Societies severally for years; but there has been little correlation and no comprehensive program. Only within a decade have engineers come to understand research in the same sense as scientists. Ambrose Swasey, by his far-sighted suggestion in 1914 of an engineering research foundation, and a gift for the beginning of its endowment, compelled study of this problem.

Then came the great war and the organizing of scientists and technologists to aid the Government should our country become involved, as in 1916 appeared inevitable. Engineering Foundation assisted, therefore, in establishing National Research Council and cooperated with it through the war and reconstruction. Indeed, it has been said repeatedly that if the Foundation had

accomplished nothing else, this service alone would have justified Mr. Swasey's gift. Scientists and engineers repeatedly gave practical demonstration of the usefulness of research in meeting war emergencies. In peace, also, wisely directed cooperative research can be useful, for it can aid in solving urgent problems, and, besides, add to the store of knowledge on which are based progress in industry, advancement of engineering practise and improvement of technical education, for the greater satisfaction of human needs and desires.

In 1923, Engineering Foundation again found itself facing its primary problem, but with experience accumulated and useful work done. Its Founder Societies in the interval had progressed in research and in development of their organizations and their joint relations. Together they attacked again this problem so important to the profession and the country. Naturally there has been variety in conception of the form and functions of the Foundation and of the relations between it and the Societies. Out of prolonged consideration a plan has emerged which assures progress and achievement. Its fundamentals are embodied in a Platform for Engineering Foundation, adopted at a meeting of its Board December 10, after approval of a draft by the governing body of each Founder Society based on a unanimous recommendation of their Joint Conference Committee, composed of their presidents and secretaries.

Platform for Engineering Foundation

Desiring to promote active and wisely directed research as a means to scientific and technical progress and believing that systematic cooperation by Engineering Foundation and the several Founder Societies is essential to any development of the research work of the Societies commensurate with the dignity, influence and resources of the profession, Engineering Foundation, while reserving entire liberty of action under the authority conferred upon it by the Founder Societies, through United Engineering Society, adopts the following declaration of its present plan and policy:

1. Engineering Foundation regards engineering research as the preferred field for its activities.
2. It will select or approve specific researches which it will assist by appropriation of funds or otherwise.
3. It will select for each project the agency, collective or individual, which it deems most effective.
4. It will assume no direct responsibility for the prosecution of any specific research.
5. It will cooperate with the national Engineering Societies and preferably support researches approved by it sponsored by one or more of them.
6. A member of Engineering Foundation, or of its staff, may be an advisory, but not an active, member of any committee or other organization in immediate charge of a research assisted financially by the Foundation. This provision will not be retroactive.
7. Engineering Foundation reserves the right to require from committees or other organizations or individuals assisted, satisfactory progress reports as a condition of continued support.
8. Engineering Foundation will cooperate with the several Founder or other national Engineering Societies in raising funds for the prosecution of approved researches.
9. It will endeavor to prevent conflict or overlap of research effort among the agencies which it supports or assists.
10. It will cooperate in securing information of the state of the art for use of committees of the Founder Societies or other agencies.

Adoption of this plan has placed the impartial and judicial attitude of Engineering Foundation beyond the questions which, without it nevitably would have arisen when the Foundation in future determined allotment and use of large sums.

Under the policy adopted, researches conducted by the Founder Societies will be doubly safeguarded in their selection, since they will have passed independent approval by the board of a Founder Society and by Engineering Foundation. Likewise, collective wisdom will be exercised in the use of funds entrusted to Engineering Foundation and to the Founder Societies.

A project having been thus endorsed, members of the Founder Society advocating it should be effective, directly or through Engineering Foundation, in raising funds or securing other aid by appeal to those who may expect to benefit.

And the time may not be far distant when the intelligence of those who have benefitted from engineering will perceive the advantage to be derived for the Profession, for Industry and for the Public from providing Engineering Foundation so adequately with funds that effort and time now expended in solicitation, with all the incidental annoyances and waste, may be conserved for earlier attainment of benefits sought.

L. B. STILLWELL, Chairman.
ALFRED D. FLINN, Director,
Engineering Foundation

PERSONNEL RESEARCH FEDERATION

Since 1921, the Personnel Research Federation, according to the fourth annual report, has been gaining support and promoting a number of researches. Since 1922 it has issued the Journal of Personnel Research, recognized not only in America but in other countries as well. Doctor Walter V. Bingham, Director of the Federation, is also editor of the *Journal of Personnel Research*. The Federation has 28 member organizations and 62 individual members, widely distributed. Recent additions to this cooperative membership include the Massachusetts Institute of Technology, Division of Industrial Cooperation and Research; Yale University, Department of Administrative Engineering; the Federal Board of Vocational Education. Officers elected for the current year are President, Howard Coonley, member, American Society of Mechanical Engineers, President, Walworth Company, Boston; Vice Presidents, Alfred D. Flinn, Director, Engineering Foundation, New York; William Green, President American Federation of Labor, Washington; Cator Woolford, Retail Credit Company, Atlanta; Secretary, Robert I. Rees, American Telephone and Telegraph Company, New York; Treasurer, Francis H. Sisson, Vice-President, Guaranty Trust Company New York.

American Engineering Standards Committee

NEW LIMIT-GAGE FOR MASS PRODUCTION

To make for the greatest possible output of the highest quality mass production, has become available to all American manufacturers of machinery, vehicles, tools, electrical apparatus and many other lines of product through the standardization of the limit gages just completed by the American Engineering Standards Committee. The limit gages upon which the new standards are based are simple devices for great accuracy in checking dimensions. The preparation of the standards was the work of a committee of twenty-one experts under the chairmanship of Colonel Eugene C. Peck, prominent manufacturer of Cleveland, Ohio; the committee was under the official leadership of The American Society of Mechanial Engineers. Not only industrial groups but the government, through the Army and Navy Departments and Bureau of Standards participated.

UNIFICATION OF WIRE AND SHEET METAL GAGES PROPOSED

The American Engineering Standards Committee has been requested by the Society of Automotive Engineers to take up the unification of wire and sheet metal gage systems in order to arrive at a national standard system of designating the diameters of metal wires and the thicknesses of metal sheets.

A conference of all industrial groups interested in this problem will be called in the near future, to discuss the desirability and

possibility of unifying the various existing gage systems into a consistent national system, or systems.

CAN AMERICAN AND BRITISH SCREW THREADS BE UNIFIED?

A conference of standardization experts is to be held in April to discuss possibilities, and the American Engineering Standards Committee and the National Screw Thread Commission have invited the British Engineering Standards Association to consider the possibility of unifying the American and British screw thread systems.

Both the American and the British systems of screw threads have been the result of a long national development, the basis for the American system having been laid by William Sellers in 1864, and that for the British system by Joseph Whitworth in 1841. The standard threads are called "American (national) standard thread" in this country, and "British Standard Whitworth (BSW) thread" in Great Britain.

A fundamental difference between the two national systems exists, however, and the importance of a possible unification between the two screw thread systems will be obvious if one realizes the innumerable applications of threaded parts to modern manufacture.

Sharon, Pa., Has New Section

Amid considerable enthusiasm manifested by the 225 who were present a new Section was formally organized at Sharon, Pa., at a meeting held on January 5 and the following Officers were elected and the first Section paper presented: W. M. Dann, Chairman, L. H. Hill, Secretary-Treasurer.

An executive committee consisting of the following members was elected: Chairman, W. M. McConahey, C. S. MacCalla, E. B. Clarke, W. J. Harrier and P. E. Cook.

Power Flow in Electrical Machinery was the title of the paper, presented by Joseph Slepian, Westinghouse Electric & Mfg. Co. Extensive discussion followed the address.

Formation of the Sharon Section brings the total number of Institute Sections up to fifty-one.

New Metallurgical Laboratories

The new metallurgical laboratories of the Pittsburgh Experiment Station of the Bureau of Mines, Department of Commerce, will be formally opened on the evening of January 26. Members of the Metallurgical Advisory Board of Carnegie Institute of Technology and the Bureau of Mines will be present. Others prominent in the mining and metallurgical fields are expected to attend.

The new metallurgical laboratories are the outgrowth of an agreement made in 1923 under which Carnegie Institute of Technology appointed an advisory board for its Department of Metallurgy and arranged for cooperative research fellowships in metallurgy at the Pittsburgh Experiment Station of the Bureau of Mines. Under the arrangement, certain problems in the metallurgy of iron and steel formerly conducted at the Northwest Experiment Station of the Bureau of Mines, Seattle, Wash., are being studied at Pittsburgh. In the study of these problems, the well equipped laboratories of Carnegie Institute of Technology will be available to supplement those of the Bureau of Mines.

Monthly Bulletin of the Mexico Section

The Mexico Section of the Institute started to publish at the beginning of 1924 a monthly Bulletin in the Spanish language, containing not only the proceedings of the Section, but also many other articles and technical papers of interest to electrical engineers.

The Bulletin is mailed free of charge to every electrical and mechanical engineer, every light and power company, and many other companies and individuals in the Republic of Mexico; and the Mexico Section is also willing to mail it to Spanish speaking members of the Institute in other countries, without charge, upon receipt of application.

Letters may be addressed to any of the following: Mr. E. F. Lopez, Fresno No. 111, Mexico, D. F., Chairman, and Mr. Hernan Larralde, Isabel LaCatolica 33, Mexico, D. F., Secretary, Mexico Section; Mr. Jorge E. Castro, Apartado Postal 124 Bis, Mexico, D. F., Editor in Chief, and Mr. J. P. Ramirez, Apartado No. 2057, Business Manager, of the Bulletin.

G. E. Review Plans 5-Year Index

An index of articles run in the magazine during the past five years is being planned by the *General Electric Review*. The index will be alphabetically arranged by subject and author, thus facilitating ready reference to articles carried during the years 1920-1925. It will be bound in a durable, heavy, stock paper cover and will be made to sell for a nominal sum. The size of the index will be 8 by 10½ in.—the same as the magazine.

Before starting the work of compiling this information, the *Review* is anxious to secure the comments of libraries and individuals interested in such a publication. It is requested that those who can make use of the index signify their interest in it by writing the magazine at Schenectady, N. Y. If sufficient interest is manifested in the work, it will be started within a few weeks.

National Academy of Sciences Appeals For Research Funds

The National Academy of Sciences announces an appeal to prominent public men to join with the leading scientists of the country in an endeavor to secure greater resources for the research in pure science, claiming that while the United States is leading all nations in industrial science, it is falling behind in pure science research. A special board created by the Academy for the handling of these funds includes Albert A. Michelson, President of the National Academy of Sciences and a Nobel prize winner; Gano Dunn, chairman of the National Research Council; Vernon Kellogg, Permanent secretary for the National Research Council; Elihu Root, Herbert Hoover, Andrew W. Mellon, Charles E. Hughes, John W. Davis, Colonel Edward M. House, Julius Rosenwald, Cameron Forbes, Felix Warburg, Henry S. Pritchett, Doctor Robert Millikan, Foreign secretary of the National Academy of Sciences, Doctor Merriam of Carnegie Institution of Washington, Owen D. Young, Henry M. Robinson, Doctor Simon Flexner of the Rockefeller Institute of Medical Research, Doctor J. J. Carty, Vice-President of the Am. Tel. & Tel. Co. and past-president of the A. I. E. E., Doctor Wm. H. Welch, Director of the School of Hygiene and Public Health, Johns Hopkins University and others of equal prominence.

PERSONAL MENTION

William S. Schmidt will shortly join the Pennsylvania-Ohio Power & Light Company at Youngstown, Ohio. Mr. Schmidt has been connected with the Penn Public Service Corporation for the past few years.

Rene A. Wurgel who has been planning engineer for the Western Electric Company New York City, has accepted a position as Purchasing Engineer with the Holly Pneumatic Systems, Inc., 100 East 45th Street, New York City.

Edgar Kobak has been elected vice-president and director of the McGraw-Hill Company, Inc., acting as publishing head of the McGraw-Hill electrical publications, *Electrical World, Electrical Merchandising, Industrial Engineer, Journal of Electricity and Radio Retailing.*

Frank A. Ketcham will be executive vice-president of the new Graybar Electric Company. Mr. Ketcham has been with the Western Electric Company for the past eighteen years, beginning as a clerk in their Chicago office. Since 1921, he has held the position of general manager of their supply department.

A. W. McLimont has been appointed president of the Winnipeg Electric Company for which he has served as vice-president and general manager for the past eight years. Mr. McLimont was formerly electrical engineer of the First District of the Public Service Commission of New York and has been connected with electric systems in both South America and Mexico.

C. M. Goddard, for thirty-five years secretary of the New England Insurance Exchange, was given a dinner on January 7th by 200 of his associates in the fire insurance field. Mr. Goddard was closely associated with the development of the National Electrical Code retiring from active business on the first of this year.

Theodore H. Dillon, professor of public utility management at Harvard University, has resigned to become manager of the Boston district of the United Fruit Company. Colonel Dillon was for several years professor of electrical engineering at Massachusetts Institute of Technology and is a graduate of West Point, holding a record for distinguished military engineering.

W. H. Sawyer, Fellow of the A. I. E. E. and H. W. Eales, a regional vice-president of the A. I. E. E., sail for Australia on February 2nd to make a report of investigation on the Yallourn brown coal electricity generation scheme and connected power undertakings of the government electricity commission. Their chief mission is to place the benefit of America's electrical experience at the disposal of Australia.

Donald McNicol, Fellow of the A. I. E. E. and last year assistant to the president of the Radio Corporation of America, has been elected president of the Institute of Radio Engineers, taking office at the time of their recent convention held in the Engineering Societies Building January 18-19. Good progress in this specific field of scientific endeavor seems assured both by the success of this, the first full membership convention of the Radio Engineers and in their choice of Mr. McNicol as president for the ensuing year.

William K. Vanderpoel, since January 1, 1916 general superintendent of distribution, of what is now the Electric Department of Public Service Electric and Gas Company has resigned to become vice-president and executive engineer of The Okonite Company and The Okonite-Callender Cable Co., Inc., manufacturers of wire and cable for electric purposes, with factories at Paterson and Passaic, and general offices in New York City. Mr. Vanderpoel came to Public Service in 1907 as superintendent of Distribution for the Newark district, and in 1916 was made general superintendent of distribution. He is a Director of the A. I. E. E. and has served, or is serving on its Executive, Finance, Power, Standards, Edison Medal committees and others.

S. L. Nicholson has recently been elected acting vice-president of the Westinghouse Electric and Manufacturing Company. Mr. Nicholson has been affiliated with the Westinghouse Company since 1898, being appointed sales manager in 1909 and assistant to the vice-president in 1917. He was the first president of the American Association of Electric Motor Manufacturers, now known as the Electric Power Club, assisted in the formation of the American Gear Manufacturers' Association, was chairman of the Power Club, Electric Manufacturers' Club and the Association of American Manufacturers of Electrical Supplies. During 1921, Mr. Nicholson was chairman of the Tariff Committee of the Council and represented the electrical industry on the National Industry Conference Board: is a member of the Electrical Safety Conference, the American Statistical Association and the Bureau of Personnel Research for Carnegie Institute of Technology.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Geo. B. Coleman, P. O. Box 322, Dayton, Ohio.
2.—Geo. E. Haines, 3538 W. Monroe St., Chicago, Ill.

Obituary

Loyal B. Alden, construction engineer, died on December 13, 1925. Mr. Alden was born in 1870 in Leicester, Addison County, Vermont. He received his engineering education at the Massachusetts Institute of Technology—later taking the student's course in the Construction Department of the General Electric Company. He was connected with the General Electric Company in Baltimore for some years, having been in charge of the construction of a transformer station in Baltimore, built in connection with the McCall's Ferry Plant and the substation of the Baltimore and Ohio Railroad on Park Avenue which furnishes current for running the Belt Line Railroad of the Baltimore & Ohio Railroad Company.

Arthur W. Jones died at his home in Schenectady, December 26, 1925. Mr. Jones was born in Philadelphia in May 1866 and took an electrical engineering course at the Massachusetts Institute of Technology—after graduation he officiated with the Thomson-Houston Company of Lynn, Mass. Several years later became chief engineer of the International Thomson-Houston Company. In 1894 he was sent to Port Elizabeth, South Africa, and as representative of the General Electric Company for that territory, in 1895 accepted a similar position in Melbourne, Australia. Returning to Schenectady in 1905, he served as manager of the railway signal department—being directly connected with the Far East department of the International General Electric Company and having direction over the company's interests in various Oriental Countries.

Otto C. Miller, of the Los Angeles Section of the Institute, died on December 11, 1925, in that city. He was born in Columbus, Texas, on September 12, 1867 and received his education as private student and co-worker with William Lundberg, a Danish mathematician and scientist in Los Angeles. Mr. Miller has been connected with the Los Angeles Gas and Electric Corporation for the past fifteen years as an Electrical Underground Engineer.

Benjamin H. Ryder, a member of the A. I. E. E., died on December 28, 1925. Mr. Ryder's birth place was Hudson, N. Y., where he was born December 3rd, 1878. He received his education in Chicago, becoming connected with the American Steel & Wire Company in Pittsburgh shortly thereafter. Later he was transferred to the Chicago office of the concern, where he remained until the time of his death. Mr Ryder's loss will be felt by his many friends and associates.

Frederick A. Huntress, for many years an official of the Brazilian Traction, Light and Power Company, Ltd., operating in the city of Rio Janeiro and Sao Paulo, Brazil, died January 27th at his apartment, Hotel Somerset, Boston.

Born in Biddeford, Maine, Mr. Huntress' late general and technical education was through Harvard College, from which he graduated in 1891 with the degree of A. B. In 1893, he affiliated himself with the Boston Elevated Railway, doing special work in

generation and distribution of power for them. In 1894 he was identified with the Montreal (Canada) Street Railway Company as assistant to the Electrical Engineer, to return in 1895 to the Boston Elevated Railway as assistant to their master mechanic. In 1896 he was made assistant to the general manager of the Halifax Tramway Light and Power Company, and later became general manager himself in 1898. In 1903, the Worcester Consolidated Street Railway Company chose him as their general manager and he remained with them until his departure from the States to connect with the Rio Janiero Tramway Company of which he was first Vice President at the time of his death. In 1922 he returned from South America to take residence in Lenox, Mass., and has remained in the United States ever since.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES DECEMBER 1-31, 1925

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AUFGABENSAMMLUNG UBER DIE GLIECHSTROMMASCHINE MIT LOSUNGEN.

By Fr. Sallinger. Ber. u. Lpz., Walter de Gruyter & Co., 1925. 108 pp., diagrs., 6 x 4 in., cloth. 1,25 gm.

This, the third volume of Professor Sallinger's concise textbook on continuous-current machines, is devoted to examples of the application of the formulas and rules given in the previous volumes. These examples are worked out in detail and illustrate clearly the practical use of the theory.

ELEMENTS OF INTERNAL-COMBUSTION ENGINEERING.

By Telford Petrie. Lond. & N. Y., Longmans, Green & Co., 1925. 236 pp., diagrs., 9 x 6 in., cloth. $3.75.

The various types of gas and oil engines, their cycles of operation, ideal cycles and their functions, the thermodynamics of the gas engine and the other theoretical considerations of these engines are discussed. The work is confined to theory and does not discuss practical details of design.

L'EMPLOI DES INDICATEURS COLORES; LA DETERMINATION COLORIMETRIQUE DE LA CONCENTRATION DES IONS HYDROGENE.

By I. M. Kolthoff. Translated from the 3rd German edition by Edmond Vellinger. Paris, Gauthier-Villars et cie, 1926. 250 pp., diagrs., tables, 9 x 6 in., paper. 50 fr.

The simplicity and rapidity of the color indicator method of measuring the concentration of hydrogen ions in aqueous solutions have led to a wide extension of its use for this important purpose. The author of this book gives a survey of the various methods used and studies their application under a wide variety of conditions, so that the work is of value to all who utilize indicators in chemical or biological work.

HEALTH MAINTENANCE IN INDUSTRY.

By J. D. Hackett. Chicago & N. Y., A. W. Shaw Co., 1925. 488 pp., diagrs., tables, 9 x 6 in., fabrikoid. $6.00.

Increasing appreciation of the relation between the health of workmen and their efficiency has led to the establishment of medical departments in many plants. This book gives an account of the organization of such a department and of the ways in which it may aid production. The subject is treated simply, from the point of view of the plant manager, who is responsible for the direction of the activities of the department, but has no medical training.

HEPHAESTUS; OR, THE SOUL OF THE MACHINE.

By E. E. Fournier D'Albe. N. Y., E. P. Dutton & Co., 1925. 76 pp., 7 x 5 in., cloth. $1.00.

An interesting, original study of the relations between man and his machines. How the age of machinery has come about and what influence machinery will eventually have on society is explained in striking fashion in this little book.

INDUSTRIAL ELECTRICITY, Part 2.

By Chester L. Dawes. N. Y., McGraw-Hill Co., 1925. (Electrical Engineering Texts) 480 pp., illus., diagrs., 8 x 6 in., cloth. $2.75.

D-c. machinery having been covered in the first volume of this text, the present book takes up alternators. The fundamental principles and the simple laws of alternating currents and a-c. circuits fill the first chapters. The construction and operating characteristics of a-c. generators and motors are then discussed and analyzed, and the relations of their characteristics to their industrial uses considered. The last three chapters are devoted to general industrial applications of electricity, such as illumination, electron emission and radio communication.

INDUSTRIAL FURNACES, Vol. 2.

By W. Trinks. N. Y., John Wiley & Sons, 1925. 405 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.50.

While the first volume of this important work was largely theoretical and of particular interest to the designer, this volume is primarily devoted to practise and makes its appeal to those who select, install and operate furnace equipment. The author discusses fuels, combustion devices, temperature control, atmosphere control and labor-saving devices, compares various fuels and types of furnaces, and offers advice on their selection. Electric furnaces are included in the discussion.

L'INDUSTRIE CHIMIQUE DES BOIS; leurs dérivés et extraits industriels.

By P. Dumesny and J. Noyer. Paris, Gauthier-Villars & cie., [1925.] 432 pp., illus., diagrs., 10 x 7 in., paper. 50 fr.

In writing this book, the authors have had in mind the needs of practical men and have given special attention to industrial methods. The book is divided into two sections. The first opens with a review of the chemical composition of wood and the properties of the products obtained by carbonization and by distillation. The principal processes of carbonization are then described. A chapter is devoted to the manufacture of acetic acid, methyl alcohol and the acetates, and another to secondary products of wood distillation. The second section treats of the extraction and use of tannins.

JAHRBUCH DER BRENNKRAFTTECHNISCHEN GESELLSCHAFT.
E. V. 1924. V. 5. Halle (Saale), Wilhelm Knapp, 1925.
112 pp., illus., diagrs., 11 x 8 in., paper. 7,80 gm.

The fifth yearbook of the Society includes a report of the proceedings at the annual meeting of December, 1924, and several of the papers read at that time. These include addresses on "Internal Combustion Engines, Especially Diesel Locomotives for Railways" by H. Nordmann; "Ignition Phenomena in Gas Engines" by J. Tausz; "Large Diesel Engines for Ships" by R. Dreves; "Raising the Power of Gas Engines through Pre-compression by Blowers, and the Use of Exhaust Gases in Turbines to Drive these Blowers" by W. G. Noack; "The Principles of High-Speed Semi-Diesel Engines" by Dr. Büchner; and "On the Numerical Expression of the Idea of the Quality Calorie" by W. Ostwald.

DIE LEISTUNG DES DREHSTROMOFENS.
By J. Wotschke. Berlin, Julius Springer, 1925. 70 pp., diagrs., tables, 9 x 6 in., paper. 5,10 g. m.

Books on the electric furnace are not numerous, and in those that exist less attention is paid to the needs of the electrical engineer than of the chemist and metallurgist. In this book the author attempts to meet electrical requirements by a discussion of the electrical theory and of the electrical factors that make for the greatest efficiency. He calls attention to opportunities for research in this field.

NIAGARA IN POLITICS; a Critical Account of the Ontario Hydro-Electric Commission.
By James Mavor. N. Y., E. P. Dutton & Co., 1925. 255 pp., 8 x 5 in., cloth. $2.00.

Professor Mavor's work is an indictment of the Hydroelectric Power Commission of Ontario, which he condemns on grounds of both public policy and of economic advantage.

PATENTS; Law and Practice. 3rd edition. 1924. 56 pp.
TRADE-MARKS, TRADE NAMES, UNFAIR COMPETITION. 4th edition. 1925. 48 pp.
N. Y., Richards & Geier, 277 Broadway. 9 x 6 in., paper. Gratis.

These pamphlets provide a convenient summary of the patent and trade-mark laws of the principal countries of the world. They are intended to give laymen the more important facts, as a guide in meeting the problems that arise most frequently.

POWER PLANT LUBRICATION.
By William Farrand Osborne. N. Y., McGraw-Hill Book Co., 1925. 275 pp., illus., diagrs., tables, 8 x 6 in., cloth. $3.00.

A concise account of the properties of lubricants and of the methods of buying, testing and using them on various classes of power-plant machinery. Intended for operating engineers.

PRACTICAL MARINE DIESEL ENGINEERING.
By Louis R. Ford. N. Y., Simmons-Boardman Publ. Co., 1925. 512 pp., illus., diagrs., 9 x 6 in., fabrikoid. $7.50.

Discusses the theoretical principles of the Diesel engine, the construction of its various stationary and moving parts, and its accessories. Descriptions of typical commercial engines of various types are given, and a large part of the book is devoted to the operation of Diesel engines and the derangements likely to occur. The book is intended for practical enginemen, especially for the marine steam engineers who wish to operate these engines.

STAUB-EXPLOSIONEN.
By Paul Beyersdorfer. Dresden u. Lpz., Theodor Steinkopff, 1925. 125 pp., illus., tables, 9 x 6 in., paper. 5,50 mk.

A summary of our knowledge of dust explosions. Discusses their character, the dangerous properties of dust, effects of heat and static electricity, the action of explosions and methods of prevention. The book is intended to present the situation in a form convenient for consultation by those engaged in dusty industries.

TAGUNG DES ALLGEMEINEN VERBANDES DER DEUTSCHEN DAMPFKESSEL-UBERWACHUNGSVEREINE.
April 1925, Karlsruhe. Berlin, VDI Verlag, 1925. 132 pp., illus., diagrs., plates, 12 x 9 in., paper. 16,-gm.

The proceedings contain reports and discussions upon a number of important matters relating to boiler operation. Among these are the tension in heavy boiler plates; the influence of temperature, shape of test-piece and speed of testing upon notched bar tests; American rules for water purifier operation; accessories for high-pressure boilers; autogenous and electric welding for boiler parts; the high-pressure boiler. Statistics of boilers are appended.

USINES HYDROELECTRIQUES.
By Charles L. Duval and J. L. Routin. Paris, J. B. Baillière et fils, 1925. 512 pp., illus., diagrs., 9 x 6 in., paper. 60 fr.

A general textbook on hydroelectric power plants. The authors give a description of these plants as a whole, showing the various apparatus used and explaining the reasons that have led to its choice in each case, its dimensions and its use. Both hydraulic and electric features are discussed, but details of the construction of the apparatus are omitted.

The book is based on the course at the Ecole Supérieure d'Electricité.

Book Review

SUPERPOWER: ITS GENESIS AND FUTURE.
William S. Murray, New York. McGraw-Hill Book Co. 1925. 238 pp., illus., 6 by 9 in. cloth. $3.00.

In this book Mr. Murray, the father of Superpower, tells in an intimate and pleasingly spontaneous way the complete story of Superpower and its possibilities, from the time he first conceived the idea up to its present development, and its future possibilities. It is pointed out that the name, Superpower, has been frequently misunderstood or misrepresented whereas its real meaning is the physical interconnection of all generating plants within certain zones in order to take advantage of diversity economy and thereby greatly reduce reserve equipment and avail interruptions to service from breakdowns. The subject is discussed from a wide variety of aspects and in non-technical language and points out why this movement, already under way, cannot but eventually furnish more adequate and economic means of power and transportation, which are the two essential elements upon which the industry and prosperity of the nation depend.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Sleeve Bearings Versus Anti-Friction Bearings, by J. L. Brown, H. D. Else and L. E. Erickson. A dinner preceded the meeting. Joint with A. S. M. E. December 18. Attendance 54.

Baltimore

Dielectrics and Insulation, by J. B. Whitehead, Johns Hopkins University. October 16. Attendance 85.

Holtwood Steam Station, by V. E. Alden, Consolidated Gas, Electric Light and Power Co.

Recent Experience with Transmission System of Pennsylvania Water Power Company, by A. F. Bang and E. Hansson, Pennsylvania Water and Power Co., and

Hydraulic Maintenance at Holtwood Plant, by T. C. Stabley. November 21. Attendance 280.

Electric Refrigeration, by Mr. Twilley, The Kelvinator Co., and

Illumination, by J. C. Fisher, Consolidated Gas and Electric Co. Ladies Night. December 18. Attendance 140.

Chicago

Power Flow in Electrical Machines, by Joseph Slepian, Westinghouse Elec. & Mfg. Co. January 11. Attendance 210.

Cleveland

Railroad Electrification—Present and Future, by N. W. Storer, Westinghouse Elec. & Mfg. Co. Illustrated with slides. November 20. Attendance 91.

Tendencies in Power Development and Transmission, by Robert Treat. Dean C. Ober, Cleveland Electric Illu-

minating Co., showed pictures of new apparatus used in his company's high-tension lines. December 17. Attendance 87.

Denver

Public Utility Securities and Financing, by J. E. Loiseau, Public Service Company. December 18. Attendance 27.

Detroit-Ann Arbor

Recent Developments in Heavy Electric Traction, by N. W. Storer, Westinghouse Elec. & Mfg. Co. A motion picture, entitled "Electrified Travelogue," preceded the talk. November 17. Attendance 100.

Polarization of Radio Waves, by E. F. W. Alexanderson, Radio Corporation of America. A motion picture, entitled "The Story of the Storage Battery," preceded the talk. December 4. Attendance 450.

Erie

Radio, by P. J. Larsen, Radio Corporation of America. The lecture was illustrated with moving pictures and the latest a-c. receiving sets and loud speakers were demonstrated. December 15. Attendance 255.

Fort Wayne

Lightning, by F. W. Peek, Jr. December 15. Attendance 80.

Electrons and Hobbies, by W. R. Whitney, General Electric Co. January 11. Attendance 150.

Ithaca

Electrical Transmission of Speech, Music and Noise, by Harvey Fletcher, Bell Telephone System Laboratories. The lecture was demonstrated with special wave-filter apparatus. December 7. Attendance 200.

Los Angeles

Electrolysis, by I. D. Van Giesen, Los Angeles Bureau of Water Works and Supply. Illustrated with slides. A dinner preceded the meeting, at which talks were given by E. A. Bailie, Los Angeles Engineering Dept., and J. E. Philips, Los Angeles Water Distribution Dept., on "The Proposed Colorado River, Los Angeles Aqueduct" and "The Existing Local Water Situation in Los Angeles," respectively. January 5. Attendance 134.

Lynn

The Quest of the Unknown, by H. B. Smith, Worcester Polytechnic Institute. Illustrated with slides. December 17. Attendance 50.

Mexico

Annual Banquet. October 24. Attendance 43.

Parasite Currents in the Bearings of A-C Machinery, by A. Cornejo.

Operation of Distributing Systems of Electrical Energy, by J. V. Crotte. December 3. Attendance 24.

Milwaukee

Design and Construction of the New Riverside Pumping Station, by Ralph Cahill. December 16. Attendance 60.

Minnesota

Communication Service on Railroads, by J. C. Rankine, Great Northern Railway Co. The talk was demonstrated by special telegraph equipment and apparatus. Motion pictures taken along the Great Northern Railway were shown. January 4. Attendance 37.

Nebraska

Automatic Stations, by C. W. Place, General Electric Co. Joint meeting with Engineers Club. December 14. Attendance 78.

Niagara Frontier

The Klydonograph, by J. F. Peters, Westinghouse Elec. & Mfg. Co. January 8. Attendance 35.

Philadelphia

High-Quality Phonographic Reproduction, by J. P. Maxfield, Bell Telephone Laboratories, Inc. December 14. Attendance 315.

Pittsburgh

Breakdown of Solid Dielectrics, by Vladimir Karapetoff, Cornell University. December 8. Attendance 348.

Pittsfield

Electrical Measurements in Medical Diagnosis, by H. B. Williams, Columbia University. December 15. Attendance 260.

Recent Theories and Developments in the Science of Radio, by E. F. W. Alexanderson, Radio Corporation of America. January 5. Attendance 375.

Portland

Baker River Hydroelectric Development, by L. M. Robinson, Stone and Webster, Inc. December 9. Attendance 81.

Providence

Costs of Operation of Isolated Power Plants, by R. L. Yates, Skinner Engine Co. Joint meeting with A. S. M. E., Providence Engineering Society and Illuminating Engineering Society. January 5. Attendance 100.

Rochester

Development and Research Work of the Bell Telephone Laboratories, by S. P. Grace, Bell Telephone Laboratories. December 4. Attendance 300.

San Francisco

Symposium on Power-Distribution Systems, by S. J. Lisberger, G. H. Hager, L. J. Moore and D. K. Blake. A dinner preceded the meeting. October 2. Attendance 190.

Oil Circuit Breakers, by J. S. Thompson, Pacific Elec. Mfg. Co. A dinner preceded the meeting. October 30. Attendance 215.

Some Engineering Aspects of the Telephone Building, by C. W. Burkett, G. M. Simonson and L. W. Whitton. December 11. Attendance 250.

Spokane

Reflections on Power Factor, by W. T. Ryan, Washington Water Power Co. December 18. Attendance 18.

Springfield

Storage Batteries, by R. D. Harrington, Electric Storage Battery Co. December 21. Attendance 47.

Syracuse

Hydroelectric Developments in Japan, by S. Q. Hayes, Westinghouse Electric & Mfg. Co. Illustrated with slides. December 14. Attendance 100.

Toronto

The Chronograph Method of Speed Measurement, by P. A. Borden, Hydro-Electric Power Commission of Ontario. Illustrated. Mr. F. K. D'Alton also gave a short talk on this same subject. Two moving pictures on the "Wizardy of Electricity" were shown by Mr. Johnston of the Canadian General Electric Co. December 18. Attendance 45.

Urbana

A Message from Herbert Hoover, by W. A. Durgin, Commonwealth Edison Co. December 9. Attendance 44.

Mechanical Force between Electric Circuits, by R. E. Doherty, General Electric Co. December 17. Attendance 108.

Worcester

Lightning and Other Transients on Transmission Lines, by F. W. Peek, Jr., General Electric Co. Illustrated with slides and moving pictures. December 10. Attendance 50.

BRANCH MEETINGS

University of Alabama

The meeting was devoted to the showing of moving pictures. December 15. Attendance 36.

University of Arizona

Railroad Electrification, by Charles Dunn, and

Electrification of Ships, by Leo Wolfson. November 7. Attendance 13.

Electrically Driven Vehicles, by Wm. R. Brownlee, and

Electric Welding, by E. Brooks. November 14. Attendance 14.

The Electron Theory, by T. E. Davis. November 21. Attendance 16.

Opportunities in the Telephone Industry. A motion picture, entitled "Rolling Steel by Electricity," was shown. December 5. Attendance 23.

The Big Creek Project, by Jos. Denzer. Moving picture, entitled "Speeding Up the Deep-Sea Cables," was shown. December 12. Attendance 20.

A motion picture, entitled "Beyond the Microscope," was shown. December 19. Attendance 17.

Brooklyn Polytechnic Institute

Engineering Features of Long-Distance Telephony, by C. S. Hawkins, American Telephone & Telegraph Co. Illustrated with slides, and

High-Frequency Radio Oscillations, by B. Adler, student. December 16. Attendance 55.

Carnegie Institute of Technology

Electrification of the Norfolk and Western Railroad, by Thomas Wurts, Westinghouse Electric & Mfg. Co. December 2. Attendance 34.

Case School of Applied Science

Business Meeting. The following officers were elected: Chairman, C. A. Baldwin; Vice-Chairman, E. W. Drexler; Secretary, A. B. Anderson; Treasurer, J. C. Erickson. October 19. Attendance 30.

University of Cincinnati

Relation of the Technical Journal to the Industry, by Earl W. Whitehorne, Commercial Editor of *Electrical World*. December 3. Attendance 59.

University of Denver

Business Meeting. January 8. Attendance 15.

Georgia School of Technology

Business Meeting. December 15. Attendance 40.

Inspection trip to Boulevard Sub-Station of the Georgia Railway and Power Company. December 17. Attendance 35.

University of Idaho

Film, entitled "Pillars of Salt," was shown. December 8. Attendance 24.

State University of Iowa

A film, entitled "The Story of an Electric Meter," was shown. December 18. Attendance 50.

Unipolar Generators, by Herman Wacker, and

Electrons and Ions, by L. A. Ware. January 6. Attendance 44.

Kansas State College

Opportunities of the Graduate, by Professor C. E. Reid. December 14. Attendance 83.

Lehigh University

Making the Most of Opportunities, by H. P. Liversidge, Philadelphia Electric Co., and

Automatic Train Control, by O. M. Corson, student. December 17. Attendance 89

Lewis Institute of Technology

Business Meeting. December 10. Attendance 11.

Marquette University

Picking a Job, by F. J. Mayer, Wisconsin Telephone Co. October 15. Attendance 29.

Super-Power, by G. G. Post, Milwaukee Electric Railway & Light Co. November 19. Attendance 28.

Massachusetts Institute of Technology

The M. I. T. Power System, by Theodore Taylor, student. Illustrated with slides. December 15. Attendance 18.

Inspection trip to the Cambridge Plant of the Simplex Wire and Cable Company. December 16. Attendance 5.

University of Michigan

Smoker. December 9. Attendance 65.

School of Engineering of Milwaukee

Industrial Management, by E. E. Brinkman, Holeproof Hosiery Company. January 7. Attendance 28.

Missouri School of Mines and Metallurgy

A general discussion on motor windings, synchronous motors, advantages of their use, and power transmissions took place. January 7. Attendance 10.

Montana State College

Lightning Generators, by Sam Thompson, and

Advantages of Electric Traction, by Rudolph Scovil. December 14. Attendance 159.

College of the City of New York

What the Designing Engineer Has to Do in Practise, by E. S. Henningsen, General Electric Co. January 14. Attendance 24.

University of North Carolina

A Supersensitive Microphone and Its Application to Surgery, by J. F. Clemenger, student. December 4. Attendance 26.

University of North Dakota

Asbestos, by H. G. Thinnes, Johns-Manville, Inc. Demonstrated. A motion picture, entitled "The Story of Asbestos," was shown. Joint meeting with A. S. M. E. December 14. Attendance 5.

Northeastern University

The Work of a Public-Utility Electrical Laboratory, by H. C. Hamilton, Edison Electric Illuminating Co. Illustrated with slides. December 30. Attendance 34.

University of Notre Dame

The Theory of Electricity, by Malcolm Knaus, and

The Fourth Dimension, by Dr. J. A. Caparo. December 9. Attendance 37.

Oklahoma Agricultural and Mechanical College

Two moving pictures, entitled "Electrified Travelogues" and "The King of the Rails," were shown. December 17. Attendance 48.

University of Oklahoma

Three moving pictures, entitled respectively, "King of the Rails," "Big Deeds" and "The Manufacture of Paper," were shown. December 10. Attendance 107.

University of Pittsburgh

Transmission Design, by T. E. Baum, student,

"B"-Battery Eliminator, by N. Orr, student, and

Photo-Electric Cells, by W. D. Carothers, student. December 4. Attendance 22.

The Measurement of Earth Currents, by J. A. Balla, student, and

The Allegheny Bridge Problem, by Chas. M. Reppert, Dept. of Public Works, and V. R. Covell, Bureau of Bridges. December 10. Attendance 25.

The Transmission of Vision and Radio Broadcasting, by H. I. Metz, student. December 17. Attendance 28.

Purdue University

Shaft Behavior, by Dr. G. E. Newkirk, General Electric Co. Joint meeting with A. S. M. E. December 17. Attendance 60.

Rensselaer Polytechnic Institute

What We can Learn from Technical Education in Europe, by C. E. Wickenden, Society for the Promotion of Engineering Education. December 9. Attendance 385.

Rhode Island State College

A moving picture, entitled "From Mine to Consumer," was shown. January 7. Attendance 27.

Rose Polytechnic Institute

The Student Course with the Westinghouse Company, by R. H. Bolin, Westinghouse Electric & Mfg. Co. January 6. Attendance 43.

Rutgers University

The Giant Power System was the title of a debate held at this meeting. December 14. Attendance 24.

A moving picture, entitled "The Story of Copper from Mine to Consumer," was shown. January 11. Attendance 105.

South Dakota State School of Mines

Business Meeting. December 16. Attendance 12.

Business Meeting. January 8. Attendance 18.

University of South Dakota

Business Meeting. October 13. Attendance 15.

What is Matter? by M. Nelles, and

Production of High-Frequency Oscillations, by R. Brackett. November 10. Attendance 9.

Progress of Science, by Dr. Millikan, was read by A. Muchow, and

Wind-Mill Electric Power for the Farm, by W. Doohen. December 8. Attendance 9.

Swarthmore College

The Steel Industry, by Mr. Munson, Atlantic Steel Co. January 7. Attendance 40.

Syracuse University

A-C Railway Electrification, by C. R. Fugill. December 2. Attendance 20.

Lightning Arresters, by R. M. Kelly. December 9. Attendance 18.

Types of Relays and Their Application, by W. H. Lawrence. December 16. Attendance 19.

Texas Agricultural and Mechanical College

Two moving pictures, entitled "Manufacture of Paper" and "Wireless Wizardy," were shown. January 8. Attendance 71.

Washington University

Inspection trip to United Railway Company's Two-Unit Automatic Substation. November 27. Attendance 35.

The Engineering Profession, by Mr. Trescott, Commercial Electric Supply Co. December 3. Attendance 28.

University of Washington

Products of the Northwest, by R. W. Frame, Kenworth Motor Truck Co., and

The Development of the Railroad, by G. T. Reid, Northern Pacific Railroad Co. December 2. Attendance 125.

University of Wisconsin

The Panama Exposition, by Professor C. M. Jansky. Illustrated with slides. December 15. Attendance 64.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DESIGNER, for manufacturing purposes of such equipment as air break switches, gang operated disconnect switches, bus supports, etc. Experience in simple station operation, design of substations, etc., does not qualify a man for this position. Experience in the actual design and manufacture of the class of equipment described essential. Location, Pennsylvania. R-8118-C.

ENGINEER, experienced in selling industrial electric heating furnaces, for manufacturing concern. Apply by letter stating age, experience and education. Location, Pennsylvania. R-8328-C.

ENGINEER, with experience in design and installation of power station switching equipment. Must be able to supervise and make schematic diagrams of station layout drawings. This is not a drafting job, but requires design ability. Permanent. Opportunity. Apply by letter. Location, Pennsylvania. R-8530-C.

ELECTRICAL ENGINEER, particularly interested and experienced in relay and breaker applications and protection problems on larger power systems. Location, Pennsylvania. R-8506.

ELECTRICAL ENGINEER, experienced in design and calculation of small high tension transformers both closed and open core type. Salary $4000-$5000 a year. Location, New York. R-8346.

ENGINEER, to develop new grinding machines line, especially versed in electrical and hydraulic application. Must have had practical shop training and particularly a thorough scientific and technical education. Apply by letter. Location, Ohio. R-8396-C.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER, age 25, married, desires position with electrical manufacturer or public utility company. Westinghouse experience. Location, East or Middle-west. B-9508.

ELECTRICAL ENGINEER, age 37, college graduate, eighteen years' experience, G. E. test course, system operation, operation, maintenance, construction, design of steam and hydroelectric plants and substations. Just completed three year connection involving design, erection and operation of large high head hydro electric plant. Desires permanent position. Available now. A-895.

ELECTRICAL ENGINEER, 26, six years iron and steel works electrical plant, installation, layout and maintenance both A. C. and D. C., three years manufacturing works, test, design and construction of industrial electrical plant, two years oil fields electrical construction engineer. Desires position either construction or maintenance of power plant, factory, oil fields or iron and steel works. C-8625.

EDITOR OR STATISTICAL ENGINEER, general scientific and electrical engineering training, including two years' post graduate study. Broad experience writing, editing magazine articles, newspaper articles, booklets, books, advertising literature, etc. Thorough knowledge printing. Experience statistical work, sales promotion, business administration, business efficiency methods as assistant to prominent executive large corporation. Location, New York City, Chicago, or Boston. C-549.

ELECTRICAL ENGINEER, age 28, single, technical graduate, desires position with manufacturer electrical apparatus. Five years' experience with engineering department of large company manufacturing industrial control equipment. A little sales experience. Minimum salary $2500. Available on reasonable notice. B-6274.

ELECTRICAL-MECHANICAL ENGINEER, age 37, married, M. E. and E. E. degrees, experienced in design, installation, operation, rehabilitation of hydroelectric and steam power plants, automatic and manual substations, transmission lines underground and overhead, diversified industrial experience in sugar mills, paper mills, mining (gold and coal), public utility, marine engineering and machine shop manufacturing processes. Location anywhere, United States or Canada. B-7944

MECHANICAL ENGINEER, age 32, single, nine years' experience in electrical and mechanical engineering. Electric lighting and power distribution, motors and control, for industrial use. Design of boiler plants, heating and piping. Machinery layouts for plants. Can report at once. Northern part of United States preferred B-3103.

ELECTRICAL ENGINEERING GRADUATE, 1917, age 29, single, desires construction, operation or maintenance with public utility, or consulting engineer; design, research, teaching also considered. Two years Westinghouse student and tester. Some radio, electrical drafting and repair work. Now in fifth year as assistant in E. E. in large Middlewest state university teaching design and power plant economics. M. S. degree 1925. Available in June. Salary $200 per month. B-2758.

ELECTRICAL ENGINEER, age 27, research, in charge of electrical testing, three years chief draftsman; inventive, tactful. Desires responsible position with manufacturing concern. Greater New York preferred. Best references. At present employed. Available on two weeks' notice. B-7270.

MANAGER - GENERAL SUPERINTENDENT-SALES ENGINEER, age 44, unmarried, degree Ph. B in E. E., twelve years with Westinghouse, ten years in utility field. Design, construction, operation four utilities in United States, Alaska, British Columbia. Available at once. B-6910.

MANUFACTURERS' REPRESENTATIVE, located in Sydney, N. S. W., Australia, desires additional agencies for American products of electrical and mechanical nature. Technical training, experience, knowledge of conditions. C-798.

ELECTRICAL ENGINEER, age 27, married, 1923 graduate of University of Washington, hydroelectric experience; nineteen months General Electric Test. Desires to locate on Pacific Coast, position leading to executive responsibility with power company, industrial concern, or large distributor of electrical equipment. Available on short notice. C-742.

EXECUTIVE, age 43, married, thoroughly competent to take charge of office, plant or factory. Many years actual experience in organization, personnel management, valuation and appraisal, installations and supervision, office management, correspondent and special confidential investigations. Available at once. Location, New York or New Jersey. C-521.

EXECUTIVE ENGINEER, age 26, desires to change his position. Has had four years' experience as assistant superintendent and superintendent for various manufacturers making electrical, mechanical, and electro-mechanical devices. Work consisted of time studies, production control, cost analysis, cost forecasts, general factory supervision, etc. Graduate electrical engineer. B-5435.

ELECTRICAL ENGINEER with wide experience in developing intricate electro mechanical and structural problems. College graduate 1910, M. E. and E. E. degrees. Fifteen years' experience here and abroad. Age 40. Location preferred, New York City. A-165.

ELECTRICAL ENGINEER, university graduate, age 28, married, one year testing course, four years experience in construction and design of railway substations, outdoor stations and large hydro and steam power plants. Efficient worker. Desires position as assistant engineer or designer or resident engineer. Available on three weeks' notice. C-792.

ELECTRICAL ENGINEER OR SUPERINTENDENT, age 34, married, eleven years' experience power plant construction, operation and maintenance of same, on steam and hydro, including electric railway, substations, power distribution, transmission. Broad experience on industrial electrifications. Can make estimates and lay-out work. Desires connection with power or engineering company. Available February 15th. C-761.

TECHNICAL GRADUATE, class 1911, age 36, married, desires position as manager of small electric light plant. Have operated my own plant until it was purchased by a large corporation. Bought this plant when it was on the verge of failure and unaided put it on a good paying basis in five years. C-738.

GRADUATE ELECTRICAL ENGINEER, three years' experience in laboratory, testing and designing of steam and gas-electric power plants, including commercial work in responsible position. Can speak and write Spanish, German, French, Russian, Norwegian. Willing to go abroad. Available on two weeks' notice. C-503.

TEACHER OF E. E., young man with extensive training and broad experience desires position. M. S. degree from Cornell University. Practical experience at Westinghouse and other places. Teacher in university for five years, in charge of department two years. Successful as manager. Well liked by students and associates. Good references. B-4968.

ASSISTANT ELECTRICAL ENGINEER, for consulting engineer, public utility or manufacturer. Technical graduate, single, 25, four years' electrical power plant and manufacturing experience before entering college, last two years assistant engineer large public utility in charge electrolysis mitigation, factory inspection electrical equipment, general testing, associated in general design and research. Two weeks' notice. Location immaterial. Salary $165.00. B-9045.

ELECTRICAL ENGINEER, age 39, married, sixteen years' experience supervision design, installation, maintenance, operation nearly all kinds electrical apparatus on over seven thousand miles of railroad, including lighting of all kinds, motor installations, overhead, underground distribution and transmission, submarine cables, building wiring, power plant electrical equipment, industrial high tension substations, meter surveys, industrial trucks. B-9772

YOUNG MAN GRADUATING IN JUNE from M. I. T. in electrical engineering wishes position. Has spent summers in public utility work, both construction and office. Has done graduate work in central stations and distribution at M. I. T. Prominent in undergraduate activities. Location, East. C-803.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 15, 1926

ALBER, GROVER F., Primary Meter Inspector, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

*ALEXANDER, DONALD FORD, Electrical Design Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

*ALIFANO, ANTONIE, Senior Engineering Student, Brooklyn Polytechnic Institute, 85 Livingston St., Brooklyn; res., Ridgewood, Queens, N. Y.

*APPLETON, WILLIAM EDGAR, Electrical Dept., Gary Heat, Light & Water Co., Gary, Ind.

ARNOLD, GUY WALKER, Electrical Engineer, Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.

ASHLINE, ROBERT, Asst. to Head Dept. Electrolysis Mitigation, City of Los Angeles, 207 S. Broadway, Los Angeles; for mail, Inglewood, Calif.

AVERY, ARTHUR BENJAMIN Jr., Student & Assistant, University of Arkansas, University Station, Fayetteville, Ark.

*AYRES, EDMUND DALE, Engineer, Jackson & Moreland, 31 St. James Ave., Boston, Mass.

*AYRES, FRANK, Student, The Southern Sierras Power Co., Riverside; res., Highgrove, Calif.

BABCOCK, GERHARDT M., Electrician, Los Angeles Gas & Elec. Corp., Los Angeles, Calif.

*BAILEY, CORNELIUS OLIVER, Radiologist, 912-14 Medical Arts Bldg., Dallas, Texas.

*BAKER, ACKLAND JAMES, Lakeside, Ont., Can.

BARSDORF, LEONARD WILLIAM, Switchboard & Meter Engineer, General Electric Co., Magnet House, Kingsway, London, Eng.

BATTISTA, LOUIS M., Service & Inspection Work, Socony Burner Corp., 40 Franklin St., So. Norwalk, Conn.

*BATY, LAURENCE EDWIN, Meter Tester, The Topeka Edison Co., 12th & Jackson Sts., Topeka, Kans.

*BAUMAN, HAROLD ADAMS, Assistant, Combustion Dept., Bethlehem Steel Co., Grey Mill Office, Bethlehem; res., So. Bethlehem, Pa.

BAUMGARDNER, CLAUDE GEROLD, Elec. Construction Foreman, Monongahela West Penn. Public Service Co., 504 Bethlehem Bldg., Fairmont, W. Va.

BEART, ERNEST ALFRED, Estimating Distribution Dept., Toronto Hydro-Electric System, Duncan St., Toronto, Ont., Can.

BEAUMONT, WILLIAM M., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Summit, N. J.

BECKER, THEODORE, Inside Plant Div., Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BECKERLEA, HERBERT, Sub-Foreman, Pacific Gas & Electric Co., 245 Market St., San Francisco; for mail, Oakland, Calif.

BENDER, ERHARD, Electrician, Goodyear Tire & Rubber Co., Plant 2, Akron, Ohio.

BENSON, OSCAR E., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

BENTLEY, ELLSWORTH F., Chief Draftsman, G. & W. Electric Specialty Co., 7789 Dante Ave., Chicago, Ill.

*BERGEVIN, WILLIAM PETER, Instructor, Rensselaer Polytechnic Institute, Troy, N. Y.

BERRY, CLARENCE HERVEY, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

*BERRY, HENRY PARMENTER, Engineering Assistant, Chesapeake & Potomac Telephone Co., 725 13th St., Washington, D. C.

BEST, EUGENE M., In charge of Electrical Work, De Vilbiss Mfg. Co., 3750 Detroit Ave., Toledo, Ohio.

BEVERS, PLEZ T., Traveling Representative, Electric Railway Improvement Co., Cleveland, Ohio.

BLAY, J. A., Salesman, Canadian Westinghouse Co., Metropolitan Bldg., Toronto, Ont., Can.

*BOCK, JOHN A., Design Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

BOOLBA, P. M., Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

*BOOTH, LOUIS FARRAND, Production Clerk, Century Electric Co., 18th & Pine Sts., St. Louis; res., Webster Groves, Mo.

*BOSTWICK, WILLIAM E., Estimator, Elec. Dept., Wisconsin Public Service Corp., 100 S. Washington St., Green Bay, Wis.

BOSWAU, HANS PAUL, Asst. Chief Engineer, North Electric Mfg. Co., Galion, Ohio.

BOYAU, JEAN, Resident Representative, French Thomson-Houston Co.; International General Electric Co., Schenectady, N. Y.

BRACKMAN, HAROLD, Jr., Asst. Distribution Engineer, Union Electric Light & Power Co., 315 N. 12th Blvd., St. Louis, Mo.

BRANDT, WILLIAM A., Dist. Operating Engineer, Automatic Electric Co., 427 Bourse Bldg., Philadelphia, Pa.

*BRIDGE, LAWRENCE RAYMOND, Instructor, Elec. Engg. Dept., Cornell University, Ithaca, N. Y.

*BRIXNER, FREDERICK W., Electrical Engineer, Engg. Dept., General Railway Signal Co., Rochester, N. Y.

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ROBSON, JOHN GREENFIELD, Operator, British Columbia Electric Railway Co., Vancouver, B. C.
ROESER, JOSEPH PETER, Inspector, Brooklyn Edison Co., Inc., Pearl & Willoughby Sts., Brooklyn, N. Y.
ROHDE, CHARLES F., Appraisal Engineer, Murrie & Co., 45 E. 17th St., New York; res., Brooklyn, N. Y.
ROLLOW, JAMES GRADY, Electrical Engineer, Los Angeles Gas & Electric Corp., 810 South Flower St., Los Angeles, Calif.
ROLNICK, Harry, Electrician, International Motor Co., 216 Seaman St., New Brunswick, N. J.
*ROSENBURG, EVERETT REYNOLDS, Student, Cornell University, 306 Stewart Ave., Ithaca, N. Y.
ROSS, DONALD, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
*ROTH, JESSE E., Multiplex Plant Attendant, Western Union Telegraph Co., 7th & Walnut Sts., Kansas City, Mo.
*ROWLAND, DAVIDGE HARRISON, Engineer, Locke Insulator Corp., S. Charles & Cromwell Sts., Baltimore, Md.
*RUMSEY, PAUL TRUMAN, Instructor, Dynamo Laboratory Dept., Mass. Institute of Technology, Cambridge, Mass.
*SAMS, JAMES HAGOOD, Jr., Student, Cornell University, 324 College Ave., Ithaca, N. Y.
SAPPER, ROBERT T., Asst. Purchasing Agent, Century Electric Co., 1806 Pine St., St. Louis, Mo.
*SCHACHT, DELBERT HERMANN, Sales Engineer, Century Electric Co., 628 Granite Bldg., Rochester, N. Y.
SCHARDT, FREDERICK O., Foreman, Electrical Construction, Public Service Production Co., Kearny; res., Edgewater, N. J.
*SCHLECHTER, ARTHUR HERMAN, Estimator, New York & Queens Electric Light & Power Co., Central Service Sta., Flushing; for mail, Corona, N. Y.
*SCHMIDT, EUGENE, Tester, New York & Queens Electric Light & Power Co., Flushing; res., Brooklyn, N. Y.
SCHMITTER, RAY M., Inspection Maintenance Engineer, Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.; for mail, Mercedes, Texas.
*SCHROEDER, JOHN HENRY, Specification Engineer, Commonwealth Edison Co., 635 Edison Bldg., Chicago, Ill.
*SHEA, DENNIS C., Asst. to Electrical Engineer, Standard Oil Co., Bayway Refinery, Elizabeth, N. J.
SHELLEY, HARRY SANDBERG, Engr., Distribution Dept., Consolidated Gas & Electric Co., Monument & Constitution Sts., Baltimore, Md.
SIMON, RAPHAEL B., Telephone Systems Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
*SIPKIN, GEORGE, Estimator, Interborough Rapid Transit Co., 600 W. 59th St., New York; res., Brooklyn, N. Y.
SISKIND, CHARLES S., Instructor, Milwaukee Vocational School, 6th & Prairie Sts., Milwaukee, Wis.
SKENE, ANDREW ALLISON, Engineer, Union Switch & Signal Co., Swissvale, Pa.
SKINNER, WILLIAM A., Electrical Foreman, Pennsylvania Power & Light Co., 117 E. Broad St., Hazleton, Pa.
SMITH, ARTHUR WILLIAM, Valuation Engineer, Murrie & Co., 45 E. 17th St., New York, N. Y.; res., Jersey City, N. J.
SMITH, ERMY R., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Maplewood, N. J.
SMITH, HOWARD MARSHALL, Vice-President, S. Edw. Eaton & Co., 591 Hudson St., New York, N. Y.

*SONNEMANN, WILLIAM KNOX, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

SONNENFELD, HUGO, Chief Engineer & General Superintendent, Cable Manufacturing Co., Ltd., Bratislava, Czechoslovakia.

*STANKA, ERHARDT W., Electrical Designer, H. L. Doherty & Co., 60 Wall St., New York, N. Y.; res., Belleville, N. J.

STANLEY, JACK SQUIRE, Line Foreman, Los Angeles Railway Corp., 717 E. 16th St., Los Angeles, Calif.

STERNBERG, THEODORE AUGUST, Electrical Draftsman, New York Rapid Transit Co., 85 Clinton St., Brooklyn, N. Y.; res., North Bergen, N. J.

STROESSLER, HANS M., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*STRONG, EVERETT MILTON, Instructor, Elec. Engg. Dept., Cornell University, Ithaca, N. Y.

STUMPF, MALCOLM WENDLING, Student Engineer, New Orleans Public Service, Inc., 201 Baronne St., New Orleans, La.

SUMMERS, CLIFFORD JOHN, Armature Winder, U. S. S. New Mexico, c/o Postmaster, San Francisco, Calif.

SUMMERS, HARRY ANDERSON, Engg. Dept., Bell Telephone Laboratories, Inc., 463 West St., New York; res., Brooklyn, N. Y.

SUTHERLAND, GEORGE ELMER, Electrician, Gibbs & Hill, Mullins; for mail, Princeton, W. Va.

SWORDS, EVERETT LAVON, Foreman of Operation, California-Portland Cement Co., Colton; res., San Bernardino, Calif.

*TANCK, HENRY, Asst. Engineer, Motor Engg. Dept., General Electric Co., River Works, West Lynn; res., Boston, Mass.

TAYLOR, ALFRED LINDSAY, Engineering Assistant, New York Telephone Co., 158 State St., Albany, N. Y.

TAYLOR, JAMES REUBEN, Salesman, Westinghouse Elec. & Mfg. Co., 1224 Miners Bank Bldg., Wilkes-Barre, Pa.

*TAYLOR, WILLIAM PRESTON, Electrical Testman, Cons. Gas Electric Lt. & Pr. Co., Baltimore, Md.

*TEALL, HARLEY ALBERT, Student, Kansas State Agricultural College, Manhattan, Kansas.

THERRIEN, RUSSELL WILLIAM, Elec. Engg. Dept., Commonwealth Power Corp., Jackson, Mich.

*THIELEMANN, GEORGE J., Station Electrician, Public Service Co. of No. Illinois, Blue Island, Ill.

*THOMSON, JOHN MILTON, Transformer Engg. Dept., Canadian Crocker-Wheeler Co., Katharine St., St. Catharines, Ont., Can.

TOWNSEND, RICHARD LEE, Engineer's Assistant, Chesapeake & Potomac Telephone Co., 725 13th St., N. W., Washington, D. C.

*TRAVERS, FRED HARTT, Student Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., Everett, Mass.

TREPTOW, FREDERICK WILLIAM, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Weehawken, N. J.

UPHAM, EDGAR HARVEY, Supt., French Cable Co., Orleans, Mass.

VAN DENBURG, EARL D., Engineer, The Montana Power Co., Great Falls, Mont.

VASSALLO, ANTHONY, Electrical Expert, Service Shop, General Electric Co., 627 Greenwich St., New York; res., Brooklyn, N. Y.

VROOM, EDWARD, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Ossining, N. Y.

*WAITS, CHARLES EDWARD, Student Engineer, Utica Gas & Electric Co., 222 Genesee St., Utica, N. Y.

*WALL, CHARLES LAYTON, Jr., Student Engineer, General Electric Co., West Lynn; res., Lynn, Mass.

WALTER, GEORGE D., Electrician, Biglerville, Pa.

WATSON, DONALD R., Designer, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

WEAVER, EARLE F., Division Supt., Pennsylvania Power & Light Co., Mt. Carmel, Pa.

WERNER, HAROLD DOUGLAS, Engineer, Foundry Dept., General Electric Co., Erie, Pa.

WETHERELL, DONALD HENRY, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

WILLIAMS, HARRY KASTE, General Foreman, General Underground Construction, Hartford Electric Light Co., 266 Pearl St., Hartford, Conn.

WILLIAMS, THOMAS, Dist. Manager, East Penn Electric Co., Minersville, Pa.

WILSON, MYRON SHEDWOOD, Asst. Engineer, Standardizing Laboratory, General Electric Co., West Lynn, Mass.

WINSLOW, JOHN CLIFFORD, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Springfield, Mass.

WITBECK, ALLEN LEE, Special Apprentice, Chicago, Milwaukee & St. Paul Railway Co., Chicago, Ill.; for mail, Pullman, Wash.

WOLF, HERMAN B., Maintenance Foreman, Southern Power Co., Salisbury, N. C.

WOLFE, T. M., Salesman, Westinghouse Elec. & Mfg. Co., 1224 Miners Bank Bldg., Wilkes-Barre, Pa.

*WOODS, STEPHEN RICHARD, Student Employ, Westinghouse Elec. & Mfg. Co., Murfreesboro, Tenn.

WRIGHT, ROLAND M., Act. General Foreman of Equipment, Cincinnati Street Railway Co., Cincinnati, Ohio.

WYNKOOP, FRANCIS BRUYN, Charge of Elec. Lab. & Meter Dept., Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

Total 352.

*Formerly enrolled Students

ASSOCIATES REELECTED JANUARY 15, 1926

DRAKE, WILLIAM A., Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

JOHO, E. C., Telephone Equipment Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MacDONALD, DANIEL F., 171 E. 94th St., New York, N. Y.

SWAN, WALTER DOUGLAS, Asst. Foreman, Elec. Laboratory, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

THOMPSON, STEPHEN WILKINS, Vocational Instructor, Dayton Co-operative Industrial High School, Stivers High School Bldg., Dayton, Ohio.

ASSOCIATES REINSTATED JANUARY 15, 1926

GREGSON, MONTRUVILA EDW., Asst. Superintendent, Bronx District, New York Edison Co., 140th St. & Rider Ave., New York, N. Y.

MEMBERS ELECTED JANUARY 15, 1926

BARKER, JOSEPH WARREN, Assoc. Professor of Elec. Engg., Mass. Institute of Technology, Cambridge, Mass.

BOMAN, CARL EMANUEL, Supervising Equipment Design Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

CLARKSON, ALBERT J., General Inspector, Elec. Div., New York Central Railroad Co., Grand Central Terminal, New York, N. Y.

COTA, ALEJANDRO R., Assoc. Editor, Business Publishers International Corp., 1403 Pennsylvania Bldg., New York; res., Queens Village, N. Y.

DIAZ, ENRIQUE, Controller Engineer, The British Thomson-Houston Co., Ltd., Rugby, Eng.

DODGE, WILLIAM LAMB, Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

FILER, WILLIAM L., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

HORR, RAY LECKLEY, Supervisor of Methods & Results, Mountain States Tel. & Tel. Co., 800 14th St., Denver, Colo.

IRISH, JOSEPH, Member of Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

KELLY, MERVIN, Research Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

*KELTON, EDWIN COIT, Major, Corps of Engineers, U. S. Army, Washington, D. C.; res., Bethesda, Md.

KEMP, CHARLES GEORGE RIDGELY, Electrical Engineer, 16 S. 5th St., Reading; res., Wyomissing, Pa.

LATHROP, GEORGE MARTIN, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., East Orange, N. J.

MATTHIES, WILLIAM H., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MORTIMER, LOUIS ANDREW, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MURPHY, PAUL BUCKNER, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Nyack, N. Y.

OBERNDORF, EDWIN S., Asst. Electrical Engineer, The J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

NOBLE, ROY EDWIN, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SHOPE, HARRY STEPHENSON, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SMITH, GORDON K., Equipment Development Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

TURNER, CLARENCE PORTER, Administrative Assistant, Marine Engg. Dept., General Electric Co., 1 River Road, Schenectady, N. Y.

VOORHIES, MICHEL B., Asst. Professor, Elec. Engg. Dept., Louisiana State University, Baton Rouge, La.

WISHART, RONALD S., Printer & Automatics Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York; res., Rockville Center, N. Y.

FELLOW ELECTED JANUARY 15, 1926

CHATELAIN, MICHAEL A., Professor, Polytechnic Institute of Leningrad; Vice-President Central Electrotechnical Council, Prosp. of 25 October 6, Apt. 7, Leningrad, Russia.

TRANSFERRED TO GRADE OF FELLOW JANUARY 15, 1926

COPLEY, ALMON W., Manager, Engineering Division, Westinghouse Electric & Mfg. Co., San Francisco, Calif.

HIBBARD TRUMAN, Secretary and Chief Engineer, Electric Machinery Mfg. Co., Minneapolis, Minn.

LEEDS, MORRIS E., President, Leeds & Northrup Co., Philadelphia, Pa.

WENNER, FRANK, Physicist, Bureau of Standards, Washington, D. C.

TRANSFERRED TO GRADE OF MEMBER JANUARY 15, 1926

EUSTIS, TRUMAN W., Superintendent, Canadian National Carbon Co., Ltd., Toronto, Ont.

FREEMAN, HADLEY F., Patent Lawyer, Cleveland, Ohio.

GILT, CARL M., Assistant Inside Plant Engineer, Brooklyn Edison Co., Brooklyn, N. Y.

GREEN, CHARLES W., Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

HOFFMAN, WILLIAM L., Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.

JENNINGS, PHILIP D., Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.

LAMB, FRANK B., Consulting Engineer, Member of Firm, West Virginia Engineering Co., Charleston, W. Va.

LOCKWOOD, ALVAH M., Field Superintendent, Phoenix Utility Co. of Cuba, Cienfuegos, Cuba.

LOWENBERG, MAURICE J., Electrical Engineer, Stone & Webster, Inc., Boston, Mass.

LOWRY, HITER H., Telephone Engineer, Bell Telephone Laboratories, Inc., New York.

MACIAS, CARLOS, Chief Engineer, Electromotor, S. A., Mexico D. F., Mexico.

MUSSER, HARRY P. President, West Virginia Engineering Co., Charleston, W. Va.

NETTLETON, LEROY A., Engineering Assistant, Brooklyn Edison Co., Brooklyn, N. Y.

REINMANN, F. L., Supt. Electric Department, Northern Indiana Gas & Electric Co., Hammond, Ind.

RHOADES, WALTER K., Professor of Electrical Engineering, Bucknell University, Lewisburg, Pa.

SHEDD, HORACE E., Superintendent, Appalachian Power Co., Bluefield, W. Va.

STAHL, CHARLES J., Manager, Illuminating Engineering Bureau, Westinghouse Elec. & Mfg. Co., South Bend, Ind.

VALK, EUGENE E., Engineer, Los Angeles Office, General Electric Co., Los Angeles, Calif.

WALKER, EWART B., Electrical Engineer, Canadian National Railways, Toronto, Ont.

WHITE, EDWARD J., Secretary, Treasurer, Engineer, Harris Wright Co., Inc., Newark, N. J.

WILLIAMS, LEROY C., District Manager, Pacific Electric Mfg. Co., Los Angeles, Calif.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held January 11 and 25, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

DIXON, AMOS F., Systems Development Engineer, Bell Telephone Laboratories, New York, N. Y.

McIVER, GEORGE W., JR., Asst. Manager, Electrical Dept., Toledo Edison Co., Toledo, Ohio.

THOMS, ALEXANDER P., Asst. Supt., Street Department, Commonwealth Edison Co., Chicago, Ill.

WILLIAMS, SAMUEL B., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

To Grade of Member

ADKERSON, BRANCH O., Inside Plant Engineer, American Tel. & Tel. Co., New York, N. Y.

AMBUHL, FRANK F., Asst. Chief Engineer, Toronto Hydro-Electric System, Toronto, Ont.

ARCEO, ANTONIO, Supt. of Distribution, Mexican Light & Power Co., Ltd., Mexico City, Mex.

BELL, JOHN H., Telegraph Engineer, Bell Telephone Laboratories, New York, N. Y.

BOSTATER, HERBERT L., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

DAVIS, URIAH, Load Dispatcher, Commonwealth Edison Co., Chicago, Ill.

EASTHAM, MELVILLE, President and Engineer, General Radio Co., Cambridge, Mass.

ENGLE, MELVIN D., Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.

EVANS, ROBERT D., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

FRIEND, HENRY M., Cable Engineer, Hugh L. Cooper & Co., New York, N. Y.

GARY, LAURENCE A., Engineer, Transmission Dept., Pacific Tel. & Tel. Co., San Francisco, Calif.

HASTINGS, MILTON B., Vice-President, Powerlite Devices, Ltd., Toronto, Ont.

INNES, FRANK R., Asst. Editor, *Electrical World*, New York, N. Y.

KERSEY, GLEN B., Field Engineer, Commonwealth Edison Co., Chicago, Ill.

McDOWELL, H. E., Electrical and Mechanical Engineer, Texas Power & Light Co., Dallas, Tex.

NASH, JOHN F., Electrical Engineer and Division Manager, Appalachian Power Co., Bluefield, W. Va.

RADER, RAY, Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.

ROBERTS, SPENCER, Engineer, Day & Zimmerman, Philadelphia, Pa.

SCOFIELD, EDWARD H., Engineer of Power, Twin City Rapid Transit Co., Minneapolis, Minn.

SMITH, GEORGE S., Instructor of Electrical Engineering, University of Washington, Seattle, Wash.

VANHALANGER, L. J., Sales Engineer, Westinghouse Electric & Mfg. Co., Chicago, Ill.

WAY, HOWARD E., Special Agent, Electrical Equipment Div., Bureau of Foreign and Domestic Commerce, Washington, D. C.

WREAKS, HUGH T., Manager, Detroit Office, Boston Insulated Wire & Cable Co., Detroit, Mich.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1926.

Aaroe, E., Electric Bond & Share Co., New York, N. Y.

Alger, C. S., Puget Sound Power & Light Co., Seattle, Wash.

Allschwager, O. A., Northern States Power Co., Minneapolis, Minn.

Altamirano, S. E., General Electric, S. A., Mexico D. F., Mex.
(Applicant for re-election).

Anderson, D. P., Western Electric Co., Chicago, Ill.

Anderson, W. B., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Apps, W. G., School of Engg. of Milwaukee, Milwaukee, Wis.

Baker, H. O., Western Electric Co., Inc., New York, N. Y.

Barrow, L. G., Brooklyn Edison Co., Brooklyn, N. Y.

Basurto, R., Control Electrotecnico de Mexico, Secretaria de Industria y Comercio, Mexico, D. F., Mex.

Bauer, C. A., Commonwealth Edison Co., Chicago, Ill.

Bauerschmidt, G. J., Commonwealth Edison Co., Chicago, Ill.

Baum, S. H., Chas. Freshman Co., New York, N. Y.

Baxter, N. M., (Member), The Ohio Public Service Co., Sandusky, Ohio
(Applicant for re-election.)

Berk, H. H., Puget Sound Power & Light Co., Seattle, Wash.

Biosca, L. F., Federal Radio Corp., Buffalo, N. Y.

Black, W. L., Bell Telephone Laboratories, Inc., New York, N. Y.

Blanding, W. P. T., Bureau of Pr. & Lt. of Los Angeles, Los Angeles, Calif.

Bollinger, N. H., Florida Pr. & Lt. Co., Miami, Fla.

Boyce, E. O., Philadelphia Electric Co., Philadelphia, Pa.

Boyce, W. H., Delta Star Electric Co., Chicago, Ill.

Boyer, Q. O., Commonwealth Edison Co., Chicago, Ill.

Bradfield, C. W., Duquesne Light Co., Pittsburgh, Pa.

Braun, A. W., William Braun & Co., New York, N. Y.

Bronski, C. R., Commonwealth Edison Co., Chicago, Ill.

Brown, G. R., Western Electric Co., Chicago, Ill.

Brugger, K. A., Public Utility Co., Chicago, Ill.

Budden, A. N., General Electric, S. A., Mexico D. F., Mex.

Buell, R. C., General Electric Co., Schenectady, N. Y.

Buhler, A. A., New York Telephone Co., New York, N. Y.

Bunce, L. I., The Belamose Corp., Rocky Hill, Conn.

Button, F. E., Hudson View Garden, W. 180th St., New York, N. Y.

Cadavero, A., New York Telephone Co., Brooklyn, N. Y.

Call, C. A., (Member), Ohio Insulator Co., Barberton, Ohio

Carney, J. S., Narragansett Electric Lighting Co., Providence, R. I.

Carr, A. V., Philadelphia Electric Co., Philadelphia, Pa.

Carrington, W. W., City of Norwich Gas & Elec. Dept., Norwich, Conn.

Charlton, O. E., Mass. Institute of Technology, Cambridge, Mass.

Chawner, W. R., Southern Sierras Power Co., Riverside, Calif.

Churchill, H., Public Service Production Co., Newark, N. J.

Clark, G. D., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

Clark, J., Brooklyn Edison Co., Inc., Brooklyn, N. Y.

Cobb, P. G., Weston Electrical Instrument Corp., Newark, N. J.

Codding, L. W., Public Service Electric & Gas Co., Newark, N. J.

Colbert, H. H., Southern Utilities Co., Fort Meyers, Fla.

Comly, J. M., Brooklyn Edison Co., Brooklyn, N. Y.

Conner, J. S., Davis Clinic, Marion, Va.

Cook, A. C., Western Electric Co., Chicago, Ill.

Cook, L. D., Commonwealth Edison Co., Chicago, Ill.

Coop, E. R., General Electric Co., Lynn, Mass.

Coughlin, J. G., Brooklyn Edison Co., Brooklyn, N. Y.

Crawford, G. W., Garrison Vacuum Tube Div., G. E. Co., Harrison, N. J.

Crumley, H. L., Georgia Railway & Power Co., Atlanta, Ga.

Cummings, E. B., United Hudson Electric Corp., New Paltz, N. Y.

Datta, R. S., Bucyrus Co., S. Milwaukee, Wis.

Davis, F. R. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Davis, J. I., Commonwealth Edison Co., Chicago, Ill.

Doyle, E. B., Westinghouse Elec. & Mfg. Co., New York, N. Y.
DuBois, A. D., Electric Machinery Mfg. Co., Minneapolis, Minn.
(Applicant for re-election.)
Dunn, R. R., with James Walker, Chicago, Ill.
Eaton, H. L., Central Coal & Coke Co., Kansas City, Mo.
Eiser, A. L., Commonwealth Edison Co., Chicago, Ill.
Ellison, M. A., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Elste, C., Standard Oil Co. of N. J., Bayway Refinery, Elizabeth, N. J.
Estrada, J. F., Havana Central Railroad Co., Havana, Cuba
Felty, W. D., Pittsburgh Transformer Co., Pittsburgh, Pa.
Field, A., Commonwealth Edison Co., Chicago, Ill.
FitzHugh, C. D., Commonwealth Edison Co., Chicago, Ill.
Forsyth, J., Jr., Electric Bond & Share Co., New York, N. Y.
Fosdick, E. R., Washington Water Power Co., Spokane, Wash.
Fredrichsen, A., Johns-Manville, Inc., Chicago, Ill.
Frisbie, C. G., Public Service Co. of No. Illinois, Chicago, Ill.
Gaezler, H., Electro-Dynamic Co., Bayonne, N. J.
Gahn, M. H., Adirondack Power & Light Corp., Schenectady, N. Y.
Galassi, D., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Galloway, R. P., Northwestern Electric Co., Underwood, Wash.
Gary, McC. L., Radio Corp. of America, Mexico, D. F., Mex.
Gentry, F. M., The New York Edison Co., New York, N. Y.
Gibson, F. D., Commonwealth Edison Co., Chicago, Ill.
Gillis, J. A., New York Edison Co., New York, N. Y.
Goetschius, W. L., Commonwealth Edison Co., Chicago, Ill.
Gordon, G., Research & Consulting Engineer, Ridgewood, N. J.
Goring, F. C., Norwich Electric Co., Norwich, Conn.
Gould, A. I., Thos. E. Murray, Inc., New York, N. Y.
Gould, A. S., General Electric Co., Schenectady, N. Y.
Graham, W. F., Continental Gin Co., Birmingham, Ala.
Grant, J. B., General Electric Co., St. Louis, Mo.
Grenzebach, S. L., Toronto Hydro-Electric System, Toronto, Ont., Can.
Grimm, G. A., Commonwealth Edison Co., Chicago, Ill.
Grossman, A. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Haifleigh, C. J., Commonwealth Edison Co., Chicago, Ill.
Hallead, H. A., Kohlenite Products Co., Inc., Chicago, Ill.
Hammond, O. W., General Electric Co., Erie, Pa.
Hansen, T., Pratt Low Preserving Co., Santa Clara, Calif.
Hartman, H. E., Kansas Gas & Electric Co., Wichita, Kans.
Hartshorn, K. L., Commonwealth Edison Co., Chicago, Ill.
Haynes, R. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hazen, H. L., Mass. Institute of Technology, Cambridge A. Mass.
Hebling, A. G., United Electric Light & Power Co., New York, N. Y.
Hebrew, J. S., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Hecht, J. L., (Member), Public Service Co. of No. Ill., Chicago, Ill.
Henig, C. W., Detroit Edison Co., Detroit, Mich.
Heisler, F., Public Service Co. of No. Ill., Chicago, Ill.
Hinson, E. G., Commonwealth Edison Co., Chicago, Ill.
Hoadley, H. E., (Member), Ohio Public Service Co., Warren Ohio
Holman, J. L., New Brunswick Telephone Co., Saint John, N. B., Can.
Horacek, J. A., (Member), Diamond Alkali Co., Painsville, Ohio
Hosticka, F. J., Western Electric Co., Chicago, Ill.
Huffman, H. F., University of Kansas, Lawrence, Kansas
Ingersoll, R. E., Westinghouse International Co., New York, N. Y.
Jarand, W. H., Northern Electric Co., Ltd., Montreal, Que., Can.
Jensen, P. J. S., Commonwealth Edison Co., Chicago, Ill.
Johnson, G. E., (Member), The Norwich Electric Co., Norwich, Conn.
Jones, R. H., The Milwaukee Elec. Rly. & Lt. Co., Milwaukee, Wis.
Jordan, W. C., Bell Telephone Laboratories, Inc., New York, N. Y.
Joseph W., Union Electric Light & Power Co., New York, N. Y.
Jost, E. R., Western Electric Co., Chicago, Ill.
Kaegi, E., American Brown Boveri Electric Corp., Camden, N. J.
Kannenberg, W. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Kanzler, O. C., Commonwealth Edison Co., Chicago, Ill.
Katz, B. J., 187 Bank St., Burlington, Vt.
Keith, F. E., General Electric Co., Chicago, Ill.
Kidd, J. R., Bell Telephone Laboratories, Inc., New York, N. Y.
Kilstofte, I. N., Commonwealth Edison Co., Chicago, Ill.
Knost, J. H., Jr., (Member), Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Knox, E. H., Electric Co. of New Jersey, Bridgeton, N. J.
Knowlton, W. D., Commonwealth Edison Co., Chicago, Ill.
Koschmeder, L. A., East Penn. Electric Co., Pottsville, Pa.
Kramer, J., Jr., Western Electric Co., Inc., Chicago, Ill.
Krejci, F. V., Commonwealth Edison Co., Chicago, Ill.
Kremer, J., 135 Central Park West, New York, N. Y.
Krueger, N. C., Commonwealth Edison Co., Chicago, Ill.
Kuhles, W. J., Commonwealth Edison Co., Chicago, Ill.
La Fever, L. H., 444 Cass St., Milwaukee, Wis.
Lambert, T. J., Brooklyn Edison Co., Brooklyn, N. Y.
Langley, E. J., Union Elec. Light & Power Co., St. Louis, Mo.
Langsam, H., 2215 N. 29th St., Philadelphia, Pa.
Largy, V. P., New York Dock Co., Brooklyn, N. Y.
Larson, C. A., Auto Specialties Co., Elkhart, Ind.
Laws, F. R., Edison Electric Ill. Co., Boston, Mass.
Leidenheimer, F. J., Baldor Electric Co., St. Louis, Mo.
Leon, C., Jr., Havana Central Railroad Co., Havana, Cuba
Leonard, R. N., New York Edison Co., New York, N. Y.
Lindblom, R. E., University of Washington, Seattle, Wash.
Long, F. A., Commonwealth Edison Co., Chicago, Ill.
Long, P. B., Union Switch & Signal Co., Swissvale, Pa.
Lorich, R. A., N. Y. & N. J. State Bridge & Tunnel Comm., New York, N. Y.
Loshbough, L., General Electric Co., Chicago, Ill.
Love, E. L., Western Electric Co., Inc., New York, N. Y.
Lund, A., Stone & Webster, Inc., Boston, Mass.
Lundgren, F. E., General Electric, S. A., Mexico D. F., Mex.
Maheu, J. J., Western Electric Co., Inc., Chicago, Ill.
Manspeaker, E. D., General Electric Co., Schenectady, N. Y.
Many, W. G., Radio Review, New York, N. Y.
Markers, H. W., Commonwealth Edison Co., Chicago, Ill.
Martin, E. F., General Electric Co., Bloomfield, N. J.
Masuno, T., Stone & Webster, Inc., Boston, Mass.
Mausshardt, M. R., Key System Transit Co., Oakland, Calif.
McClarren, A. E., Puget Sound Power & Light Co., Seattle, Wash.
McGowan, L. F., Rochester Gas & Electric Co., Rochester, N. Y.
McKinley, J. L., Public Service Co. of Colorado, Denver, Colo.
McLean, J., Commonwealth Edison Co., Chicago, Ill.
Mercereau, J. T., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Merrill, M. S., General Electric Co., Schenectady, N. Y.
Metz, J., Commonwealth Edison Co., Chicago, Ill.
Michael, J. J., Pacific Tel. & Tel. Co., Seattle, Wash.
Miller, F. H., with Frank A. Boedtcher, New York, N Y.
Miller, J. H., Firestone Tire & Rubber Co., Johnstown, Pa.
Miller, R. F., Naomi Pines Electric Co., Inc., Pocono Pines, Pa.
Miller, R. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Miller, W. H., Canadian Westinghouse Elec. & Mfg. Co., Toronto, Ont., Can.
Misner, F. D., Commonwealth Power Corp., Jackson, Mich.
Mitchell, J. I., Public Service Co. of No. Illinois, Evanston, Ill.
Miyasaki, M., University of Wisconsin, Madison, Wis.
Mode, H. C., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Molina, F., J., Calle 59 No. 447, Merida, Yucatan, Mex.
(Applicant for re-election).
Monaco, J., with M. R. Greenblatt, Brooklyn, N. Y.
Mussfeldt, A., Public Service Co. of No. Ill., Chicago, Ill.
Muth, L. R., Junior Elec. Draftsman, City of Seattle, Seattle, Wash.
Myers, F. W. A., Philadelphia Electric Co., Philadelphia, Pa.
Nelson, N., Adirondack Power & Light Corp., Schenectady, N. Y.
Olds, C. D., Puget Sound Pr. & Lt. Co., Bellingham, Wash.
Ortlieb, O. P., Street Lighting Engr., City of Trenton, Trenton, N. J.
Otto, E. D., Royal Eastern Electrical Supply Co., New York, N. Y.
Over, H. A., Commonwealth Edison Co., Chicago, Ill.
Palmer, G. W., L. D. Smith Dock Co., Sturgeon Bay, Wis.
Patterson, E. B., "Public Ledger" & "Evening Ledger," Philadelphia, Pa.
Pennybacker, M., Raytheon Mfg. Co., Cambridge, Mass.
Perry, D. J., Bell Tel. Co. of Pa., Philadelphia, Pa.
Peterson, V. C., Western Electric Co., Cicero, Ill.
Pettet, C. C., Northern Electric Co., Ltd., Montreal, P. Q., Can.
Philleo, E. W., Victor X-Ray Corp., San Francisco, Calif.
Polley, L. P., Puget Sound Power & Light Co., Tacoma, Wash.
Price, A. V., Northern Electric Co., Toronto, Ont., Can.
Price, J. R., Western Electric Co., New York, N. Y
Pruddhomme, D. J., Oregon State College, Corvallis, Ore.
Putnam, R. C., Case School of Applied Science, Cleveland, Ohio
Rankin, H. C., The New York Edison Co., New York, N. Y.
Reilly, F. W., General Electric Co., Boston, Mass.

Reimel, S. R., B. D. Goodrich Co., Akron, Ohio
Rice, J. M., Pennsylvania State College, State College, Pa.
Richards, F. L., General Electric Co., Schenectady, N. Y.
Rieman, H. M., Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.
Rodewig, L. F., General Electric Co., New York, N. Y.
Roger, W. H. G., c/o Fraser, Frew & Dryer, Ltd., Vancouver, B. C.
Rose, D. L., So. California Edison Co., Big Creek, Calif.
Ross, W., with James Martin, New York, N. Y.
Roughen, R. H., (Member), Duquesne Light Co., Pittsburgh, Pa.
Rowley, C., Commonwealth Edison Co., Chicago, Ill.
Ruppell, E. A., Kimball Elec. Construction Corp., New York, N. Y.
Sassen, C. H., Hudson Coal Co., Scranton, Pa.
Schaefer, P. E., Commonwealth Edison Co., Chicago, Ill.
Schnug, G., Pacent Electric Co., Inc., New York, N. Y.
Schroeder, H. W., Commonwealth Edison Co., Chicago, Ill.
Schultz, H. G., Commonwealth Edison Co., Chicago, Ill.
Schultz, S. W., Commonwealth Edison Co., Chicago, Ill.
Scott, C., Commonwealth Edison Co., Chicago, Ill.
Sederberg, N. W., Brooklyn Edison Co., Brooklyn, N. Y.
Seelye, A. F., Boise Payette Lumber Co., Barber, Idaho
Sharpsteen, J. K., Pacific Gas & Electric Co., San Francisco, Calif.
Shulze, G. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Shuman, U. S., Philadelphia Suburban Gas & Electric Co., Newtown, Pa.
Sibley, W. C., Commonwealth Edison Co., Chicago, Ill.
Sisler, F. G., The Electric Controller & Mfg. Co., Cleveland, Ohio
Smith, H. W., Commonwealth Edison Co., Chicago, Ill.
Smith, J. L., Commonwealth Edison Co., Chicago, Ill.
Smith, O., Thomas E. Murray, Inc., New York, N. Y.
Smith, V. G., University of Toronto, Toronto, Ont., Can.
Smith, W. J., Commonwealth Edison Co., Chicago, Ill.
Spencer, R. M., (Member), Los Angeles Gas & Elec. Co., Los Angeles, Calif.
Stahl, C. P., General Electric Co., Schenectady, N. Y.
Starr, A. L., Clapp & LaMores, Los Angeles, Calif.
Steinberg, B. B., New York Edison Co., New York, N. Y.
Stock, R. J., Supervisor, Electrical Equipment, Cincinnati, Ohio
Story, T. H., Turner Construction Co., New York, N. Y.
Stover, M. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Stover, J. R., Metropolitan Edison Co., Reading, Pa.
Stowers, L. G., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Sudler, E. O., Bliss Electrical School, Washington, D. C.
Taggart, C. W., City of Norwich Gas & Elec. Dept., Norwich, Conn.
Taylor, F. F., Salt River Valley Water Users Assn., Roosevelt, Ariz.
Tarzian, S., Atwater Kent Mfg. Co., Philadelphia, Pa.
Thomas, C. H., Electrical Testing Laboratories, New York, N. Y.
Thomas, W. A., 3rd, (Member), Sonora Phonograph Co., Inc., New York, N. Y.
Thompson, A. C., American Tel. & Tel. Co., New York, N. Y.
Thompson, G. S., Colorado Fuel & Iron Co., Pueblo, Colo.
Thompson, H. E., Brooklyn Edison Co., Brooklyn, N. Y.
Thomson, T. B., U. S. E. M. Co., New York, N. Y.
Thorson, W. R., Commonwealth Power Corp., Jackson, Mich.
Thurston, H. A., Columbus Railway, Power & Light Co., Columbus, Ohio
Tietz, W. J., Western Electric Co., Inc., Chicago, Ill.
Tisdale, W. H., Connecticut Power Co., Middletown, Conn.
Torgan, N., Jr., Horni Signal Mfg. Corp., Newark, N. J.
Trimble, L., Commonwealth Edison Co., Chicago, Ill.
Trone, E. M., Western Electric Co., Inc., Chicago, Ill.
Tuckerman, L. P., De Forest Radio Co., Jersey City, N. J.
Van Etten, F. C., Delta Star Electric Co., Columbus, Ohio
Van Sickle, R. C., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Van Why, F. W., Passadena Star-News, Pasadena, Calif.
Walker, F. V., Bureau of Pr. & Lt. of Los Angeles, San Fernando, Calif.
Wallis, C. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Weber, H. P., Commonwealth Edison Co., Chicago, Ill.
West, G. H., Louisiana Electric Co., Inc., Lake Charles, La.
Westbrook, J. L., Compania Agricola y de Fuerza Electrica del Rio Conchos, S. A., C. Camargo, Chih., Mex.
Westerman, A. G., Commonwealth Edison Co., Chicago, Ill.
Westhoven, C. J., Commonwealth Edison Co., Chicago, Ill.
Whitaker, E. R., Union Electric Light & Power Co., Ashley Station, St. Louis, Mo.
Wick, R. J., Commonwealth Edison Co., Chicago, Ill.
Wilbur, D. E., Pennsylvania Pr. & Lt. Co., Allentown, Pa.
Wilcox, J. E., New York Telephone Co., New York, N. Y.
Williams, G. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Williams, N. B., Puget Sound Power & Light Co., Seattle, Wash.
Winograd, H., American Brown Boveri Electric Corp., Camden, N. J.
Wishard, W. W., Commonwealth Edison Co., Chicago, Ill.
Wollebak, T., Delta Star Electric Co., Chicago, Ill.
Wright, C. T., (Member), The Pennsylvania-Ohio Pr. & Lt. Co., Toronto, Ohio
Young, P. N., Brooklyn Edison Co., Brooklyn, N. Y.
Turner, H. E., General Electric Co., Schenectady, N. Y.
Zimmer, F. M., Ohio Power Co., Canton, Ohio
Total 242

Foreign

Akers, R. E., (Member), Carrick Wedderspoon, Ltd., Christchurch, N. Z.
Albiston, W. A., Christmas Island Phosphate Co., Christmas Island, Indian Ocean
Bhaman, R. C., Tata Iron & Steel Co., Ltd., Jamshedpur, India
Buchanan, T., The British Thomson-Houston Co., Ltd., Willesden, London, N. W., 10, Eng.
Downie, C. G., Metropolitan-Vickers Elec. Co., Ltd., Manchester, Eng.
Ferreira, A. C., The Sao Paulo Tramway Lt. & Pr. Co., Sao Paula, Brazil, S. A.
German, C., College of Engg., Univ. of Philippines, Manila, P. I.
Glover, G. C., Chile Exploration Co., Chuquicamata, Chile, S. A.
Jacobsen, C. J., Braden Copper Co., Rancagua, Chile, S. A.
Kirkpatrick, K. J., Metal Manufacturers Proprietary, Ltd., Port Kembla, N. S. W., Aus.
Kloss, M., (Fellow), Technische Hochschule, Charlottenburg, Germany
Longy, V., British Engine, Boiler & Electrical Ins. Co., Barcelona, Spain
Milne, K. H., Adelaide Electric Supply Co., Ltd., Adelaide, South Australia
McCulloch, H., Hydroelectric Dept., Hobart, Tasmania
Monroe, G. W., Braden Copper Co., Rancagua, (Pangal), Chile, S. A.
Mountain, C. E., Burma Elec. Tramways & Lighting Co., Ltd., Mandalay, Burma, India
Nixon, J. H. R., Messrs. Brush Elec. Engg. Co., Ltd., Loughborough, Leicestershire, Eng.
Noguchi, K., Mitsubishi Research Laboratory, Komagome, Hongo, Tokyo, Japan
Patel, D. B., Brown, Boveri & Co., Baden, Switzerland
Sahgal, G. R., Engineering College, Poona, India
Scanlon, D. L., Chile Exploration Co., Chuquicamata, Chile, S. A.
Sharma, S. M., Messrs. India Elec. House, Delhi, India
Sleeman, H., (Member), Electric Tramway & Supply Co., Rangoon, Burma, India
Thompson, A. L., (Fellow), La Carlota Sugar Central, La Carlota, Negros Occ., P. I.
Timoffeeff, W. A., Electrotechnical Inst. of Leningrad, Leningrad, Russia
Total 62

STUDENTS ENROLLED

Agnew, Norman F., Ohio State University
Akers, Chauncey Lee, Rose Poly. Inst.
Anderson, Aldrich B., Case School of Applied Science
Asfalt, Filip J., Univ. of Minn.
Bailey, Homer L., Worcester Poly. Inst.
Bailey, Stuart L., Univ. of Minnesota
Baines, Harold A., Worcester Poly. Inst.
Baker, Allan K., Univ. of Michigan
Barberie, Frederick M., Virginia Military Inst.
Barton, James P., Univ. of Minnesota
Bates, Allen W., Northeastern Univ.
Bauer, Rudolph W., Penn. State College
Beach, George, Univ. of Minnesota
Benedict, John C., Univ. of Michigan
Berger, Harold J., Univ. of Wisconsin
Berglund, Erick B., Univ. of Minn.
Berkner, Lloyd V., Univ. of Minn.
Bezek, Albert J., Univ. of Minnesota
Bickmore, William J., Ohio State Univ.
Bishop, W. E., Univ. of Maryland
Blanchard, J. Wayne, New York Univ.
Blankenbeker, Everett L., Kansas State College
Boger, Clair E., Ohio State Univ.
Boisseau, Alexander C., Washington & Lee Univ.
Bonner, Arthur L., Univ. of Minnesota
Boyce, Harold J., Univ. of Minn.
Bricker, Lowell E., Ohio State Univ.
Brightfelt, John C., Univ. of Minn.
Briscoe, Andy, Montana State College
Brooke, Edward F., Ohio State Univ.
Brooks, James W., Cornell Univ.
Brooks, Ralph R., Univ. of Wisconsin
Brown, Frederick A., Lewis Inst.
Brown, George E., Ohio State Univ.
Brown, George W., Ohio State Univ.
Brown, Percy S., Univ. of Southern California
Broyles, Harmon E., Virginia Poly. Inst.
Buccowich, Paul, Univ. of Minnesota
Burmeister, Charles H., Univ. of Minnesota
Campbell, James L., N. Car. State College
Carlson, C. Paul, Univ. of Michigan
Carson, Lester G., N. Car. State College
Carson, Sam A., Jr., Virginia Military Inst.
Case, Myron D., Stanford Univ.
Cerney, Jospeh A., Case School App. Science
Chute, Dudley H., Northeastern Univ.
Clancy, Walter J., Univ. of Pa.
Connolly, Ethan F., Univ. of Toronto
Cook, F. W., Ohio State Univ.
Cook, William P., Ohio State Univ.

Cooper, C. M., N. Car. State College
Cooper, George V., Univ. of Denver
Copper, Joseph B., Wash. & Lee Univ.
Cox, Lester D., Ohio State University
Cram, Charles C., Ore. Agri. College
Craugh, Paul T., N. Y. Univ.
Crawford, Kelsey, Univ. of Okla.
Croll, Raymond H., Ohio State Univ.
Cruse, J. W., Univ. of Arizona
Dannecker, Martin C., Purdue Univ.
Davis, Julius E., North Car. State College
Dearth, Sam C., Ohio State Univ.
Decino, Alfred, Univ. of Colo.
DeHaven, Thomas V., Univ. of Denver
Deist, John W., Univ. of Wisconsin
De Jean, Clare L., Penn. State College
Delong, Carl L., Ohio State Univ.
DeStefano, Anthony C., Polytechnic Institute of Brooklyn
Dexter, D. M., Univ. of Arizona
Divguid, John H., Virginia Military Inst.
Dolezal, Edward G., Case School of Applied Science
Dortort, Isadore, Univ. of Pa.
Douglas, A. J., Univ. of Toronto
Dreher, Carl E., Rose Poly. Inst.
Dresser, Weyburn H., Univ. of Wisconsin
Due, Paul A., Ore. State College
Dunn, Charles, Jr., Univ. of Arizona
Dunn, W. Francis, Cornell Univ.
Eatman, Frank L., Jr., Univ. of Alabama
Eckstein, Moritz, N. Y. Univ.
Edgar, Merton W., Univ. of Denver
Edgar, Robert F., Univ. of Minn.
Edwards, Manley W., Cal. Inst. of Tech.
Ellis, Clarence W., Rose Poly. Inst.
Fagan, James W., N. Car. State College
Fahlstrom, Clifford I., Worcester Poly. Inst.
Fairchild, Marshal T., N. Car. State. College
Falls, Theodore F., Univ. of Pa.
Fatig, Raymond O., Ohio State Univ.
Ferris, W. Robert, Rose Polytechnic Inst.
Fischer, Edgar C., Newark Technical School
Fowler, Robert E., Cornell Univ.
Fraser, Willard B., McGill Univ.
Freston, Robert B., Lewis Inst.
Frink, Frederick W., Leland Stanford Univ.
Fulton, Walter J., Univ. of Pa.
Gartin, James W., Univ. of Idaho
Gerhan, Charles F., Case School of Applied Science
Gibson, Robert, Univ. of Minn.
Glover, Robert L., Univ. of Pa.
Goldman, Samuel, Lewis Inst.
Goldsmith, Lloyd T., Poly. Inst. of Brooklyn
Goodlin, Carl L., Ohio State Univ.
Graf, Glenn F., Ohio State Univ.
Graham, William M., Montana State College
Green, Francis N., University of Tennessee
Griffith, Lewis S., Virginia Military Inst.
Hamilton, Sam, Univ. of Alabama
Hammell, Kemper M., Ohio State Univ.
Haner, Norman W., University of Washington
Hansen, Elmer, Worcester Poly. Inst.
Hardy, Wilbur G., Ohio State U.
Hargreaves, William, Northeastern Univ.
Hargrove John W., Va. Poly. Inst.
Harris, Henry J, Va. Poly. Inst.
Harris, William A., Rose Poly. Inst.
Hawk, O. L., Lewis Inst.
Hayashi, Francis M., Stanford U.
Haydock, Jesse G., Jr., Univ. of Pa.
Hendershott, Leroy W., Ohio State University
Hicks, Ben C., McGill Univ.
Hitchcock, Jackson G., Jr., Univ. of Alabama
Hilbert, Walter F., Worcester Poly. Inst.
Hill, Carl C., N. Car. State College
Hobson, Leland S., Kansas State Agri. College
Hoody, J. Stanley, Ohio St. Univ.
Hopkins, Alva R., Ohio State U.
Hortberg, Reynold O., Univ. of Minn.
Howe, James S., Lewis Inst.
Huggins, Allen E., N. Car. State College
Hughes, Kenneth M., Ohio State Univ.
Hulstede, George E., Stanford Univ.
Humbert, Locke R., N. Car. State College
Humphrey, George D., N. Car. State College
Hurley, Henry C., N. Car. State College
Hutcheson, Richard M., Virginia Poly. Inst.
Hyde, H., Univ. of Toronto
Hyer, John, Kansas State Agri. College
Joehlin, Homer W., Ohio State Univ.
Jones, Robert F., Ohio State U.
Kadota, Koichi, Univ. of Toronto
Kane, Elias K., Univ. of Ill.
Kappanadze, Roman J., Case School of Applied Science
Karakiz, Socrates, Lewis Institute
Keller, G. V., Jr., N. Car. State College
Kemp, Russell E., Ohio State Univ.
King, Belton D., Clemson College
Kingston, George H., McGill Univ.
Kinnear, Arthur, Stanford Univ.
Kinsey, Alfred S., Cornell Univ.
Kleiner, Eugene M., Ore. Agri. College
Kloster, Walter W., University of N. Dak.
Knowles, Howard F., Northeastern Univ.
Kohler, Richard William, Washington State College
Krebs, Sylvester G., Case School Applied Science
Kres, Alfred J., Case School of Applied Science
Kromm, Charles F., Brooklyn Poly. Inst.
Lally, C. K., Univ. of Toronto
Lane, William C., Jr., N. Car. State College
Leahy, Edward F., Univ. of Pa.
Lee, Albert C., Univ. of Minn.
Lee, Paul R., Univ. of Minn.
Leedy, Walton O., Ohio State Univ.
Legge, Thomas A., Univ. of Toronto
Lehman, Charles D., Ohio State Univ.
Leider, Albert E., Univ. of Minn.
Lewis, Lloyd W., Univ. of Minn.
Ligh, Charles, New York Univ.
Lightfoot, Thomas C., Swarthmore College
Lowrance, Frederick H., Univ. of Minn.
Lussky, Lionel B., Denver Univ.
MacCannon, Bruce T., Univ. of Denver
Magne, Robert, Drexel Inst.
Marquette, Fabian W., Ohio St. U.
Marzulli, Angelo M., Purdue Univ.
Matsch, Leander W., Lewis Inst.
Mathews, William E., N. Car. State College
Mattes, William F., Jr., New York Univ.
Maxim, George, Case School of Applied Science
May, John Willard, Washington State College
Mayer, Philip H., Univ. of Pa.
McColl, F. Harold, Univ. of Toronto
McCulloh, Marvin W., N. Car. State College
McCullough, J. R., Univ. of Toronto
McDonnell, Lawrence, Univ. of Minn.
McGarrell, Edmund J., Worcester Poly. Inst.
McGuire, C. H., Univ. of Toronto
McPheeters, John W., Purdue Univ.
Mead, Rolan J., Northeastern Univ.
Mebs, Russell W., Ohio State Univ.
Mekeel, Nelson M., Ore. Agri. College
Mendelsohn, Harry, Univ. of Michigan
Merkle, Joseph D., Ohio State Univ.
Messex, Leland C., Univ. of Colo.
Michels, Walter C., Rensselaer Poly. Inst.
Miller, Earl R., Okla. A. & M. College
Miller, Edward F., State Univ. of Iowa
Miller, John W., Ohio State University
Miller, Sennet W., Case School Applied of Science
Milligan, Fred C., Ohio State Univ.
Mills, Lester F., N. Y. U.
Minici, Joe, Jr., Univ. of Colo.
Moccabee, Frederick M., Ohio State Univ.
Mong, Frederick M., Ohio St. U.
Montgomery, C. G., N. Car. State College
Moore, Gordon B., Univ. of Minn.
Moore, William H., McGill Univ.
Morris, Edmund T., Jr., Virginia Military Inst.
Morris, John C., Cornell, Univ.
Morrow, Thomas A., N. Car. State College
Muir, Walter, Cornell U.
Murray, John M., Northeastern Univ.
Mustoe, Anthony Q., Virginia Poly Inst.
Neisser, Wilson R., Univ. of Pa.
Nelson, Clarence E., Univ. of Minn.
Nelson, John M., Univ. of Iowa
Nemela, Hugo W., Univ. of Wisconsin
Nielsen, Andres H., Univ. of Minnesota
Nolan, George C., Univ. of Minn.
Nuhfer, William L., W. Va. Univ.
Oberg, Rudolph O., Northeastern University
Oliver, Franklin S., Va. Poly. Inst.
Paisley, S. Roy, Univ. of Toronto
Palmer, Carl C., Purdue Univ.
Parr, Merl W., Univ. of Wisconsin
Patrick, Horace M., Penn. State College
Pering, Alfred V., Stanford Univ.
Peters, C. Max, Univ. of Minnesota
Peterson, Carl L., Case School of Applied Science
Pettibone, Gilbert W., Univ. of Southern Calif.
Phillips, Carey A., N. Car. State College
Pickford, Stanley H., Worcester Poly. Inst.
Pilger, Clarence L., Univ. of Minnesota
Plank, Lewin H., Univ. of Denver
Plott, Hubert K., N. Car. State College
Pollock, C. A., Univ. of Toronto
Porter, Charles S., Northeastern Univ.
Prasar, Hans R., Univ. of Wisconsin
Prentke, Edwin M., Case School of Applied Science
Prescott, Harold R., Univ. of Kansas
Pritchett, Edward H., Univ. of Alabama
Quinean, H. D., Univ. of Toronto
Quinlan, Joseph W., U. of Notre Dame
Raichilson, Robert, Univ. of Michigan
Rauscher, Paul F., Univ. of Minn.
Rawlins, Herbert L., Ohio State Univ.
Rawls, James A., Va. Polytechnic Inst.
Recer, Beo W., Okla. Agri. & M. College
Reed, Donald P., Worcester Poly. Inst.
Rembusch, Joseph E., Purdue Univ.
Rew, Clair W., Case School of Applied Science
Richart, Ralph R., Univ. of Ill.
Rindlaub, Willard W., Univ. of Pa.
Rinehart, Vene E., Oregon Agri. College
Riordan, Forrest H., Jr., Univ. of Pa.
Ritland, Hubert O., Stanford Univ.
Roberts, Walter F., Ohio State U.
Roberts, William F., N. Car. State College
Robinson, Lawrence T., Univ. of Minn.
Robinson, Richard B., Univ. of Minnesota
Rockfield, Martin L., N. Car. State College
Rohn Richard L., University of Denver
Rolston, David R., Va. Polytechnic Inst.
Rooney, Lewis K., Case School of Applied Science
Rumble, George, Univ. of Toronto
Rutherford, James F., McGill University
Sabbagh, Elias M., Ohio State U.
Sano, Joseph Y., Stanford Univ.
Scarafino, Anthony J., Poly. Inst. of Brooklyn
Schmal, Charles L., Lewis Inst.
Scholz, Edmund H., Univ. of Minn.
Schramm, John W., W. Va. Univ.
Schultz, Albert W., Univ. of Minnesota
Schulze, Leroy E., Univ. of Minn.
Sciotti, Fred, Brown University
Sekerl, Alfred, S. Dakota State College
Shiland, J. E., Case School of Applied Science
Sinclair, Shull A., Univ. of Arizona
Singer, Ferdinand Leon, New York Univ.
Singer, Willard E., Ohio State Univ.
Skilling, Hugh H., Stanford Univ.
Smathers, James L., N. Car. State College
Smith, James A., N. Car. State College
Snively, L. Clifton, Univ. of Colo.
Sparrow, Chester D., Univ. of Missouri
Stallard, Guy H., Rose Poly. Inst.
Stone, Walter, Purdue Univ.
Stuart, Paul L., N. Car. State College
Stuff, Arthur R., Ohio State Univ.
Summers, Erwin R., Univ. of Wisconsin
Sundblad, Everts, Univ. of Minn.
Swain, Robert R., Univ. of Michigan
Taber, Lloyd E., Northeastern University
Tanner, Stephen C., Univ. of Colo.
Tarnoczi, Stephen, Jr., Ohio State U.
Taugher, Frank P., Ohio State Univ.
Tchinnis, Paul M., Poly. Inst. of Brooklyn
Teed, Currie N., Univ. of Idaho
Test, Laurence J., Swarthmore College
Thomas, Almon D. Thomas, Univ. of Colorado
Thompson, Samuel, Montana State College
Thomson, William L., Cornell Univ.
Townsend, H. J., Northeastern University
Tucker, Everett L., Oregon Inst. of Technology
Van Cleve, Charles F., Ohio State Univ.
Vaughn, Gerald O., Stanford U.
Verman, Lal C., Univ. of Michigan

Vest, William L., Jr., N. Car. State College
Vietzen, Elmer R., Lewis Inst.
Vieweger, Arthur, Univ. of Pa.
Volkenant, Gordon W., Univ. of Minn.
Wahrman, Harry, Va. Poly. Inst.
Wald, Joseph H., Univ. of Minn.
Ward, Stanley A., Univ. of Minn.
Wasson, Arthur, Kansas State Agri. College
Watts, Plato Hilton, N. Car. State College
Webb, G. Kenneth, Northeastern University
Webb, Grady W., Va. Poly. Inst.
Weeks, L. H., Univ. of Minn.
Wehlitz, Hubert F., Univ. of Minn.
Weis, Jacob F., Ohio State Univ.
Westerberg, Oliver D., Lewis Inst.
White, James W., N. Y. U.
Whitely, Howard O., Univ. of Minn.
Wiggins, Leonard A., Ohio State U.
Wike, Reginald E., Ohio State Univ.
Williams, William W., Jr., Ohio State U.
Willson, Harry Leon, Rose Poly. Inst.
Wilson, Edwin W., N. Car. State College
Wirtel, William E., Univ. of Missouri
Wood, John Samuel, N. Car. State College
Woodring, William R., Kansas State Agri. College
Word, George L., Jr., Georgia School of Technology
Worth, Donald G., Univ. of Southern Cal.
Wrasman, John J., Ohio State Univ.
Yarling, Frank C., Purdue Univ.
Yeager, Robert, Jr., Virginia Military Inst.
Yusas, Mathew, Lewis Inst.
Zulandt, George K., Ohio State Univ.

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(The Institute is represented on the following bodies; the names of the representatives may be found in the January issue of the JOURNAL.)

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U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION
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A. I. E. E. SECTIONS AND BRANCHES

See the January issue for the latest published list. The Institute now has 50 Sections and 84 Branches.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Switchboards.—Bulletin 111, 4 pp. Describes "Ideal" switchboards and synchronous motor starting panels. The Ideal Electric & Mfg. Company, Mansfield, O.

Blowers.—Bulletin 1608, 16 pp. Describes "ABC" pressure blowers and exhausters. American Blower Co., Detroit, Mich.

Steam Turbine Generators.—Bulletin GEA-54, 44 pp. Principally a photographic presentation of the Curtis turbine as installed in notable power plants, ranging up to 60,000 kw. General Electric Co., Schenectady, N. Y.

Safety Switches.—Catalog, 56 pp., entitled "Westinghouse Safety Switches," describes industrial, motor starting and meter service switches. Westinghouse Electric & Mfg. Company, East Pittsburgh.

Switchboards.—Bulletin No. 1006-2, 16 pp. Describes construction and pictures installations of Condit switchboards in various industries. Condit Electrical Mfg. Corporation, Boston, Mass.

Automatic Switching Equipment.—Bulletin GEA-295, 24 pp. Describes the application of automatic switching equipment to railway service, hydro-electric generators, mining, industrial, central station service, etc. General Electric Company, Schenectady, N. Y.

Rail Bond Testers. Bulletin 200, 8 pp. The Type BBT bond tester and Type B contact bar described are new devices just placed on the market. The particular application of the new tester lies where the current on the rail is very feeble, or absent altogether. The sensitivity of the new device is claimed to be five times as great as any heretofore made. It can be used with the current from a single No. 6 dry cell. Roller-Smith Company, 12 Park Place, New York.

Automatic Direct-Current Starter.—Bulletin 215, 4 pp. Describes Type C-1220 current limit automatic d-c. starter, for use in starting constant speed shunt or compound wound motors up to 30 h. p., 115 volts; and 50 h. p., 230 or 500 volts, for any applications where it is desired that the time of acceleration correspond with the load on the motor. **Crane, Hoist and Mill Controller.** Bulletin 330, 8 pp. Describes Type F-2250 controllers, for general crane and mill service. Allen-Bradley Company, Milwaukee, Wis.

NOTES OF THE INDUSTRY

Simplex Wire & Cable Company, Boston, has opened a branch office in the Union Trust Building, Cleveland, in order to better care for a steadily increasing volume of business. William H. Lamond will be manager of the new office.

Kohlenite Products Company, Inc., New York, manufacturer of carbon brushes, has opened a branch office located at 1555 Monadnock Block, Chicago. This office will be in charge of H. A. Hallead.

The Griscom-Russell Company has moved its general offices in New York to the new Murray Hill building, 285 Madison Avenue.

The Foxboro Company, Inc., Foxboro, Mass., maker of indicating, recording and controlling instruments, has moved its Pittsburgh office from the Park Building to what will now be known as the Foxboro Building, located at the corner of Sixth Avenue and Grant Street. The four upper floors will be utilized for offices and the maintenance of a substantial stock of new equipment.

130,000 Kilowatts to be Added to Detroit Power Supply.—Three turbine generators, totalling 130,000 kilowatts in capacity, are to be added to the facilities of the Detroit Edison Company. Two of these machines, 50,000 kw. each, will be placed in the Trenton Channel station, and the other, 30,000 kw., in the Marysville station. The turbines are being made by the General Electric Company and will be delivered within eight months.

Largest Lighting Contract to Westinghouse.—What is said to be the largest contract for street lighting equipment ever placed, consisting of 10,000 standard lighting units, reflectors and auxiliary equipment, was recently awarded to the Westinghouse Electric & Mfg. Company through the Ryckoff Construction Company of Chicago for a new street lighting system for the City of St. Louis. A plant will be erected in St. Louis for delivery of the hollowspun concrete poles at the rate of 1000 each month, as required by the contract.

General Radio Company Promotions.—At the annual meeting of the company on January 12, the position of Chairman of the Board of Directors was created to meet the growth of the company. Henry S. Shaw, Treasurer for the past eight years, was elected to this position. H. B. Richmond, formerly Secretary and Assistant Treasurer, was elected to the position of Treasurer. No other changes were made in the officers; Melville Eastham who has served as President for the past eleven years will continue in that office and E. H. Locke enters his sixth year as Vice-President, in charge of manufacturing. During the past year the company completed its new factory at Cambridge, Mass., which provides 50,000 square feet of ideal manufacturing space.

Master Electric Sales Conference.—On January 11 and 12 the branch office representatives and the distributing agents of The Master Electric Company met at the factory, Dayton, Ohio, for a sales conference. The primary object of the meeting was to acquaint the field organization with the greatly increased facilities offered by the new plant at Linden and Master Avenues and into which the company just recently moved. On the evening of January 11 the visiting representatives and a number of plant executives held a banquet at the Engineers Club.

General Electric Orders for 1925.—Orders received by the General Electric Company for the year ending December 31, 1925, amounted to $302,513,380, according to an announcement by Gerard Swope, president of the company. Compared with $283,107,697 for the year 1924, this is an increase of seven per cent. For the three months ending December 31, 1925, orders totalled $78,636,669, compared with $80,009,978 for the same quarter of 1924, a decrease of two per cent.

Sales Organization Changes in W. N. Matthews Corporation.—Louis M. Meckler has succeeded W. J. McIlvane as New York representative of the W. N. Matthews Corporation, St. Louis, manufacturers of Matthews electrical specialties. The Baltimore territory, which was formerly covered by Mr. McIlvaine, will be under the supervision of H. C. Biglin, southern district manager of the corporation. J. T. Pearson, district manager in Detroit, has resigned and this territory will be covered by H. L. Brueck, Chicago district manager. The Iowa territory which was formerly covered by Mr. Brueck will be taken care of by W. M. Watters. The northern section of Pennsylvania, which has been covered by the New York office, has been transferred to J. A. Jaques of the Pittsburgh office.

J. H. Bunnell & Company Changes Hands.—Control of J. H. Bunnell & Company, founded in 1879 and known as one of the world's leading manufacturers of high-grade telegraph apparatus; also as manufacturers of fire alarm apparatus and other electrical equipment, has been acquired by J. J. Raftery and J. G. Dougherty. Mr. Raftery was previously connected with the Western Electric Co., and later with Manhattan Electrical Supply Co., Inc., as Eastern General Manager. Mr. Dougherty was formerly with the Illinois Steel Corporation. The retiring President, J. J. Ghegan, who has been associated with Bunnell for forty years, will retain a financial interest in the business and will continue to give it the benefit of his long experience. Plans for expansion are being worked out.

JOURNAL OF THE A·I·E·E·

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33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Annual Business Meeting, New York, N. Y., May 21

Annual Convention, White Sulphur Springs, W. Va., June 21-25

Pacific Coast Convention, Salt Lake City, Utah, (Dates to be announced in subsequent issue)

Regional Meetings

Middle Eastern District, Cleveland, Ohio, March 18-19

Great Lakes District, Madison, Wis., May 6-7

Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

National Electric Light Association, Atlantic City, May 17-21

Middle West Division, Ft. Des Moines Hotel, Des Moines, April 8-10

Southwestern Division, Galveston, Tex., April 13-16

Southeastern Division, Pinehurst, N. C., April 27-29

American Welding Society, New York, April 21-23

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OF THE
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Current Electrical Articles Published by Other Societies

Engineering Journal, January, 1926
Power Transformers, by C. E. Sisson

Journal of the Franklin Institute, January, 1926
Direction and Intensity Changes of Radio Waves, by C. C. Bidwell
Standard Electrical Cells, by M. Eppley

Journal of the Western Society of Engineers, December, 1925
Electrical Equipment in the Chicago Union Station, by C. W. Post

Proceedings of the Institute of Radio Engineers, February, 1926
Some Studies in Radio Broadcast Transmission, by Ralph Bown, De L. K. Martin and R. K. Potter
Transatlantic Radio Telephone Transmission, by Lloyd Espenschied, C. N. Anderson and Austin Bailey

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV MARCH, 1926 Number 3

Intellectual Renaissance in America*

Idealism found its clearest expression in the men who immediately after the Civil War had inaugurated a new epoch in American history, the epoch of the *intellectual renaissance in America.* It was the epoch of the new movement in the direction of higher endeavor in all intellectual, aesthetic and spiritual activities of our national soul. Joseph Henry, Barnard, White, Draper, Eliot, Lowell and many other intellectual leaders led the movement, but it took its first concrete form in Baltimore, when Johns Hopkins University was formally opened fifty years ago.

The wisdom of the trustees of the princely gift which a modest Baltimore merchant had placed into their hands was that of inspired men when they selected Daniel Coit Gilman as the interpreter of the wish of Johns Hopkins.

The quality of the men whom Gilman selected for his original faculty proclaimed this idealism. Sylvester, the mathematician; Gildersleeve, the Grecian; Morris, the classicist; Remsen, the chemist; Rowland, the physicist, and Martin, the biologist, were the members of the original faculty over which the genius of Gilman presided. This was the famous heptagon, a new constellation of seven brilliant stars in the intellectual firmament of America.

Associated with this constellation there were other young and brilliant stars like Brooks, Elliott, Adams and Scott. No finer group of idealists was ever assembled in any university faculty. But their idealism was not that of a vague and misty type.

A knowledge of the truth which uplifts the soul of man and makes it free was always a part of the gospel of Johns Hopkins University. Gildersleeve's ancient classics and Remsen's modern chemistry; Sylvester's and Cayley's abstract mathematics and Welch's concrete science of medicine; Martin's modern physiology and Haupt's language of ancient Babylon; Rowland's latest theories in physics and Johns Hopkins' inquiries into the earliest documents of the Christian creed; Lowell's discourse on Dante and Brook's story of the Chesapeake oyster; Huxley's evolution and Dean Stanley's theology; Kelvin's structure of the vibrating atom and Sidney Lanier's structure of the sonorous verse—all these sources of God's eternal truth were welcome topics to the gospel which was proclaimed in the lecture rooms of Johns Hopkins University. It thrilled the American intellect as it had never been thrilled before.

I can pass over in silence many discoveries in mathematics, physics, chemistry, physiology, biology and other branches of knowledge; they are very important and well understood by the experts. But there are three achievements which have a great national significance, and they are not all as well understood by our nation as they ought to be. These I must describe, even if briefly.

The first great achievement of national significance which I must mention is the Johns Hopkins Medical School. Thirty years ago I was told by a great medical authority in London that the Johns Hopkins Medical School is second to none and that its professors and former pupils are the prophets of the medical profession. I found out later that the names of Welch, Osler, Halstead and Kelly were household words in the medical profession.

The ideals of the university were the same as those of its medical school. Welch, the first dean of the medical school, and his colleagues were guided by the same idealism which guided Gilman and his famous heptagon.

I must now mention another achievement of great national significance. The modern American medical school did not exist before William H. Welch became the dean of the Johns Hopkins Medical School; neither did the American university exist before Daniel Coit Gilman became president of the Johns Hopkins University.

But there is an achievement which is of even greater national significance than the two that I have just mentioned. Nothing is as difficult as molding the mental attitude of men; the average mind has an enormous inertia. There was a time when the so-called practical man had little use of the idealist of the Johns Hopkins heptagon type. The movement in the direction of higher endeavor, with its lofty ideals, gave no thrill to the prosy soul of the practical man.

The American industries controlled by the stubby hand of the practical man had no points of sympathetic contact with the subtle touch of science of the research laboratory. But presently industrial problems arose which were too scientific for the practical man. The harnessing of Niagara Falls and the electrification of the New York subways, for instance, were too much for the practical man. Rowland, the idealist, and Duncan, his pupil, had something to say on this subject and they received a respectful hearing. It was found that their

*Abstract of an address at the fiftieth anniversary of Johns Hopkins University on Feb. 22, 1926.

scientific idealism had a practical side, just as Brook's idealism in biology had a practical side when he told the biological story of the Chesapeake oyster.

Pretty soon the practical man opened the door of his industries and welcomed the disciples of the John Hopkins heptagon of idealists. Their idealism gave birth to the idealism of the American university research laboratories, and from these it moved into American industries. The scientific idealism which Rowland and his colleagues preached is today the idealism of our industrial research laboratories.

The words uttered lately by three distinguished American engineers are still ringing in my ears; they are the words of Jewett, Durand and Hoover. Their ideas are accepted everywhere as the practical ideas of practical men. What is their message? It is this: The greatest need of this nation is thorough training and research in the fundamental sciences. But this was the gospel of Johns Hopkins fifty years ago, and it is today. The adoption by the practical engineer of the creed of this gospel is one of the greatest services of Johns Hopkins to our nation.

My old friend President Goodnow and his distinguished colleagues are making every effort not only to continue this national service but even to amplify it. Our nation never needed it more than it does at the present moment.

M. I. PUPIN.

Some Leaders of the Institute

Gano Dunn, the twenty-fourth president of the Institute, was born in New York City, October 18, 1870. He attended the College of the City of New York, from which he was graduated with the B. S. degree in 1889; he also received the degree of M. S. from that institution in 1897. In 1891 he received the E. E. degree from Columbia University, and honorary M. S. from Columbia in 1914.

His professional work began in 1886, in the service of the Western Union Telegraph Company, where he remained five years. He then entered the service of the Crocker-Wheeler Company, at Ampere, N. J., and from 1898 until 1911 was vice-president and chief engineer of that company. In the latter year he was elected vice-president in charge of engineering and construction by the J. G. White Company, and in 1913, when the J. G. White Engineering Company was organized to take over the engineering and construction work of the parent company, Mr. Dunn was made president, in which position he still continues.

From 1900 until 1902, Mr. Dunn was president of the New York Electrical Society. He was president of the A. I. E. E. throughout the term 1911-12; president of the United Engineering Society from 1913 to 1916; of the John Fritz Medal Board of Award in 1914; the Engineering Foundation 1915-16, and vice-chairman of the National Research Council, 1917, afterwards becoming chairman.

He is the author of various important papers on engineering subjects, and has served on many important technical committees and boards.

Mr. Dunn was secretary of electric lighting and distribution, for the International Electrical Congress, St. Louis, 1904, and a delegate and vice-president of the International Electrical Congress, Turin, 1911. He is a member of the International Electrotechnical Commission, and in 1916-18 was a member of the Engineering Committee of the Council of National Defense; also, during the war he was chairman of the State Department Committee on submarine cables.

He is a member of several American and foreing technical and engineering societies, beside belonging to various clubs in the United States and a broad.

Companies Encouraging Convention Attendance

More organizations are realizing the advantages of having interested members of their forces attend the meetings of professional societies such as the Institute. The benefits of such attendance are felt not only by the individuals but they are carried back to the parent companies in the form of increased information, broader viewpoint, greater enthusiasm and development of personality.

As a matter of fact many companies appreciate these benefits to such an extent that they make it the duty of some members of their staff to attend certain features of conventions. They realize the importance of encouraging the attendance of their members in order that they may gain technical knowledge from the reading and discussion of the papers and from inspection trips, and that they may develop their characters through informal conversation with others at the meeting and through the social functions.

This practise certainly indicates a healthy state of mind and shows a far-sightedness of managers and managements which is entirely commendable.

Auxiliary Radio Language

The recently held International Conference of Radio Amateurs, at Paris, France, appointed a committee to study and report upon the problem of an auxiliary language for use in communication, correspondence and conversation between members of the International units of the organization. About twenty artificial languages were considered, including Esperanto and Ido, as well as a few national languages. After considerable debate, in which the Scandanavian representatives strongly urged the adoption of English as the approved auxiliary language, the committee reported in favor of Esperanto.

A High-Frequency Voltage Test for Insulation of Rotating Electrical Apparatus

BY J. L. RYLANDER[1]
Member, A. I. E. E.

***Synopsis.**—For many years the need for a higher test voltage between turns of individual coils or complete windings has been recognized. To obtain this higher test voltage, high frequency has been introduced. The high frequency used for this test is produced by damped oscillating discharge from a condenser and applied directly to the leads of the coil or winding. Practically any desired voltage can be applied to a coil or winding provided a sufficiently high frequency is used.*

As a shop method for checking defects in material, or poor workmanship, the high-frequency test method has been found very effective in those classes of windings so far tried.

The method used for detecting short circuits on the principle of the radio receiving set are described.

INSULATION is used on rotating electrical apparatus to insulate between its various parts which have a difference of potential and also to insulate all parts of the circuit to "ground." The "ground" insulation is thoroughly tested by the present method of applying a high potential, usually at normal frequency, between the winding and the core or frame at various stages of construction. The present methods of testing the insulation of various parts of the same circuit such as from one turn to other turns, one layer of wire to other layers of wire, are far from adequate. It is the purpose of this paper to present a method of making a thorough and practical test between various parts of a coil or winding.

Present Method of Test

The present method of testing between turns and layers of coils consists of placing the coil over a pole piece magnetized by a primary coil which induces a voltage in this coil as the secondary coil of a transformer. The maximum voltage that can be induced by this method will not exceed 10 or 20 volts per turn in most coils as the voltage is limited by the size of pole piece that can be inserted into the opening of the coil and to the frequency of the circuit. Usually 133 or 500 cycles per second are used. This test discovers short circuits where there is actual copper to copper contact. However, it does not discover any weak or damaged insulation where there is not actual copper contact. Therefore many coils are given no insulation test.

The windings of d-c. armatures are tested by this same induction method by revolving the armature slowly and testing each coil separately. This test discovers any short circuits caused by actual copper to copper contact and also discovers open circuits. As this type of testing apparatus is only adaptable for rotating windings, induction motor primary windings are not given this test.

The completed motor or generator is given a running test with rated voltage for one-half hour to several days depending on the test data needed. This test is applied to the motor when new and operating at normal voltage and under normal conditions of operation. It makes no allowance for future deterioration of the insulation or for any abnormal conditions of operation.

In order to obtain a higher test voltage between turns of coils both before and after winding the coils in the machine, that would be considered a real insulation test, high-frequency voltage is applied directly to the terminals of the coil or windings.

Types of High Frequency

With high frequency, advantage can be taken of the inductance of the coil or winding and thus obtain almost any voltage desired.

The use of high frequency for various test purposes is not new but as far as the author is aware it has not been applied to the commercial testing of individual coils and wound apparatus.

In general, there are two types of high-frequency voltage; (1) undamped oscillations and (2) damped oscillations. The first type includes the high frequency voltage produced by high frequency generators which is, comparatively speaking, limited as regards the range of frequency. This class may also include the high frequency produced by vacuum tubes, such as used in radio work and which has a very high range of frequency compared to any generator.

The second type is produced by the oscillating discharge of a condenser through an inductance with a comparatively low resistance.

The production and control of both types of high frequency has been known practically and theoretically for many years and is described in many text books on radio and physics so no detailed description need be given.

The oscillating discharge high frequency was chosen for commercial test purposes because of its comparative ease of production and control.

It may be of interest to enumerate briefly a few of the experiments which were made with other types of high frequency. The reason for these experiments was mainly that when the damped oscillating high frequency

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1. Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

was first put in use the spark-gap was the only practical means of measuring the voltage. As is well known, the measurement of voltage with the sphere spark-gap is not very accurate under 2000 or 3000 volts. Inasmuch as there were many cases where a lower high frequency test voltage was desired attempts were made to measure the damped oscillating voltage by other means than spark-gap. Ordinary voltage measuring instruments were entirely unsuitable and it was also found, as was anticipated even before trial, that the electrostatic voltmeter would not give the correct measurements.

At this point, therefore, attempts were made to use the undamped high frequency obtained from vacuum tubes. However, the necessary frequency from this source was so high that it was difficult to screen the indicating instruments from the indirect effect, so this also was discarded for commercial reasons.

The high-frequency voltage obtained from a high frequency generator was next resorted to but the current required up to 5000 cycles was so high that serious heating occurred in the bands of banded armatures in the case of direct-current machines.

In the meantime methods of detecting short circuits on wound apparatus, including commutating machines, were developed. This development permitted the high frequency test voltage to be applied across the normal span of the brushholders on a commutating machine, so the necessity for very low voltage at high frequency was largely removed. Later, also a method of instrument measurement of damped high-frequency voltage was developed, and for this reason all efforts were finally concentrated on the damped high-frequency test voltage.

The Principle of Operation of the Damped High-Frequency Set

A very high voltage can be applied to any winding if the frequency is sufficiently high. The voltage drop due to the inductive reactance is $E = 2 \pi f L I$ where f is the frequency per second and L is the inductance in henries and I is the current in amperes. For example, a 15-turn circular coil with a 12-in. diameter having a d-c. resistance of 0.1 ohm and an inductance of 0.001 henry would have approximately the following voltages across its terminals with 10 amperes in the circuit: one volt d-c.; 4 volts, 60 cycles per second, and 4000 volts with 60,000 cycles per second. It is thus seen that practically any desired voltage can be placed across a coil or a winding if sufficiently high frequency is applied. The voltage is applied by connecting the two leads from the high frequency apparatus directly to the terminals of the coil or winding either partial or completely finished.

When high frequency is applied to the apparatus under test, it sets up an alternating electromagnetic field of a particular frequency in a manner similar to a radio transmitter. If a short circuit occurs in the winding, the wave length and frequency will be changed accordingly, and the strength of the outgoing signals is reduced. A wave meter is used to measure the outgoing waves and thereby determine whether any insulation failure has occurred.

The wave meter consists of a set of inductance coils, variable condenser with a vernier attachment, two variable resistances and a low reading ammeter of the thermo-element type, all connected in series with one of the inductance coils. The inductance coils are such that by changing the setting of the variable condenser, resonance may be obtained for the frequency generated by the coil or winding under test. The condenser, the ammeter and the variable resistances are mounted on a panel and a tuning coil is placed near the apparatus being tested. The tuning coils have low resistance and a minimum capacity for a given inductance. Coils with taps are unsatisfactory on account of the end-turn loss.

The wave meter is tuned to the frequency of the waves omitted by the apparatus under test and it acts in a manner similar to a radio receiving set. A current flows in the wave meter circuit which is measured by the ammeter. The variable condenser is adjusted until a maximum current is shown on the meter which thereby indicates the condition of resonance and also the frequency of the circuit. The meter reading alone does not mean anything in particular; it is the relative meter readings used in connection with the condenser readings and the distance from the tuning coil to the apparatus under test which tells the story.

The principle by which high frequency is produced by this outfit is that a condenser placed across the secondary terminals of the transformer is charged during each alternation of the 60-cycle current. The condenser is automatically discharged through rotating disks when the voltage reaches a predetermined value on each alternation. The discharge of the condenser through the apparatus under test produces a high-frequency current whose frequency is determined by the apparatus under test and the capacity of the condenser.

Description of High-Frequency Testing Apparatus for Commercial Use

The high-frequency testing apparatus consists essentially of (1) equipment for generating the high frequency and applying it to the apparatus under test, and (2) a means of detecting any short circuits or failures in the insulation of the apparatus under test while the high frequency is being applied. A photograph of the apparatus is shown in Fig. 1. A schematic diagram of this apparatus in shown in Figs. 2A and 2B, Fig. 2A showing the generation of the high frequency and its application to the coil or winding and Fig. 2B showing the apparatus used in the detection of an insulation failure.

The power is furnished by a transformer of 10-kw. capacity with 7500-15,000 and 30,000 volts on the secondary. A 70 per cent reactance limits the current to one and a third times full-load current with the short-

circuit current in the secondary. The condensers have a capacity of 0.05 microfarads at 30,000 volts. The air-gap for discharging the condenser is formed between two motor-driven rotating brass alloy disks so that the arc across the gap will not burn the metal. The sphere-gap limits and measures the voltage across the apparatus under test. A resistance of 15,000 ohms is placed in series with the sphere-gap to prevent the spheres from being burned by the arc. For voltages of 5000 and

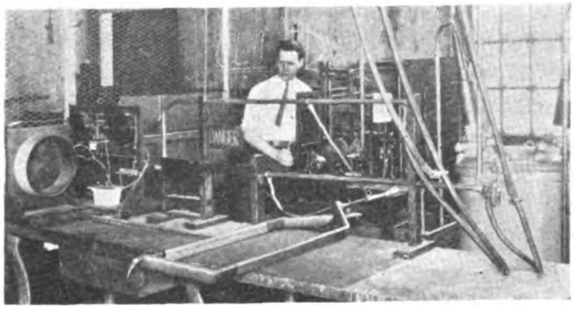

FIG. 1

higher, five-cm. spheres are used, and for lower voltages one-cm. spheres are used, also instrument measurement. A panel contains switches for the circuit breaker and plugs for tapping in different values of reactance. A hand-wheel is used for controlling the spacing of the gap of the rotating disks. Voltages ranging from 2000 to 30,000 volts can be obtained with this particular apparatus. By a combination of series and parallel connections the transformer will give 7500, 15,000 or 30,000 volts and intermediate voltages are obtained by adjustment of the rotating gap.

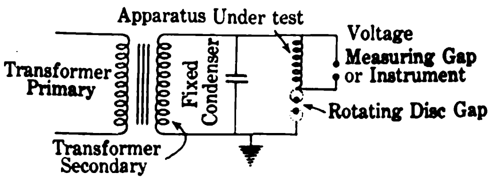

FIG. 2A

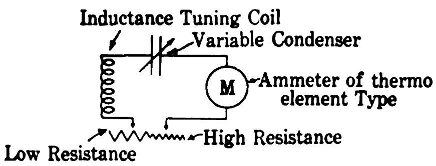

FIG. 2B

The manipulation of the test apparatus consists of connecting the leads to the coil or winding under test and setting the sphere-gap for the value corresponding to the desired test; then closing the circuit breaker and opening up the rotating disk gap until the desired voltage is obtained. This is indicated by a spark across the measuring gap. The voltages are generally applied for from 10 to 15 seconds. The frequency is determined by the apparatus under test usually within the limits of 10,000 to 200,000 cycles per sec. for individual coils and 5000 to 100,000 cycles per sec. for wound apparatus.

THE HIGH-FREQUENCY VOLTAGE

The damped high-frequency voltage as produced by this set gives a somewhat more severe test on the insulation than a corresponding voltage at normal frequency. Fortunately such a test can be used to discover faults without damage to the normal insulation.

In general the voltage builds up somewhat on the end coils. At first thought this may seem to be a disadvantage, but in actual service the end coils of a group are subjected to greater voltage in the case of surges than are the other coils. The voltage on the inner coils is sufficiently high, however, to give an adequate test for defects in material or workmanship.

VALUE OF TEST VOLTAGES USED

The high-frequency test voltage applied to the terminals of wound apparatus corresponds closely to the regular ground test as given by the A. I. E. E. standards. This allows a liberal margin of safety over the strain due to operation at its normal voltage, and also to the momentary high voltage, high frequency surges that may be impressed in service.

The voltage which it is desirable to apply to individual coils before winding into a machine is largely a question of judgment based on experience. We have used successfully on induction regulator coils a test voltage on single coils somewhat higher than the operating voltage of the machine for voltages lower than 2500 volts while for voltages over 2500, a test voltage somewhat lower than the operating voltage, has been used.

METHODS USED IN TESTING WITH HIGH FREQUENCY

The methods used for various types of apparatus are somewhat different, depending on various conditions. The method of testing a single coil is shown in Fig. 1.

The method of testing the windings of a two-pole, single-phase, induction regulator is shown diagrammatically in Fig. 3 for the stator and Fig. 4 for the rotor. The two leads from the high frequency set are connected to leads *A* and *B* of one pole and the tuning coil of the wave meter is placed alongside the frame as shown at *C*. The voltage is applied for 10 to 15 seconds. The two high frequency leads are then connected to the leads *E F* of the other pole of the winding and the tuning coil placed at *G*.

The high-frequency leads can be connected to three-phase machines by either of the methods shown in Figs. 5 to 8 inclusive.

The high-frequency leads may be connected either across each pole-phase group as shown in Fig. 5, or from each lead to the star connection, as illustrated in Fig. 6 or across the leads as in Figs. 7 and 8. Each of these connections have merits for certain conditions as determined by the number of poles, the voltage of the

machine, the number of turns in the winding, the number of parallel connections and the size of the machine.

On a d-c. armature the voltage is applied at two

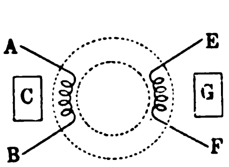

Fig. 3—Two-Pole Single-Phase Stator Winding

points on the commutator corresponding to the location of the brushes, and the armature is then rotated.

The tuning coil of the wave meter is placed in the

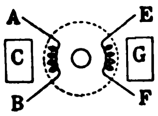

Fig. 4—Two-Pole Single-Phase Rotor Winding

most advantageous position which usually is close to the outside circumference of rotors and either inside the bore or outside the frame of stators.

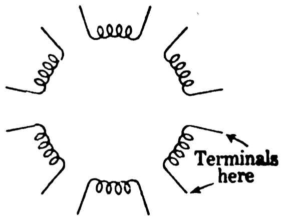

Fig. 5—Voltage Applied to each Group Separately

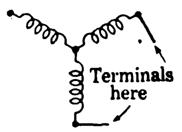

Fig. 6—Voltage Applied to Each Phase Separately

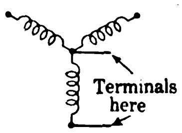

Fig. 7—Voltage Applied Across Two Terminals of a Star Connected Winding

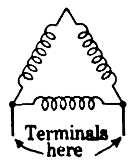

Fig. 8—Voltage Applied Across Two Terminals of a Delta-Connected Winding

For each coil and winding the wave meter settings are recorded. These settings show both the frequency and the strength of signal transmitted from any particular apparatus when the winding is normal and free from faults. As each coil or winding is tested, the readings will correspond to the standard readings if the winding is free from faults, but if short-circuited, different readings will be obtained. It is thus easy to check any apparatus that has been previously tested. If new, the approximate readings can usually be estimated with sufficient accuracy by comparing the general characteristics of the windings with other known windings, and checking one part of the winding with another is an additional check. The fact that a short circuit has a deadening effect on the radiations transmitted as well as changing the wave length and frequency facilitates the discovery of any short circuits.

Scope of Application

This method of insulation testing was first applied commercially in the testing of induction regulator coils. The results were so satisfactory that the test was extended to the wound regulators, both stators and rotors of single-phase and three-phase regulators. Thousands of induction regulator coils for machines of all voltages up to 14,000 volts and hundreds of wound primaries and wound secondaries are now being tested each month with high frequency. The development has now reached a point where completely wound d-c. armatures, a-c. generator coils, turbo-generator coils and wound induction motors either partly or completely connected have been tested experimentally.

Considerable experimental work must be done before this method can be applied safely as a commercial shop test to complete windings of large alternators or induction motors. For example, sufficient information as to satisfactory test values is not yet available to apply high frequency voltage as a test to the complete windings which will be a proper measure of their ability to withstand surges in operation.

Benefits Derived from High Frequency Testing

Testing coils and windings with high frequency has had an effect on the insulation of the apparatus to which this test is applied. It showed that insufficient insulation for reliable operation was used in some cases, that different kinds of material should have been used in others, that certain insulating materials had been badly crushed during one of the coil forming operations, that the vacuum impregnation had not fully penetrated to all parts of the coil and that the moisture had collected into these spots and that the insulation used on certain designs was too liberal. It also furnished a good idea as to whether the insulation was sufficiently balanced between the various turns and layers to withstand the natural uneven voltage distribution that occurs in coils and windings whenever the windings are subjected to surges and line disturbances. It is thus seen that high frequency testing has enabled the improvement of the insulation of the windings by eliminating

weak or defective coils, which might otherwise have been used. High frequency also checks the ability of the insulation to withstand the occasional severe dielectric strains that will occur in service and to which at present so many of the otherwise unaccountable insulation failures are attributed.

Test Results

As induction regulator coils have been tested regularly for over four years some of the results of these tests will be of interest. During the first two years 5 per cent of all coils tested failed to stand the prescribed test but the weekly percentage of failure varied from 1 per cent to 30 per cent. During the past year the percentage failures varied from 0 to 2 per cent weekly with an average of 1 per cent. This great reduction in the number of coils that failed to stand the test was accomplished by correcting the cause of the trouble which can usually be determined by a thorough examination. However, if these coils had not been rejected on account of the high frequency test, all of the coils would otherwise have been used, as none of the coils had any defect that could have been discovered by any other method than high frequency testing.

A record of the complete windings that have been tested shows that out of 100 machines of a certain particular type there were no failures, but on other types there were as high as 10 per cent and an average of all the types of 1 per cent. It is not to be inferred that the faults detected by this test would all have resulted in service failures. The applied test has purposely been made severe in order to certainly weed out all weaknesses of this class.

There has been a distinct improvement in these machines from the service standpoint. Whereas, there was a considerable number of failures, before high-frequency testing was started on these coils, there has not been reported a single insulation breakdown in service of any machine on which high-frequency test had been applied to the coils or the winding.

High-Frequency Testing Meets A Great Need

High-frequency testing shows up poor workmanship, checks the insulation design and the processes of manufacture. It insures that proper and adequate insulating materials are in their proper place and not missing or damaged and that no harmful foreign materials are present. It checks up such features as the elimination of moisture and the thoroughness of impregnation, undue mechanical pressure at any point and the ability of the materials to stand the mechanical operations of coil construction, and whether the various materials are sufficiently uniform.

All of the above conditions may exist but they may not be detected or discovered without the aid of high frequency testing as they are hidden from view and visual inspection is useless.

One real merit of high-frequency testing is that it invariably shows the cause of the failure, as the arc is of only such intensity as to burn out the weak insulation without burning the copper. When a machine fails in service the opposite nearly always occurs, as the copper is usually so badly burned as to destroy all evidence of the cause of the insulation failure.

High-frequency testing has now reached a stage of development where it is used as a shop test on some classes of apparatus as a check on manufacturing processes. The author does not wish to convey the idea that a point has been reached where the method may be applied as a universal commercial test.

ULTRAVIOLET RADIATIONS

For years the scientists have attempted to make artificial sunlight and to apply it to achieve the marvels of nature; they have delved into the actual sunlight and determined its constituents; they have studied radio-activities in nature and have utilized electrical phenomena. As a result the world has a great variety of new light waves to apply. Of these the ultraviolet rays so frequently encountered from electric arcs have long been known. Much erroneous matter about the ultraviolet-ray effects has been published, but at the present time a truly astonishing list of useful applications exists.

Control of the reactions of many gases and of several chemical reactions has been achieved. In photochemical and photolytic reactions the ultraviolet ray has an important place. It is effective in halogenation reactions and in sterilization. A real field has been found in applications to biology and therapeutics, and it has come to have a very great commercial importance for industrial work in testing and bleaching.

The ultraviolet ray is applied to bring quick aging and testing of industrial materials; it detects the fastness of dyes and the quality of inks. It can be used to dry oils and leather and to determine the durability of coatings such as paints. In many bleaching operations the ultra-violet radiations are useful and they can be used to vulcanize rubber, to test the quality of paper, to waterproof paper and to detect impurities in food products.

In the field of mineral and metal fluorescent studies lie a large number of commercial possibilities, and even the cold light so eagerly sought may at last be found through the use of these radiations. Researches of many kinds are continuing, and in the near future it should be possible to reconcile and summarize a vast number of data on ultraviolet applications. It has been proved beyond doubt that this radiation from electric arcs, once considered only as an element deleterious to eyesight, is a very useful industrial and scientific tool.—*Electrical World.*

Rating of Heating Elements for Electric Furnaces
Test Data and Integration of Interference Between Resistors

BY A. D. KEENE[1] AND G. E. LUKE[1]
Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*A study of the practical considerations involved in assigning kilowatt ratings to radiant heating elements in furnace chambers. Constants for radiation and absorption are given. Consideration is given to shape and spacing of elements with respect to shielding due to adjacent elements. A method of determining the equivalent unshielded element is worked out to provide a basis for comparing dissimilar shapes of heaters.*

* * * * *

THE failure of an electric-furnace heating element is usually due to the chaotic methods used in establishing its ratings. Frequently heating elements are given arbitrary ratings, with no analysis of the conditions under which they are to operate. Some designers have developed rule-of-thumb methods of rating elements, based on current density, or on energy dissipated per unit area. Many of these methods are further elaborated to allow for increased ratings at low chamber temperatures. These methods must be used with considerable caution as they are almost invariably based on experience with only one type of heating element, used under restricted conditions. The determination of the general constants involved has been hampered by the cost of making scientific measurements at high temperatures. A general formula must provide for the following variables:

1. The physical characteristics of the heating surfaces.
2. The relative spacing and location of the component parts of the heating surfaces.
3. The allowable difference in temperature between the element surface and the surrounding atmosphere.

Data and mathematical analysis, made available within the last year, give these constants and make it possible to determine factors of safety of various shapes and arrangements of heating elements, and so make direct comparisons. This will permit the heating engineer to select his units with greater freedom and predict the temperatures at which they will operate. The calculation is analogous to the calculation of the mechanical engineer, who determines the unit stress on the extreme fiber of the beam he is loading with a fairly accurate knowledge of the stress at which it may be expected to fail.

A conductor supported in air, and carrying electric current will increase in temperature until the heat removed by conduction, convection, and radiation, equals the heat generated within the conductor by the passage of the current. This is true whether the conductor is inclosed in a furnace chamber to act as a source of heat, or is a part of a transmission line where heat is an undesirable by-product. The relative amounts of heat removed by the three different means of transmission change rapidly with the operating temperature of the conductor.

The convection loss from a surface increases as the $1\frac{1}{4}$ power of the difference in temperature between the surface and the surrounding room, while the radiation loss increases as the fourth power. At a surface temperature of 1000 deg. cent. (1832 deg. fahr.), the loss from a conductor in free air is roughly 90 per cent by radiation and 10 per cent by convection. (Conduction through air is so small as to be negligible and will be disregarded throughout the remainder of this article.) At this temperature, it is evident that an air space is a very inefficient heat insulator, since 90 per cent of the energy travels freely and almost without loss between the enclosing surfaces.

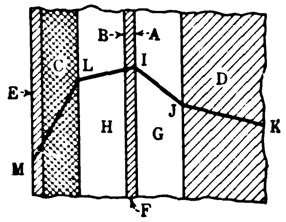

FIG. 1

The simplest heating element might be a sheet of resistance material covering an area of furnace wall and parallel to the wall, the arrangement being as indicated in Fig. 1, F is the plate in which heat is generated with surface A toward, and parallel to the charge D which is to be heated, and surface B toward, and parallel to wall C which is a partial heat insulator. We will consider F, a large thin plate so the losses from the edges may be eliminated as negligible. Heat generated in the plate is conducted to the surfaces A and B. We will assume that wall C is of such material and thickness that 20 per cent of the heat generated in the plate escapes to the outside. Surface B can then dispose of only 20 per cent of the energy, generated so surface A must attain such a temperature as to dispose of the remaining 80 per cent of the energy. Surfaces A and B are opposite sides of a thin plate and so are at approximately the same temperature. When a state of equilib-

1. Both of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

rium of heat-flow is reached, the temperature-gradients will be approximately as represented by lines I–J–K and I–L–M, the temperature at the surface of the wall L will be considerably higher than the temperature J at the surface of the charge because the difference in temperature between I and J is forcing four times as much heat across the space G as the difference in temperature between I and L is forcing across the space H.

It is particularly noticeable in this example that all surfaces of an element are not equally effective in disposing of the generated heat. If we consider surface A as 100 per cent effective, we can then consider the surface B only 25 per cent effective because under operating conditions it disposes of only one-fourth as much of the generated heat. The surfaces of plate F as located are then only 62.5 per cent as effective in disposing of heat as they would be if charge D were disposed on both sides of plate F. The factor 62.5 per cent (in this case) may be called the "surface efficiency" since it is the factor by which the total surface area of the resistor must be multiplied to obtain the area of an equivalent resistor whose surface is 100 per cent effective.

Theory and Experimental Data

(*a*) *Single Linear Heater.* Due to the relatively poor thermal conductivity of the supporting refractories, and to the small area of contact, very little heat is conducted away from the heater elements. Hence radiation and convection are the principal agents in the transfer of heat from the elements. The fundamental equation, expressing the rate of heat dissipated by radiation and convection from surfaces, is:

$$W = a(T_2 - T_0)^{1.25} + 36.9\,e\left[\left\{\frac{T_2}{1000}\right\}^4 - \left\{\frac{T_1}{1000}\right\}^4\right]$$

Where

- W = Watts dissipated per sq. in. of surface
- T_2 = Absolute temperature deg. cent. of heater surface
- T_0 = Absolute temperature deg. cent. of room or furnace air
- T_1 = Absolute temperature deg. cent. of surrounding surfaces
- a = Convection constant
- e = Coefficient of emissivity (1.00 for a black body)

In the above equation, the convection loss is shown as proportional to the 5/4th power of the temperature rise of the heater above the ambient air. The radiation loss, however, increases at a much greater rate, since it is a function of the fourth power of the absolute temperatures. The constants (a) and (e) vary slightly with the temperatures; however, the variation is so small that it can be neglected for practical purposes. The values of these constants were determined from experimental tests. The single linear heater element was suspended in free air. The input was measured electrically and the final temperatures were determined by the use of thermo couples. An optical pyrometer was also used to check the heater temperatures. The thermo couples were 0.008-in. diameter platinum and platinum-rhodium spot welded to the conductor.

From the large number of tests made, average values of the constants were obtained as follows:

Heater Element	Constant (a)	Constant (e)
¼-in. diameter nickel chromium...........	0.0032	0.91
¾-in. wide strip nickel chromium..........	0.0013	0.90

Using these constants in the equation previously given, the curves shown, Fig. 2, were plotted. Experimental tests on this curve covered the range of 100 to 1100 deg. cent. The elements were tested both vertically and horizontally and very little difference was found, especially at commercial temperatures where most of the heat is transmitted by radiation.

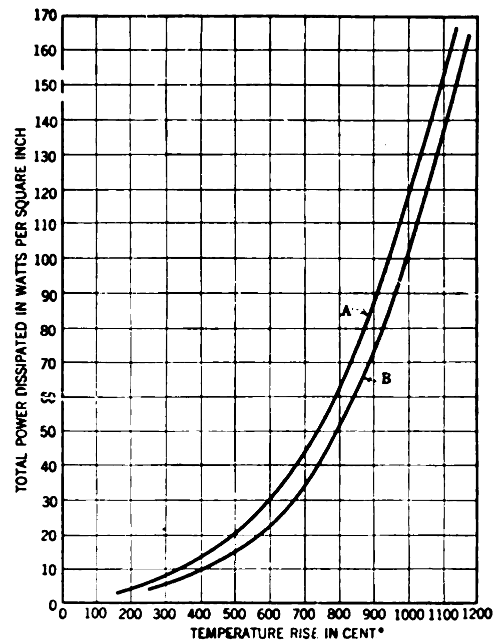

Fig. 2

A = ¼-inch rod
B = 1⅕-inch wide strip
Ambient temperature 27 deg. cent.

(*b*) *Parallel Heater Elements—Single Row.* In a commercial furnace, the heater consists of a large number of parallel ribbons or rods. It is evident that the rating of such elements will not be as great as a single element, due to interference of the adjacent elements. For such parallel heater elements arranged in a row, the relative heat loss can be calculated on the basis of the angle subtended by the opposite interfering resistor. Thus, in Fig. 3 is shown a row of parallel strip resistors. The approximate radiation from any small element ($d\,x$) will be proportional to the ratio of (180 deg. $- \alpha$) per 180 deg. An integration of these elements, either mathematically or graphically, over the total surface will give the effective radiation. Results

of such calculations are given in Figs. 5 and 6 for round rods and strips respectively. The curves are plotted in terms of ratios in order to be applicable to any particular arrangement and size of heating element. While these curves as calculated refer only to radiated energy, tests show that they also represent very closely the effectiveness of the surface for both radiation and convection. The reason for this primarily is due to the relatively small amount of heat lost by convection —although it is a fact that by the grouping of the elements the convection and radiation losses are reduced to about the same degree. These curves were experimentally checked throughout the range shown, both round rods and strips being used. In making these tests, three equally spaced parallel elements were used. Thermo couples were placed on all three. Means were provided for independently varying the current through the middle heater and the two outside heaters. In this way the current was adjusted so as to give equal temperatures for all three heaters. The loss from the middle conductor was measured.

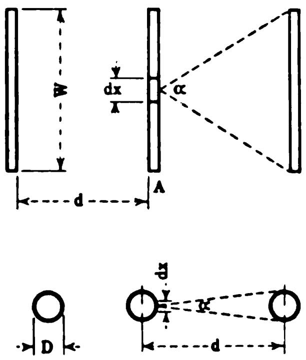

FIG. 3

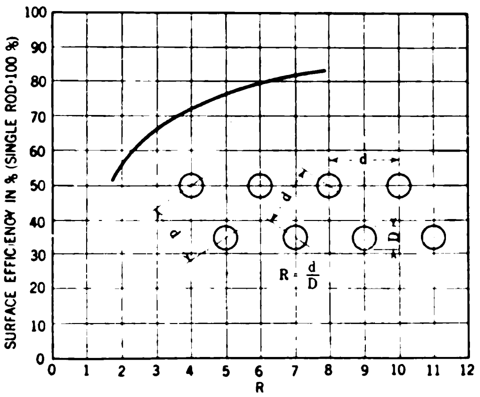

FIG. 4—CURVE OF SURFACE EFFICIENCY FOR DOUBLE BANKED RODS

(c) *Parallel Heater Elements—Double Row.* In some furnaces it is desirable to double bank the heating elements. The two rows of elements will interfere to some extent so that the rating will be reduced. The "surface efficiency" of a double bank resistor composed of round parallel rods arranged equidistant from each other, was calculated in the same manner as the single bank. The calculated curve is shown in Fig. 4.

The curves Figs. 4, 5, and 6 show values of surface efficiencies plotted against the ratios of spacings to widths and diameters respectively. The curves are not directly comparable as the abscissas are not expressed as ratios of similar dimensions.

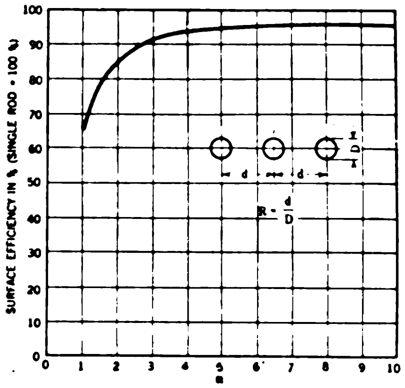

FIG. 5—CURVE OF SURFACE EFFICIENCIES FOR RODS

It is interesting to analyze commercial heating elements on the basis of the above data.

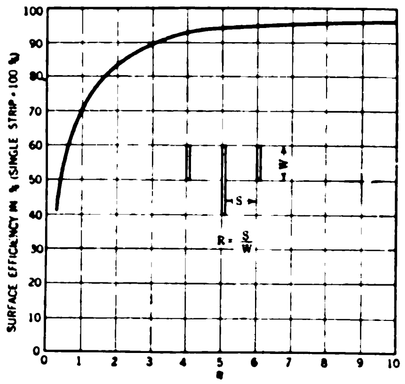

FIG. 6—CURVE OF SURFACE EFFICIENCIES FOR STRIPS

Let us assume the following conditions:

1½ in. wide strip 1/10 in. thick spaced, 1½-in. centers arranged as in Fig. 3, 0.289 in. diameter rod 1-in. centers arranged in two layers, (double banked) as shown in Fig. 7, and 0.289-in. rod ¾-in. centers single layer (single banked) also shown in Fig. 3. In each case power, equivalent to 15 watts per square inch of radiating surface, is generated in the element. The furnace chamber temperature is fixed at 900 deg. cent. (1652 deg. fahr.). Room temperature 27 deg. cent.

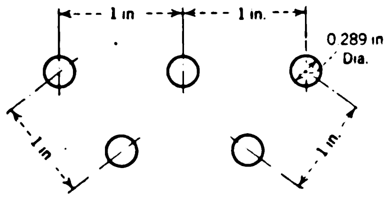

FIG. 7—ARRANGEMENT OF FURNACE HEATING ELEMENT RODS

We will assume that the resistor enters the danger zone, in which oxidation becomes progressive and, therefore, destructive at 1100 deg. cent. (2012 deg. fahr.).

For the Case of the Double-Banked Rod

d = 1-in.
D = 0.289
R = 03.46

The surface efficiency from Fig. 4 is then 70 per cent.

Then 15 watts per sq. in. is equivalent to 15 ÷ 0.70 = 21.43 watts per sq. in. dissipation.

To use the curves in Fig. 2 at furnace chamber temperatures, we must transpose from 27 deg. cent. ambient temperature to 900 deg. cent. ambient temperature as follows:

900 deg. − 27 deg. = 873 deg. which corresponds to 78 watts on the Curve A for rods (Fig. 2).

Then 78 + 21.43 (the equivalent dissipation determined above) = 99.43 watts which corresponds to a temperature rise of 950 deg. cent. (Curve A, Fig. 2). The operating temperature of the rod is then 950 deg. cent. + 27 deg. cent. = 977 deg. cent.

If 1100 deg. cent. marks the entrance to the danger zone, a 12.6 per cent rise in temperature will be required to bring the temperature of this heating element up to a dangerous value. This 12.6 per cent may then be considered as the factor of safety.

In the Case of the 1½ in. Ribbon

W = 1½
S = 1½ − 1/10 = 1 4/10
R = 0.933

Surface efficiency = 69 per cent from Fig. 6.

Then the dissipation equivalent to 15 watts per sq. in. = 15 ÷ 0.69 = 21.74 watts per sq. in.

900 deg. cent. minus 27 = 873 deg. cent. which corresponds to 65 watts dissipation on Curve B, Fig. 2.

65 watts + 21.74 = 86.74 watts per sq. in. This is equivalent to a 960 deg. cent rise. The operating temperature is then 960 deg. cent. + 27 deg. cent. = 987 deg. cent.

This gives a factor of safety as above of 11½ per cent.

For the Single Banked Rod

d = 0.75
D = 0.289
R = 2.6

From Fig. 5 the surface efficiency is 89.5. Then the dissipation equivalent to 15 watts per sq. in. is 15 ÷ 89.5 = 16.65.

900 − 27 deg. cent. = 873 deg. cent. which corresponds to 78 watts on Curve A, Fig. 2. Then 78 + 16.65 = 94.65 watts per sq. in. which corresponds to a temperature rise of 930 deg. cent. The operating temperature of the rod is then 930 deg. + 27 deg. = 957 deg. cent. This gives a factor of safety of 14.94 per cent.

It should be noted that these factors apply only to the physical conditions specified. A narrower ribbon or smaller rod would have a higher factor of safety for this spacing. A wider strip would have a considerably lower factor of safety as we are working on the steep part of the surface efficiency curve, Fig. 6.

We may also make an analysis of the cost of metal required to generate one kilowatt of heat energy in a furnace chamber. Let us assume the same conditions of physical size and spacing as were used in the preceding illustration, the operating temperature of the resistor 1000 deg. cent. and the furnace chamber temperature 900 deg. cent.

Considering the Double Banked Rod

The dissipation of energy at 100 per cent surface efficiency on a rod at 1000 deg. cent. is 106 watts per sq. in. (from Curve A, Fig. 2). The dissipation at 900 deg. cent. (chamber temperature) = 79 watts per sq. in. correcting for 27 deg. ambient temperature in each case.

The difference is 27 watts per sq. in. or the permissible dissipation from a rod having 100 per cent "surface efficiency."

The double banked rod as before is 70 per cent efficient so the actual watts permissible dissipation is 70 per cent of 27 = 18.9 watts per sq. in.

To dissipate 1000 watts will require 1000 ÷ 18.9 = 52.91 sq. in. of rod surface.

The area of one foot of .289 in diameter rod is 10.9 sq. in.

52.91 ÷ 10.9 = 4.854 linear feet of rod required weighing 0.239 lb per foot = 1.16 lb.

At a list price of $4.05 per pound this is $4.80 for the cost of double banked rod to dissipate one kilowatt.

For the Strip

The watts per sq. in. dissipation at 100 per cent surface efficiency on a strip at 1000 deg. cent = 92 from Curve B, Fig. 2.

At 900 deg. cent. = 65 (correct for 27 deg. ambient temperature).

The difference is 27 watts per sq. in. permissible dissipation from a strip having 100 per cent "surface efficiency."

The strip as before is 69 per cent efficient so the actual watts permissible is 69 per cent of 27 = 18.6 watts per sq. in. and to dissipate 1000 watts will require

1000 ÷ 18.6 = 53.8 sq. in.

The area of one linear foot of strip is 38.4 sq. in.

53.8 ÷ 38.4 = 1.4 linear feet of strip weighing 0.81 lbs. per foot = 0.782 lbs. at $5.10 per pound = $3.99 for the cost of strip to dissipate one kilowatt.

In the Case of the Single Banked Rod

The dissipation from a 100 per cent surface efficiency rod as in the case of the double banked rod is 27 watts per sq. in.

The efficiency as in the earlier single banked rod example is 89.5 per cent so the actual watts permissible is 89.5 per cent of 27 = 24.16.

To dissipate 1000 watts will require 1000 ÷ 24.16 = 41.35 sq. in. of heater area.

The area of a linear foot of 0.289 inch diameter rod is 10.9 sq. in.

41.35 ÷ 10.9 = 3.793 feet of rod at 0.239 pounds per foot this weighs 0.9065 lb. at $4.05 per pound = 0$3.67 for the cost of single banked rod to radiate one kilowatt.

In computing the above costs prices have been listed for nickel chromium as quoted by a well-known manufacturer. As in the case of efficiencies, other physical dimensions will materially change the results. The dimensions used are those of heating elements in common use.

For convenience, the results of the above problems are tabulated below:

Shape of element	Arrangement of element	Factor of safety at 15 watts per sq. in. dissipation	Cost of metal per Kw. radiated at constant factor of safety
Strip 1½ in. wide	Single banked Fig. 3	11½ per cent	$3.99
Rod 0.289 in. dia.	Single banked Fig. 3	14.94 per cent	$3.67
Rod 0.289 in. dia.	Double banked Fig. 7	12 6 per cent	$4.80

The above problems serve to illustrate several important points in design.

1. A resistor element of any shape may be supported in a furnace and so rated as to give a suitable factor of safety and reasonable service.

2. The shape of the element does not inherently insure a lower first cost of material. (Low cost frequently sacrifices a part of the factor of safety).

3. The selection of the elements for any furnace is an engineering problem requiring proper analysis. It should be approached with the idea of applying a suitable heating equipment, not with the idea of adopting some specific type of element to the installation.

In the foregoing calculations, we have disregarded the effect of adjacent walls. This should not introduce a serious error where the element itself is not so located as to act as a screen preventing reradiation and reflection of heat energy from the wall. The wall would perhaps have considerable effect on convection currents, but convection plays a relatively small part in the dissipation of heat at these temperatures.

Heat radiated to the wall is either reflected or is absorbed by the wall. That absorbed is conducted away from the surface or re-radiated into the furnace chamber. For the relative values of these various heat transfers, we must again refer to test data available. Fire brick at a temperature of 1000 deg. cent. reflects 40 per cent of the radiant heat falling on its surface and absorbs the other 60 per cent. If 50 per cent of the heat generated finds its way to the wall surfaces as radiant energy, then 20 per cent of the heat generated in the furnace is reflected from the walls much as light is reflected from a mirror. Thirty per cent is absorbed by the walls. If one-half of this heat absorbed is conducted to the external surface and lost, the remainder, 15 per cent of the heat generated in the heating elements, is re-radiated from the walls into the furnace chamber.

Thus, it can be seen that with the above data, the furnace engineer can calculate with reasonable accuracy the temperatures attained by resistor elements in service and can determine the factors of safety. He can also anticipate the manner in which heat will be transmitted to the charge. These calculations are of utmost importance to the furnace buyer. The fact that the conditions in a projected furnace can be determined by competent engineers, much as the loading of a bridge is determined, is insurance against loss through furnace failure.

A REAL CONTRIBUTION TO KNOWLEDGE OF STABILITY

System stability has been a debatable subject for several years. The advocates of transient stability and those of static stability have argued for their respective criteria for system performance in many papers and meetings. Data on an actual system, however, have been unavailable until lately, and the discussions have waxed warm on the basis of the relative importance different specialists attached to assumed factors.

It is encouraging to find that executives of the Pacific Gas & Electric Company consented to submit the system of that company to a series of stability tests for the benefit of the whole industry. In his paper before the meeting of the American Institute of Electrical Engineers this week Roy Wilkins gave the results of the tests and made available to all properties many valuable data. The executives and engineers of the Pacific Gas & Electric Company have thus contributed greatly to the development of the art, and it is to be hoped that tests by other utilities covering data needed to develop other phases of the art will likewise be published for the benefit of the industry instead of being merely placed on file on dusty shelves.

The normal limit, or even rating, of a power system is difficult to define because of the ever-changing electrical and physical conditions in lines, equipments and loads. For a specific system, however, both the static and transient stability limits can be agreed upon and determined quite accurately for given conditions. Thus progress has been made. Debates on technicalities and attempts to generalize about stability should not be permitted to obscure this fact.—*Electrical World.*

Operating Performance of a Petersen Earth Coil-II

BY J. M. OLIVER[1] AND W. W. EBERHARDT[1]

Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*At the A. I. E. E. Spring Convention, Pittsburg, April 24-26, 1923, a paper was presented by the authors on the operation of a Petersen Earth Coil installed by the Alabama Power Company on its Lock 12-Vida 44,000-volt system. That paper reported an excellent performance record for the coil, although several unaccounted for bus insulator flashovers occurred at Lock 12, indicating that further investigations on the action of the coil were necessary.*

This paper presents eleven months' additional operating experience with the Earth Coil, which shows that over-voltage disturbances can be eliminated by doing all line switching operations with the Petersen Coil out of service; that is, with the system neutral solidly grounded. It is believed that the same results can also be obtained by under-tuning the coil.

The Lock 12 Coil is no longer in service, as the system has outgrown the need of such equipment; additional power sources have been added to the system and reliable service can be maintained without the use of flashover suppressing devices.

It appears that the application of Petersen Earth Coils is limited to comparatively low voltage lines (66,000 volts and less) of moderate length with a single source of power supply. In such an application, the use of a Petersen Coil between system neutral and ground has the advantage over grounded neutral operation by reducing line outages due to flashovers and over isolated neutral operation by eliminating arcing grounds.

* * * * *

The purpose of this paper is to present eleven months' additional operating experience with the Alabama Power Company's Petersen earth coil installed on its Lock 12-Vida 44,000-volt system, shown in Fig. 1. A detailed description of this installation is given in the writers' earlier paper[2] presented at the A. I. E. E. Spring Convention, Pittsburgh, April 24-26, 1923. A complete operating log of the Lock 12 coil for the period extending from October 12, 1921 to March 1, 1923 was also given in that paper, which showed an excellent performance for the coil, the number and duration of interruptions due to lightning flashovers having been reduced by 83.5 and 94 per cent respectively, by its use. There were, however, several unaccounted for bus insulator flashovers at Lock 12, which indicated that further investigations on the action of the coil were necessary.

The bus insulator flashovers in question occurred when the line switch at Lock 12 opened automatically or was opened by hand while the Petersen coil was in service. It was the consensus of opinion of those who discussed the Pittsburgh paper that the high-voltage flashovers were caused by the non-simultaneous opening of the three poles of the line breaker. This is a very plausible explanation of the trouble because at that time the coil was overtuned,—that is, it had excess reactance—and the disconnection of one line conductor ahead of the other two would change the line capacitance in the right direction to produce a condition of resonance in the series circuit, in which case there would be nothing to limit the rise of voltage except the system losses. Assuming that this is the correct explanation for the high-voltage disturbances, there are two remedies which can be applied; namely (a) to undertune the coil, and (b) to electrically interlock the control circuit of the grounding switch with the overload protective relay scheme on the line switch so that the grounding switch is always automatically closed before the line switch opens to clear phase-to-phase short circuits.

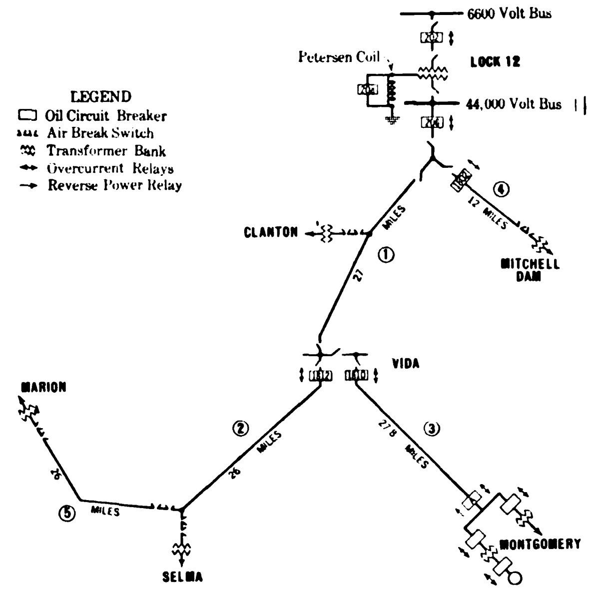

Fig. 1—Lock 12—Vida 44, 00-Volt System

Of these two methods, (a), if successful, would prove the more advantageous since no change in the normal control connections is required. Method (b) has the disadvantage of introducing complications in the control scheme and also slows up the relay operations on phase-to-phase short circuits, since additional timing must be allowed for the closing of the ground switch. Method (b), however, had already been applied and was in operation when the theory of undertuning was advanced so it was decided to continue operation with the interlocking feature between the ground and line

1. Both of the Alabama Power Co., Birmingham, Ala.
2. A. I. E. E. Transactions, 1923, page 435-45.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

switches during the 1923 lightning season, and then perhaps operate the coil under-tuned during the 1924 season. Unfortunately, the coil had to be taken out of service before the 1924 lightning season for reasons stated in the latter portion of this paper, and the under-tuning principle of operation thus far has not been given a trial.

Operation with Interlock Between Line and Ground Switches

Fig. 2 is a connection diagram of the complete control equipment on the Lock 12 Petersen coil, the interlocking of the grounding switch control circuit with the

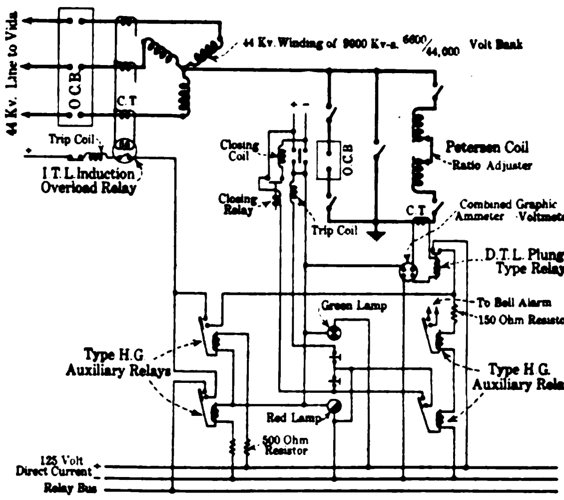

Fig. 2—Lock 12—Petersen Coil Installation—Schematic Diagram of Connections

protective relay scheme on the line switch being accomplished by the use of the two type *H G* auxiliary relays shown in the lower left hand corner of the diagram. Operators were also given instructions to always close the neutral grounding switch; that is, to take the Petersen coil out of service before doing any line switching. The Lock 12 coil operated under this new operating procedure from February 24, 1923 to January 26, 1924, during which time no further high-voltage disturbances were experienced, indicating that a satisfactory solution to the problem had been found.

A complete log of all the operations was taken during the period mentioned and summary of these operations is given in Table I which shows the following results:

Flashovers. There was a total of 109 insulator flashover indications recorded on the combined graphic ammeter and voltmeter, 94 of which, or 86 per cent, did not result in line interruptions and are considered perfect operations of the Petersen coil.

On the remaining fifteen flashover indications the line switch opened causing an interruption to service. In each case, however, the line was promptly put back into service, O. K., indicating that the trouble was not a solid ground, but rather a flashover which the Petersen coil failed to clear. These operations are therefore considered faulty.

Solid Grounds and Phase-to-Phase Short Circuits. There was a total of five solid grounds and 21 phase-to-phase short circuits, due to line and transformer troubles. These cases of trouble were outside of the operating sphere of the Petersen coil, but in each case the line overload relays functioned properly and promptly to clear the disturbance.

Interruptions to Lock 12-Vida Line Due to all Causes. Table II is a classification of service interruptions to the Lock 12-Vida line from March 1, 1923 to January 26, 1924, exclusive of prearranged interruptions and those due to trouble on other parts of the Alabama Power Company's system. This tabulation shows that there was a total of 40 interruptions to service with a total outage of 221 minutes for this eleven months' period, which is a far better service record than was obtained for any previous period of similar duration.

TABLE I

SUMMARY OF PETERSEN COIL OPERATIONS.[1]

Month	Flashover Indications				Transformer Trouble		Line Trouble	
1923	Under 6 Amperes	Over 6 Amperes	Faulty Operation of Coil Line Switch Opened	Switch 208 Closed but no Interruption	Phase-to-ground	Phase-to Phase	Phase-to-Ground	Phase-to-Phase
March	—	2	1	-	1	-	-	-
April	—	2	2	—	-	1	-	2
May	4	5	3	6	-	-	1	5
June	—	4	—	—	-	1	-	3
July	—	4	—	—	-	-	2	3
August	15	22	7	—	-	-	-	5
Sept	2	9	1	4	-	-	-	1
Oct	—	4	—	4	-	-	-	-
Nov	—	—	1	1	-	-	-	-
Dec	2	2	—	—	-	-	-	-
1924								
Jan.	—	1	—	1	-	-	1	-
Total	23	55	15	16	1	2	4	19

Total number of operations...........135

1. Copies of the complete log from which this Summary was compiled may be obtained from the authors on request.

This service record is especially remarkable for a long radial feeder when it is taken into consideration that 144 minutes of the total time out were due to a single case of trouble when a tree fell into the line.

Since the function of the Petersen coil is to reduce the interruptions due to lightning, a comparison of service interruptions to the Lock 12-Vida line chargeable to lightning for the years 1922, 1923 and 1924 proves very interesting as the following tabulation will show:

TABLE II

INTERRUPTIONS ON LOCK 12-VIDA 44-KV. SYSTEM MARCH 1, 1923 TO JAN. 26, 1924.
(Exclusive of Interruptions due to Trouble on Other Parts of Alabama Power Cmpany's System.)

Month	Lightning		Trees Falling Into Line		Insulator on Lightning Arrester		Transformer		Unknown		Total	
	No. of Cases	Time Out Min.	No. of Cases	Time Out Min.	No. of Cases	Time Out Min.	No. of Cases	Time Out Min.	No. of Cases	Time Out Min.	No. of Cases	Time Out Min.
1923												
March	1	2	–	–	–	–	1	2	–	–	2	4
April	3	5	1	6	–	–	1	2	–	–	5	13
May	1	2	–	–	1	2	–	–	7	11	9	15
June	2	4	1	2	–	–	1	2	–	–	4	8
July	2	3	1	2	–	–	–	–	2	3	5	8
Aug.	11	23	–	–	–	–	–	–	1	2	12	25
Sept.	2	2	–	–	–	–	–	–	–	–	2	2
Oct.	–	–	–	–	–	–	–	–	–	–	–	–
Nov.	–	–	–	–	–	–	–	–	1	2	1	2
Dec.	–	–	–	–	–	–	–	–	–	–	–	–
1924												
Jan.	–	–	1	144	–	–	–	–	–	–	1	144
Total	22	41	4	154	1	2	3	6	11	18	41	221

Year	Method of Operation	Number of Lightning Storms Over Line	Interruptions due to Lightning	
			Number	Total Time Out
1922	System neutral solidly grounded	82	43	230 minutes
1923	Neutral grounded through Petersen Coil	97	7	14 minutes
1924	Ditto	80	22	41 minutes

This tabulation shows that although approximately the same number of lightning storms have occurred in the vicinity of Lock 12 each year, the interruptions due to lightning were greatly reduced while the Petersen coil was in service, proving its effectiveness in suppressing flashovers.

LIMITATIONS IN USE OF THE LOCK 12 COIL

The Lock 12 coil was taken out of service and the system neutral solidly grounded January 26, 1924, because

(a) At that time the line mileage of the Lock 12-Vida system was practically doubled by the addition of new lines, making the total line charging current greater than the Petersen coil was designed for and to take care of which would have required new taps on the coil, and

(b) A generating station was added at Upper Tallassee which was connected to the system through a delta-star transformer bank with a solidly grounded neutral on the 44,000-volt winding.

Of course, a second Petersen coil could have been introduced between the Upper Tallassee neutral and ground since on a Petersen coil system a reactor must be installed at each grounding point; but with two sources of power supply to Lock 12-Vida system, it was felt that reliable service could be maintained at Montgomery without the use of Petersen coils and their expense was, therefore, not justified. It was also foreseen

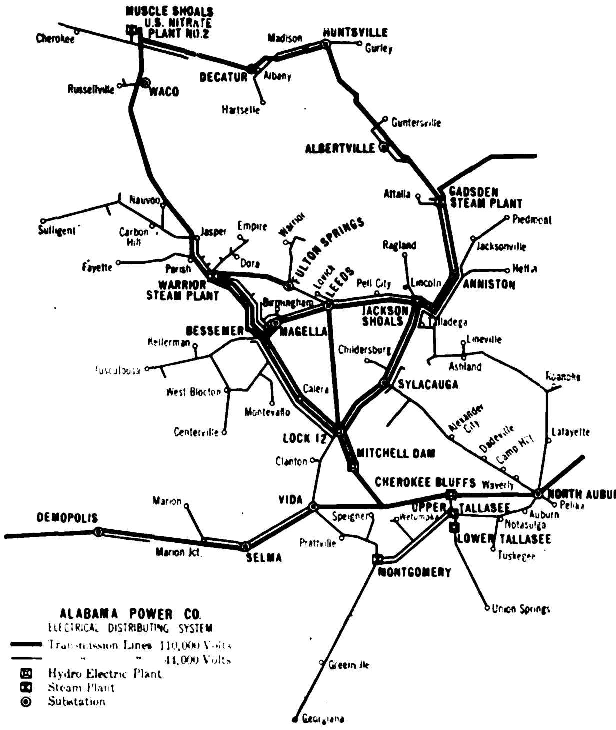

FIG. 3

that the Lock 12-Vida system would be further extended and linked with the Alabama Power Company's main 44,000-volt network, which is solidly grounded at Warrior, Bessemer, Leeds, Jackson Shoals and Anniston substations. This interconnection was completed in the

latter part of 1924 and the 44,000-volt system network now exists, as shown in Fig. 3.

CONCLUSIONS

The Alabama Power Company's experience with the Petersen earth coil indicates that it will greatly reduce the number of interruptions due to insulator flashovers during lightning storms.

All high-voltage disturbances which were experienced when the coil was first placed in service have been entirely eliminated by making provisions to do all line switching, both hand and automatic, with the coil out of service—that is, with the system neutral solidly grounded.

The application of Petersen coils appears to be limited to comparatively low-voltage lines (of 66,000 volts and less) of moderate length, with a single source of power supply. On an interconnected network, such as the Alabama Power Company now operates, several sources of supply are maintained to all principle load centers and good service can be carried on without the use of flashover suppressing devices. In other words the expense and complications of a Petersen coil installation are justified only on radial feeder systems where it is desired to improve service to an important load center which is connected to the power source by only a single line. The Petersen coil in such an application has the advantage over grounded neutral operation by reducing line outages due to flashovers and over isolated neutral operation by eliminating arcing grounds.

LAKE MERRIT HAS SPECIAL LIGHTING

Equipping streets and exteriors of public buildings with special electric lighting is now quite common, but doing this to a lake is a different story. In fact, Lake Merritt, Oakland, Cal., is probably the only one of its kind which has such electric lighting.

Around the shore of the lake there are now special electric lamp posts from each of which hang Gothic lanterns provided with amber glass. Each of the lanterns has a reflector so adjusted that a large portion of the lantern light will fall on the surface of Lake Merritt. In addition to these, electric floodlight units have been placed around the lake to illuminate clumps of shrubbery and groups of trees and also between the lamp posts, concrete sockets have been put in place so that for special celebrations poles carrying festoons of streamer lights may readily be put in place.

All of this electric lighting is controlled from a single central switch house where there is equipment which makes it possible to dim the light of the various lamps to such an extent that the filament of each is only a dull red. Then within a minute by turning the gears these lamps are once more producing their full candlepower of light. With all this lighting Lake Merritt on ordinary nights is a sight worth seeing and when dressed up for special occasions it is a veritable fairyland that attracts people from far and wide.

THE COMPARISON OF NATURAL AND ARTIFICIAL LIGHTING

In connection with the efforts that are now being made to trace the relation between better lighting and higher efficiency of work, it is natural that experimenters should try to base their conclusions on the results achieved by daylight.

The greater part of the work of the world is still done by natural light, and a comparison between natural and artificial lighting conditions affords much interesting information. It is doubtful, however, whether all investigators realize the complexity of the factors involved in such a comparison. The illumination available by the best daylight conditions is far greater than is usually furnished by artifiical means. On the other hand, daylight is a highly variable quantity. Photometric measurements show that remarkable changes may occur even during a relatively short working period. In making comparisons, the experimenter is usually driven to adopt as a measure the *average* daylight illumination during the working period. But it is questionable whether an average between illuminations varying, perhaps, in a ratio of 10 to 1 can be regarded as a measure of the effective daylight illumination. The eye is inevitably affected by these changes, and it would seem better, in making comparisons, to devise some method (*e. g.*, by adjustment of blinds) by which the actual daylight illumination can be kept practically constant during the test period.

Again, the *nature* of daylight illumination, as well as the intensity, may be quite different from artificial light. The presence of the bright sky overhead out of doors causes corresponding adaptation of the eye, and leads it to demand illuminations much higher than might otherwise be required. Even in a room the presence of a window near at hand, through which the sky can be seen, has a similar effect.

Taking all these facts into consideration, it is not surprising that quite different answers are often received to the simple question: "Does one require more or less illumination by natural light than by artificial light?" The whole subject is one that deserves careful investigation, and would furnish material for an interesting discussion. Meantime there is one obvious lesson—investigators who attempt to make comparisons between artificial and natural lighting should be careful to specify as exactly as possible the daylight conditions in the room in which the comparison is made. Daylight illumination is not under our control, but an increase in artificial lighting involves corresponding increased cost. If standards recommended to consumers are unnecessarily high, a reaction towards economy and a set-back to future progress may occur. Supply undertakings could, however, materially smooth the path towards higher illuminations by closer co-operation and reduced rates.—*The Illuminating Engineer.* (London).

Mechanical Force Between Electric Circuits

BY R. E. DOHERTY[1] and R. H. PARK

Associate, A. I. E. E. — Non-member

Synopsis.—A general equation is developed for the mechanical force exerted by a system of n electric circuits, upon any part of that system. The electric circuits are assumed to contain resistances, and the reluctance of the several magnetic circuits is assumed to be a function of both the currents and the relative positions of the circuits. The equation is therefore applicable to circuits involving saturated iron.

Special cases of a single circuit and of n circuits are treated, in which a method of graphical solution is given. Also an approximation is made, which results in fairly simple analytical expressions for the force in the case of circuits involving saturated iron.

The results are preliminary to an investigation of the forces existing in synchronous machines under the condition of short circuit, which subject will be treated in a forthcoming paper.

I—Discussion of Problem and Method of Solution

ALTHOUGH methods have been available for calculating the force of an electromagnet, or between simple circuits of constant inductance, such as reactance coils containing no iron, nevertheless general methods have not, to the authors' knowledge, been developed for calculating the force exerted between dissimilar circuits which contain iron and which therefore have magnetic reluctances that may vary both with the magnetic density and the relative position of the circuits. It is the purpose of the present paper to offer methods for these cases. The work presented here, as well as that in a forthcoming paper in the near future, is largely the result of an investigation made by one of the authors in 1922 on the mechanical forces in synchronous machines under short circuit conditions.

Historical

The basic contributions regarding the mechanical force exerted by electro-magnetic circuits were, of course, made by Ampere[2], Kelvin and Maxwell[3]; and the greater part of the subsequent development of the subject has been the application of their fundamental equations to particular cases.

Maxwell's equation for the "mechanical action between two circuits" is, in different notation,

$$f_x = \frac{1}{2} I_1^2 \frac{d L_1}{d x} + I_1 I_2 \frac{d M}{d x} + \frac{1}{2} I_2^2 \frac{d L_2}{d x} \tag{56}$$

where I_1 and I_2, L_1 and L_2 are the respective currents and inductance coefficients of the two circuits; M, the mutual inductance; f_x, the component of force in the direction of x, "one of the geometrical variables on which the form and relative position depend."

Quoting Maxwell, "If the motion of the system corresponding to the variation of x is such that each circuit moves as a rigid body, L_1 and L_2 will be independent of x and the equation will be reduced to the form,"

$$f_x = I_1 I_2 \frac{d M}{d x} \tag{57}$$

Although it is clear from the above statement and his original assumptions, that the electrical circuits are not considered to be in proximity to iron or other magnetic material, nevertheless the equation holds, as will appear later, for circuits which do enclose, or are near, iron provided there is no saturation.

If there is a single circuit only, such as an electromagnet, all terms of (1) drop out except the first, thus reducing to the well-known expression,

$$f_x = \frac{1}{2} I^2 \frac{d L}{d x} \tag{58}$$

Thus for any circuit or pair of circuits in which the inductances are functions of shape or position only, Maxwell's equation applies.

Now there is another classical method of analysis according to which the force is obtained by integrating over the circuit member in question, the force on each current element, due to the magnetic density in which the element exists. In some cases this is more convenient to apply than the foregoing equations. It depends, of course, upon the nature of the problem. An excellent example of the application of the latter method is Dwight's[4] work regarding the electromagnetic force on switches.

Other authors, as listed in the bibliography, have also treated special cases, and in one or two of these, where saturation is considered, an additional step of fundamental nature has been taken. In 1911, Steinmetz[5] treated the special cases of electromagnets and transformers in accordance with existing theory, but in addition, considered the case of a single-circuit electromagnet containing iron and involving saturation. While his results were not carried further than the detailed expression of the *energy* relations which obtain during a change in position[6], this nevertheless consti-

1. Consulting Engineer, General Electric Co., Schenectady, N. Y.

2. Clerk Maxwell, Electricity and Magnetism, Vol. II, Arts. 502 to 528.

3. Clerk Maxwell, Electricity and Magnetism, Vol. II, Art. 583.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies containing apendixes here omitted, available upon application.

4. H. B. Dwight, "Magnetic Force on Disconnecting Switches," Trans. A. I. E. E., 1290, Vol. 39, Part II, pp. 1337-1355.

5. Mechanical Forces in Magnetic Fields, Trans. A. I. E. E., 1911, Vol. 30, pp. 357-413.

6. This case is reviewed by Rudolph Richter in his *Elektrische Maschinen*, in which the equations are interpreted graphically.

tuted the initial step toward the derivation of a general equation for *force* of a single circuit.

Scope of Paper

Thus, the development to the present appears to include the solution of the cases of one and two circuits involving inductances which are not functions of the current, and of the case of a single circuit involving saturation, to the extent of the mathematical expressions for the various terms in the energy equation. It is the purpose here to give the general equation for a system of n circuits which may contain iron, either saturated or not, but assumed to have no hysteresis,

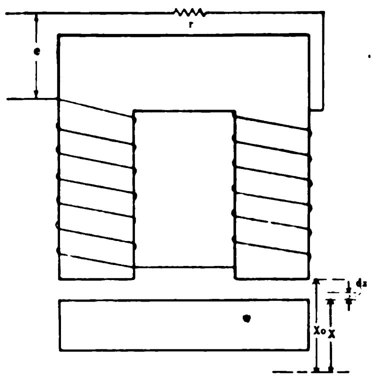

Fig. 1

and thus having inductances which are functions of both position and current; and in a subsequent paper in the near future, to apply the results to the case of mechanical forces in synchronous machines under short-circuit condition.

Two cases will be taken up in order; single circuit, and n circuits.

Single Circuit

The magnet in Fig. 1 is assumed to be excited to a point a on the saturation curve Fig. 2.

Let

ω = magnetic linkages $\times 10^{-8} = L\, i$

Ω = value of ω at which the force is to be determined; viz., $\Omega = L\, I$

L = inductance in henrys, defined as *linkages-per-ampere* $\times 10^{-8}$, and is a function of the current.

i = current in amperes.

I = value of i at which force is to be determined.

f_x = mechanical force exerted *on* the armature *by* the magnetic field, in the direction of x.

x = distance in cm. from arbitrary reference.

Although the electromagnet in Fig. 1 is a special case involving, as a result of symmetry, only one space coordinate, the general case is fully treated in Appendix A, equations (**5**) and (**6**).

Applying the principle of *virtual displacement* to the system in Fig. 1, let there be a displacement $d\,x$ of the armature, thus allowing the force f_x to do work. Then, referring to Fig. 2, the curve $o\,a$ corresponds to position x; curve $o\,b$, to position $x + d\,x$:

(a) Energy increment from electrical source during the position change $d\,x$ (I and Ω being variable during the change) $= I\, d\,\Omega$ = area $a\,b\,c\,d$, where $d\,\Omega$ is the increment due to the change $d\,x$.

(b) Total energy storage at position x and current $I = \int_0^\Omega i\, d\,\omega$ = area $o\,a\,d$ where $d\,\omega$ is the increment in ω, due to increment in current at constant x.

By conservation of energy, the increment in energy received from the electrical source during the change $d\,x$ must equal the sum of the mechanical work plus increment in stored magnetic energy. Thus,

$$I\, d\,\Omega = f_x\, d\,x + d \int_0^\Omega i\, d\,\omega$$

from which, by equations in Appendix A,

$$f_x\, d\,x = -\int_0^\Omega \frac{\partial i}{\partial x}\, d\,x\, d\,\omega \qquad \text{joules} \qquad (\mathbf{59})$$

In Fig. 2,

$$\frac{\partial i}{\partial x}\, d\,x = h$$

Thus,

(c) Mechanical work $= f_x\, d\,x = o\,a\,b'$

In equation (**59**), $d\,x$ is a constant in the integration. Hence

$$f_x = -\int_0^\Omega \frac{\partial i}{\partial x}\, d\,\omega \qquad \text{joules/cm.} \qquad (\mathbf{60})$$

which is the same as equation (**5**), Appendix A. Or,

$$f_x = -\,22.5 \int_0^\Omega \frac{\partial i}{\partial x}\, d\,\omega \qquad \text{lb.} \qquad (\mathbf{60a})$$

This is the *general equation* for force by a single

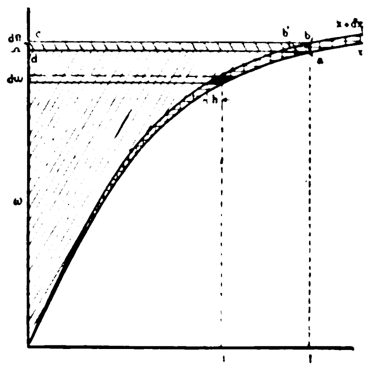

Fig. 2

circuit in which the inductance is a function of both position and magnetic flux, and is therefore applicable to electromagnets involving saturation.

Equation (**60**) is applied as follows:

Let,

$$i = f\,(\omega, x)$$

With ω as parameter, plot

$$i = F(x)$$

as in Fig. 3.[7] From this, plot

$$\frac{\partial i}{\partial x} = \varphi(\omega)$$

corresponding to X, as in Fig. 4. Then by equation (60), the force corresponding to the position X, current I, and linkages Ω, is the shaded area in Fig. 4.

Special Case. An interesting and important simplification is made possible by an assumption which will apply approximately to many actual cases. In Fig. 3, if no saturation exists, and neglecting the magnetic reluctance of the iron.

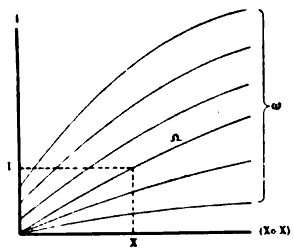

FIG. 3

$$i = 0 \text{ at } x = x_0$$

that is, when the air-gap $(x_0 - x) = 0$, since obviously no current would be required for zero reluctance. However, at values of ω which involve saturation, i has a definite value when the air-gap $(x_0 - x) = 0$, namely, the value required to sustain the magnetic flux in the saturated iron. But if, as in Fig. 3, the change in x is made at constant flux linkages, that is at approximately constant magnetic flux, the magnetic reluctance of the iron path should remain unchanged. Under this assumption *there is no change in that component of current which sustains the flux in the iron.* Thus the change in current due to such a change in x would be due wholly to the change in reluctance of the air path. This increment is indicated by h in Fig. 2, and corresponds to a change from x to $x + dx$, at a constant value of ω.[8]

These relations will now be written into equation (60).

By definition,

$$i = \frac{\omega}{L} \text{ amperes} \qquad (61)$$

and

$$L = \frac{N^2}{\mathcal{R}} \text{ henrys} \qquad (62)$$

where

$$N = \text{number of series turns.}$$

$$\mathcal{R} = \mathcal{R}_a + \mathcal{R}_i \text{ turns}^2/\text{henry} \qquad (63)$$

$\mathcal{R}$ = magnetic reluctance coefficient, which is made up of $\mathcal{R}_0$, applying to the air portion of the magnetic circuit; $\mathcal{R}_i$, to the iron portion.

Substituting (62) and (63) in (61) and differentiating partially with respect to x, taking ω constant,

$$\frac{\partial i}{\partial x} = \frac{\omega}{N^2}\frac{\partial}{\partial x}(\mathcal{R}_0 + \mathcal{R}_i)$$

But under the assumption,

$$\frac{\partial \mathcal{R}_i}{\partial x} = 0$$

Hence,

$$\frac{\partial i}{\partial x} = \omega \frac{\partial}{\partial x}\left(\frac{\mathcal{R}_0}{N^2}\right)$$

$$= \omega \frac{\partial}{\partial x}\left(\frac{1}{L_0}\right)$$

Thus,

$$\frac{\partial i}{\partial x} = -\frac{\omega}{L_0^2}\frac{\partial L_0}{\partial x} \text{ amperes/cm}$$ [redacted] (64)

Substituting (64) in (60),

$$f_x = \int_0^{\Omega} \frac{1}{L_0^2}\frac{\partial L_0}{\partial x}\,\omega\, d\omega$$

Making the assumption that in this integration

$$L_0 \text{ and } \frac{\partial L_0}{\partial x}$$

are not functions of ω, they may then be placed outside of the integral sign[9]. The integral then becomes

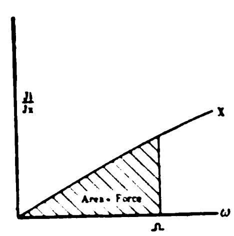

FIG. 4

$$f = \frac{1}{2}\frac{\Omega^2}{L_0^2}\frac{\partial L_0}{\partial x} \text{ joules/cm} \qquad (65)$$

Thus, for those cases where the above assumptions approximately hold, the force is expressed in the following known and convenient terms: the actual magnetic

7. It is more convenient in the particular case of Fig. 1 to plot i as $F(x_0 - x)$ instead of $F(x)$.

8. In calculating force, it makes no difference in the value whether it is assumed that the change dx is made at constant linkages, as above, or at constant current. Referring to Fig. 2, the difference in mechanical work is represented by the second order area $a\,b\,b'$, which vanishes in the limit.

9. Thus, equation (63) holds only in so far as R_0 and the ratio $\frac{d\,\mathcal{R}_0}{d\,x}$ are independent of ω.

linkages corresponding to the existing current I and position X; the constant (with respect to ω) inductance L_0 corresponding to the straight part of the (ω, i) curve, Fig. 1; and the rate at which that inductance changes with respect to x.

Equation (**65**) can be written in the following form:

$$f = \frac{1}{2} I_f^2 \frac{\partial L_0}{\partial x} \text{ joules/cm.} \quad (66)$$

where I_f is the fictitious current,

$$I_f = \frac{\Omega}{L_0} = I \frac{L}{L_0} \text{ amperes} \quad (67)$$

thus smaller than the actual current I by the ratio of the inductance at the actual current, to the inductance corresponding to no saturation.

Or in still another form,

$$f = \frac{1}{2}\left(\frac{L}{L_0}\right)^2 I^2 \frac{\partial L_0}{\partial x} \text{ joules/cm.} \quad (68)$$

Or, in pounds

$$f = 11.25\left(\frac{L}{L_0}\right)^2 I^2 \frac{\partial L_0}{\partial x} \text{ lb.} \quad (66a)$$

Thus if,

$$L = L_0$$

that is, with no saturation,

$$f = \frac{1}{2} I^2 \frac{\partial L_0}{\partial x} \quad (69)$$

This is the well-known expression for a single circuit with no saturation. Comparison of (**68**) and (**69**) shows that saturation decreases the force, at the same current I, by the ratio

$$\left(\frac{L}{L_0}\right)^2$$

It is interesting to note that under the assumptions contained in equation (**65**), equation (**60**) also reduces to the familiar form

$$f_x = \frac{\beta^2 A}{8\pi} 10^{-7} \qquad \text{joules/cm.}$$

when applied to the special case of a magnet with relatively small uniform air-gap.

Let the total magnetomotive force for the magnetic circuit corresponding to the linkages ω be,

$$N i = F(\omega) + \frac{\omega (x_0 - x) 10^8}{0.4 \pi N A}$$

where A is the cross section in sq. cm., β is the magnetic density in lines per sq. cm. of the air path, and $F(\omega)$ represents the saturation curve of the iron alone. Thus, differentiating partially with respect to x,

$$\frac{\partial i}{\partial x} = -\frac{\omega 10^8}{0.4 \pi N^2 A}$$

Substituting this in (**60**) and integrating,

$$f_x = \frac{10^8}{0.8 \pi A}\left(\frac{\Omega}{N}\right)^2 = \frac{\beta^2 A}{8\pi} 10^{-7} \text{ joules/cm.}$$

n CIRCUITS

General Case. From Appendix B, the general equation for f_x for the case of n circuits is given in the following two forms:

$$f_x = -\sum_1^n \int_0^{\Omega_u} \frac{\partial i_u}{\partial x} d\,\omega_u \qquad \text{joules/cm.} \quad (9)$$

and

$$f_x = \sum_1^n \int_0^{I_u} \frac{\partial \omega_u}{\partial x} d\,i_u \qquad \text{joules/cm.} \quad (11)$$

The application of (**9**) may be illustrated as follows: As discussed in Appendix B, any functional relation between the currents, or between the linkages may be assumed during the integration indicated, provided that relation brings all currents to their given values, which are the limits of the integrals. Thus, assume the currents are brought up, proportional to each other, the proportionality constants being the ratios of the final values I_1, I_2, I_3, etc. Then, for any value of i_u, all other currents and values of ω, at a given value of x, are fixed. Thus, for each circuit, following the same procedure as indicated for the case of a single circuit, equation (**60**), Figs. 3 and 4,

$$i_u = f_u(\omega_u, x)$$

with ω_u as parameter, plot

$$i_u = F_u(x)$$

for each circuit. From these, plot the corresponding curves,

$$\frac{\partial i_u}{\partial x} = \phi_u(\omega)$$

corresponding to the particular value of x. Then the force is the sum of the areas corresponding to that in Fig. 4.

A similar procedure may be followed in the application of the other form, equation (**11**).

Special Case: Inductance Independent of Current. From Appendix C, one of the two equations derived for f_x, under the assumption that L's and M's are independent of the current is

$$f_x = \sum_1^n{}_u \sum_1^n{}_v \frac{I_u I_v}{2} \frac{d M_{uv}}{d x} \text{ joules/cm.} \quad (21)$$

where M_{uv} = mutual inductance in henrys of circuit v upon circuit u.[10]

Thus for $n = 3$, for illustration,

$$f_x = \frac{1}{2} I_1^2 \frac{d L_1}{d x} + \frac{1}{2} I_2^2 \frac{d L_2}{d x} + \frac{1}{2} I_3^2 \frac{d L_3}{d x}$$

10. When $u = v$, self induction is indicated. Thus $M_{11} = L_1$, $M_{22} = L_2$, etc.

$$+ I_1 I_2 \frac{d M_{12}}{d x} + I_1 I_3 \frac{d M_{13}}{d x} + I_2 I_3 \frac{d M_{23}}{d x}$$

$$\text{joules/cm.} \qquad (70)$$

For two circuits only, equation (70) reduces to Maxwell's equation, as given in (56).

The other equation for f_x for this case is

$$f_x = - \sum_1^n {}_u \sum_1^n {}_v \frac{\Omega_u \Omega_v}{2} \frac{d K_{uv}}{d x} \text{ joules/cm.} \qquad (26)$$

where K_{uv} is a "coefficient of magnetization," discussed in Appendix C, and defined in general by

$$I_u = \sum_1^n {}_v K_{uv} \Omega_v \text{ amperes} \qquad (24)$$

Approximation. Making the same simplifying assumptions as contained in equations (64) and (65), discussed under "Single Circuit," saturation may be approximately taken into account in the equations.

As explained in Appendix *D*, the above mentioned assumptions reduce equation (9) to the form,

$$f_x = - \sum_1^n {}_u \sum_1^n {}_v \frac{\Omega_u \Omega_v}{2} \frac{d K_{uv}}{d x} \qquad (32)$$

where Ω_u and Ω_v are the linkages of circuits u and v corresponding to the actual currents I_1, I_2, I_3, etc., under the existing condition of partial saturation of the iron paths of the magnetic circuit; and where K_{uv} is the coefficient of magnetization, discussed in Appendix C, applying to the *non-saturated* condition. In other words, equation (32) is of exactly the same form—indeed, the same equation—as (26), which applies to the *non-saturated* case. Thus, under the assumptions, different expressions for the force are encountered for the saturated and non-saturated conditions, only when the force is expressed in terms of *currents*; but the same equation is obtained for either case when it is expressed in terms of linkages.

In Appendix E, expressions have been worked out for K_{uv} for 1, 2, 3, and 4 circuits in terms of the self and mutual inductances without saturation, namely L_u and M_{ur}.

To illustrate the application of (32), take the case of a single circuit. Here,

$$K_{uv} = K_{11} = \frac{1}{L_0}$$

Then

$$f_x = \frac{\Omega_1^2}{2} \left(\frac{d}{d x} \frac{1}{L_0} \right)$$

or

$$f_x = - \frac{1}{2} \frac{\Omega_1^2}{L_0} \frac{d L_0}{d x}$$

It will be noted that this is the same as equation (65). Thus, under the assumption, if the values of $\Omega_1, \Omega_2, \Omega_3$, etc., are known in any system involving saturated iron, the force is approximately determined by (32), using K_{uv} as given in Appendix E.

It is possible to express the force, in the case of n circuits, and under the above assumptions, as follows: Equations (21) and (26) express exactly the same result for the non-saturated case. But equation (32), which is the same as equation (26), gives the force for the saturated case. Therefore, equation (21) *will apply also to the saturated case, under the assumptions, provided such fictitious current values are used as will cause the actual existing values of* $\Omega_1, \Omega_2, \Omega_3$, etc.

Thus, knowing the values of Ω_1, Ω_2, etc., n simultaneous equations may be written for the n values of current, in terms of L's and M's as follows:

$$\left.\begin{aligned} \Omega_1 &= I_1 L_1 + M_{12} I_2 + M_{13} I_3 + \ldots \\ \Omega_2 &= I_2 L_2 + M_{21} I + M_{23} I_3 + \ldots \\ \Omega_3 &= I_3 L_3 + M_{31} I_1 + M_{32} I_2 + \ldots \end{aligned}\right\} \frac{\text{Linkages}}{10^8} \qquad (71)$$

The force is then obtained by substituting in equation (21) the fictitious values of current I_1, I_2, I_3, etc., as found by solving equation (71). The solution for these currents may be readily obtained by substituting in

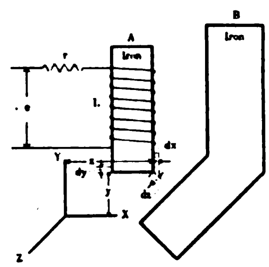

Fig. 5

equation (24) the known values of linkages Ω_v and the values of K_{uv} as determined by the equations given in Appendix E.

The authors gratefully acknowledge the valuable suggestions and encouragement of V. Karapetoff, and the assistance of J. M. Bryant, D. S. Snell and R. M. Ryan.

PHOTOELECTRIC CELL SPOTS FOREST FIRES

A new use has been found for the photoelectric cell, that delicate electrical device that has made sending pictures by wire possible. This unusual application is the detecting of forest fires. Strung between two points in a mountainous and heavily timbered region, a cable carries a car upon which is mounted a powerful electric searchlight.

The car travels back and forth on this cable and the beam of the searchlight is constantly focused upon the photoelectric cell mounted upon the platform of the forest fire lookout tower. Nothing happens until the beam of the searchlight has to pass through smoke arising from a forest fire. Then the photoelectric cell, because the beam of light is dimmed, comes into action and sounds an alarm and the forest rangers are "turned out" to fight the fire.

Theory of Absorption in Solid Dielectrics

VLADIMIR KARAPETOFF[1]

Fellow, A. I. E. E.

Synopsis.—*Most solid dielectrics are imperfect in the sense that when a constant d-c. voltage is suddenly applied, a displacement of electricity first takes place almost instantly to a certain value, and then continues to increase asymptotically towards an ultimate magnitude. Accordingly, an initial electric charge and a greater final charge may be distinguished, with the corresponding values of initial and final permittivities. The purpose of the present investigation is to establish certain general properties of the function which expresses the increase in the initial electric displacement with the time. The initial and the final leakage conductivities of the material are also taken into consideration.*

An assumption is made that the law of relaxation of electric displacement in the individual particles of the dielectric is a simple exponential function of time, but that the exponent varies from particle to particle. In some "non-viscous" particles the final displacement takes place instantly, in some others it occurs infinitely slowly, while for a great majority of the particles the relaxation proceeds at various finite rates. A "distribution function" for the numbers of different particles is introduced and the general conditions which this function must satisfy are established.

The results are then applied to a particular form of distribution function which has a large enough number of parameters for representing experimental data on a given dielectric with sufficient accuracy. Integrations are carried out for the cases of direct and sinusoidal applied voltages. With direct voltage, expressions are deduced for the permittivity and conductivity as functions of time. Since experimental curves of these two quantities can be obtained, a comparison with the theoretical formulas will permit a determination of the numerical values of the parameters in the assumed distribution function. With alternating voltages, the apparent permittivity and the apparent conductivity are expressed as functions of the frequency. Since experimental values of these quantities may be computed from measurements of capacitance and dielectric loss, another possibility is thus afforded for checking an assumed distribution function.

The ultimate aim of the theory (as now developed and as may be improved in the future) is to make it possible to correlate and to mutually check a vast amount of experimental data on absorption and on dielectric loss, and to enable one to predict these quantities within the range of voltages and frequencies for which no test figures are available.

* * * * *

WHEN a constant continuous voltage is suddenly applied to an imperfect solid dielectric, a phenomenon, shown in Fig. 1, takes place. Let the piece of dielectric be in the form of a slab of thickness a and let the applied voltage be E. Then the *voltage gradient* in the material is

$$G = E/a \tag{1}$$

By assumption, this gradient remains constant, as shown by a horizontal line in Fig. 1. Let the cross-section of the slab in the plane normal to the lines of force be A, and let the total quantity of electricity displaced through the slab be Q. Then the density of displacement, or the *dielectric flux density*, is

$$D = Q/A \tag{2}$$

Experiment shows that D does not reach its final value D_f at once, but continues to increase from an initial value $D_0 = O\,a$ to $D_f = O\,b$ over an appreciable interval of time. Accordingly, a charging current is produced,

$$i = d\,Q/d\,t \tag{3}$$

which continues to flow into the dielectric. Since D refers to unit cross-section of the slab, we shall also introduce the *current density*

$$u = d\,D/d\,t \tag{4}$$

instead of the total current i. At $t = o$, the density u is equal to zero; then it rapidly rises to a value $O\,c$ determined by eq. (4), and begins to decrease. We are not interested in the part $O\,d$ of the curve, since it is determined by the inductance of the circuit, and we shall assume that point d is reached practically at $t = o$. If the applied voltage is of very high frequency instead of being continuous, the inductance of the circuit, including the magnetic field in the dielectric itself, may become a factor of appreciable magnitude. If the conductivity of the dielectric is zero, the current finally becomes equal to zero. Otherwise, the current density asymptotically reaches a steady small value, $u_f = h\,f$.

The above described phenomenon is known as *dielectric absorption*, and is present to some degree in most solid dielectrics, especially in those whose molecular structure is non-homogeneous or complicated. Absorption affects both the charge and the discharge of a condenser, causes the true capacitance to be a somewhat indefinite quantity and, with alternating voltages, causes dielectric loss.

A study of absorption is of interest not only from the point of view of the nature of dielectric phenomena, but also in application to charge and discharge of condensers and to dielectric loss.

In view of our meager knowledge of the atomic structure and electronic forces in solids, the time for a rational theory of dielectric absorption has not arrived. It is therefore necessary to establish a semi-empirical theory, with functions chosen by trial to represent the general character of the curves shown in Fig. 1 and with constants determined by tests. Nevertheless, such a theory is useful in permitting us to interpret some observed phenomena and to predict numerical values not actually measured. The theory given below is a further extension of that given by K. W. Wagner.[2] A

1. Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

Presented at the Midwinter Convention of the A. I. E. E., New York, February 8-11, 1926. Complete copies including Section 5, here omitted available upon request.

2. *Annalen der Physik*, 1913, Vol. 40, p. 817. Wagner's work is based on earlier investigations by Pellat, von Schweidler etc., references to whose writings will be found in his article.

somewhat different approach to the problem, based on the idea of "stratified" dielectrics, was given by Maxwell[3] and recently further developed by Grünewald.[4]

The character of the curves shown in Fig. 1 suggests the presence of three kinds of paths or "fibers" between the electrodes (Fig. 2); namely, (a) portions of a perfect dielectric, in which an electric displacement faithfully

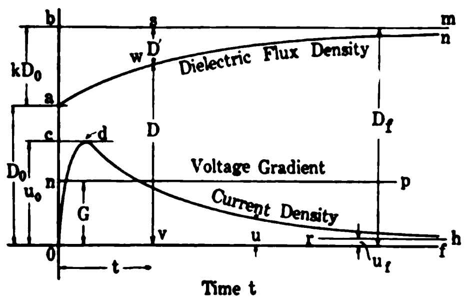

FIG. 1—VARIATIONS IN THE DIELECTRIC FLUX AND CURRENT DENSITY WITH THE TIME

When a constant d-c. voltage is applied suddenly

and instantly follows the applied voltage; (b) portions of an imperfect dielectric in which the final orientation of molecular charges requires some time and is opposed by some kind of viscous reactions; and (c) conducting paths. Of course, all these portions are of irregular shapes and intermingled in series and in parallel, the three distinct fibers being shown merely for the sake of convenience. Such a dielectric would behave as indicated in Fig. 1.

A mechanical analog to the behavior of an imperfect dielectric is shown in Fig. 3. $A\,B$ is a stationary plate and $C\,D$ is an identical plate connected to it by two springs, S_1 and S_2. A vessel V, filled with viscous liquid, is attached to $A\,B$. A plate q, supported by the

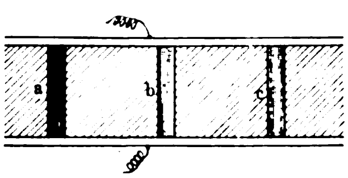

FIG. 2—THREE ASSUMED KINDS OF FIBERS OR PARTICLES IN AN IMPERFECT DIELECTRIC

Viz., a. perfectly elastic, b. viscously elastic, c. conducting

spring C, is immersed in the liquid. Two weights, G_1 and G_2, rest on supports h_1 and h_2, and are attached to $C\,D$ by strings over the stationary pulleys P_1 and P_2. The lower ends of the springs S_1 and S_2 are attached to the stems K_1 and K_2 fitted into the board $A\,B$ with considerable friction.

Assume the apparatus to be initially in equilibrium with no tension in the springs and with the weights resting on their supports. Now let h_1 and h_2 be suddenly withdrawn, causing the weights to pull $C\,D$ upward and to stretch the springs S_1, S_2 and C. Consider the stems K_1 and K_2 to be so tight as not to move, and assume the motion of q to be negligible at first, due to the viscosity of the liquid. The tension is then initially taken up by the three springs. As the pull continues, the plate q moves upward, relieving the tension of C so that ultimately the whole tension is taken up by S_1 and S_2 only. This subsequent increase in the tension and displacement of the springs S_1 and S_2 illustrates the effect of absorption. Let now the supports K_1 and K_2 be slightly yielding. Then the motion of $C\,D$ will never stop, thus giving a picture of a conduction current.

If the stress be suddenly changed before the final stage has been reached, the additional stress put on C depends upon the position of the plate q. Thus, the amount of absorption depends upon the previous history of the sample.

If the weights be suddenly removed (corresponding to

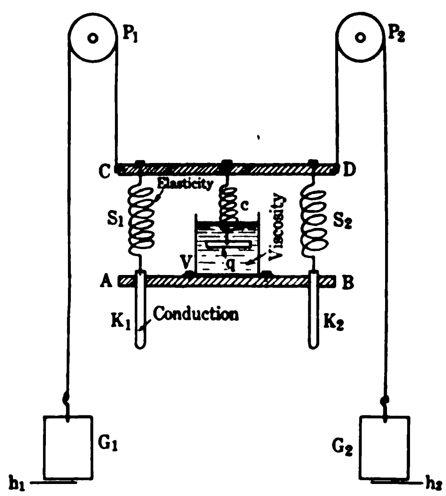

FIG. 3—A MECHANICAL ANALOG OF AN IMPERFECT SOLID DIELECTRIC

a short-circuit), there will be an instant position of equilibrium at which the tension of the springs S_1 and S_2 will balance the compression of the spring C. Then, gradually, the bar $C\,D$ will go down to a final position of equilibrium. If, however, the short-circuit be removed before the final position has been reached, and the bar $C\,D$ locked (to correspond to an open circuit) a readjustment of stresses will take place, with a residual charge. Thus, later, upon releasing $C\,D$, another movement will take place without an application of the weights.

The influence of temperature can be taken into account by changing the viscosity of the liquid in V; for instance, by heating it.

Of course, this analog cannot be followed in detail, but it may facilitate an understanding of the general nature of phenomena taking place in an imperfect dielectric. The writer has also designed a kinematic

3. Electricity and Magnetism, Vol. 1, p. 452.
4. Archiv für Elektrotechnik, 1923, Vol. 12, p. 96.

linkage with a spring and a dashpot, to illustrate the ideas discussed in the above mentioned article by Grünewald. See also Maxwell's model, *ibid.*, p. 462.

2. The Fundamental Equations

The phenomenon shown in Fig. 1 is primarily determined by the ratio of D_0 to D_f and by the shape of the curve $a\,n$. Let the final displacement be $1 + k$ times the original displacement. Then, in Fig. 1, $a\,b = k\,D_0$, and the *absorption coefficient* k may be defined by the equation

$$k = (D_f - D_0)/D_0 \quad (5)$$

For a perfect dielectric, $k = 0$; the greater k, the more absorption manifested by the material.

Assume $a\,b = 1$ and let the equation of the curve $a\,n$, referred to the axis $b\,m$, be $\phi\,(t)$. The function $\phi\,(t)$ may be called the *relaxation function*, as it characterizes the rate at which the absorbed charge is being released with the time. Let κ_0 be the *initial permittivity* of the material; that is, the permittivity that would be obtained from a ballistic test at the first instant of voltage application. In other words, let

$$D_0 = \kappa_0\,G \quad (6)$$

and

$$D_f = (1 + k)\,\kappa_0\,G \quad (7)$$

At any instant, t, the *deficiency* $D' = w\,s$ between the final displacement D_f and the actual displacement D is

$$D' = k\,D_0\,\phi\,(t) = k\,\kappa_0\,G\,\phi\,(t) \quad (8)$$

Hence

$$D = D_f - D' = \kappa_0\,G\,[(1 + k) - k\,\phi\,(t)] \quad (9)$$

According to eq. (4),

$$u = -\,\kappa_0\,\kappa\,G\,d\,\phi\,(t)/d\,t \quad (10)$$

In these equations, the function $\phi\,(t)$ is as yet arbitrary, except that it must correspond to a curve the general shape of which is that of the curve $a\,n$, and must satisfy the terminal conditions

$$\phi\,(o) = 1 \text{ and } \phi\,(\infty) = 0 \quad (11)$$

The factor k may be expressed through the *final permittivity* of the material, κ_f, as follows: After the sample has been subjected to a constant d-c. voltage for a long time, we have, by analogy with Equation (6):

$$D_f = \kappa_f\,G \quad (12)$$

so that

$$(D_f - D_0)/D_0 = (\kappa_f - \kappa_0)/\kappa_0 \quad (13)$$

Comparing this expression with equation (5), it will be seen that

$$k = (\kappa_f - \kappa_0)/\kappa_0 \quad (14)$$

and

$$\kappa_0\,k = \Delta\,\kappa = \kappa_f - \kappa_0 \quad (14a)$$

where $\Delta\,\kappa$ is the apparent increase in the permittivity, due to absorption.

The next step is to generalize Equations (9) and (10) for the case when the applied voltage is not constant but varies with the time in a prescribed manner. Let us begin with the simplest case when a constant stress G_1 (Fig. 4) is applied from $t = 0$ to $t = \tau$, and is then increased by an amount G_2. The new stress, $G_1 + G_2$, may be assumed to last indefinitely. The flux density curve, $a\,w$, is similar to that in Fig. 1 as long as G_1 is acting alone. At the instant of application of G_2 the flux density is suddenly increased by an amount $w\,w'$ and then continues to increase asymptotically towards a new limit $b'\,m'$.

It is impossible to deduce, theoretically, the relationship between the displacement $p\,w$, existing at the instant τ and the resultant displacement $p\,w'$ an instant later, due to a suddenly increased voltage. We shall therefore make the simplest assumption; namely, that the added voltage G_2 produces its own displacement curve, just as if G_1 did not exist, and that the displacements due to G_1 and G_2 are simply added together.

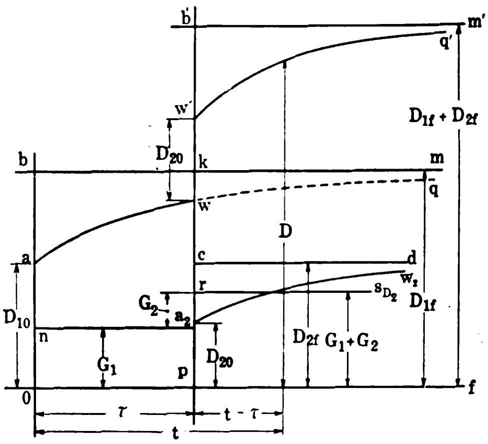

FIG. 4—VARIATIONS IN THE DIELECTRIC FLUX DENSITY
When a constant d-c. voltage is applied in two steps

According to this principle of superposition (due to Hopkinson), the curve $a\,w$ continues in the range $w\,q$ as if G_2 did not exist, while the stress G_2 causes a new curve, $a_2\,w_2$, the initial ordinate of which is $D_{2o} = \kappa_0\,G_2$, and the final value is $D_{2f} = (1 + k)\,\kappa_0\,G_2$; equations (6) and (7). The ordinates of the curve $a_2\,w_2$ added to those of $w\,q$ will give the curve of resultant displacement, $w'\,q'$. This is a mathematical hypothesis, justified only by the possibility of deducing on this basis a set of formulas which can be made to fit observed curves to a sufficient degree of accuracy. From a physical point of view, we know that the a fibers (Fig. 2) satisfy the law of superposition because, in a perfect condenser, the charge is strictly proportional to the voltage. The c fibers also satisfy the law of superposition in that a current is proportional to the applied voltage. Therefore, it is only necessary to grant that the viscous or b fibers also obey this law. In a viscous fluid, at low velocities, the velocity is proportional to the applied force, so that the superposition hypothesis seems reasonable for these fibers as well.

Thus, for any instant $t > \tau$, we may write

$$D = \kappa_0 (1 + k) (G_1 + G_2) - \kappa_0 k [G_1 \phi (t) + G_2 \phi (t - \tau)] \quad (15)$$

Let now the total stress G_t, which exists at the instant t, be gradually built up in small increments ΔG_τ, each of which is applied at a different instant τ. Generalizing equation (15), we get

$$D = \kappa_0 (1 + k) G_t - \Delta \kappa \Sigma \Delta G_\tau \phi (t - \tau) \quad (16)$$

where

$$\Sigma \Delta G_\tau = G_t \quad (17)$$

and $\Delta \kappa$ is used in place of $\kappa_0 k$, according to equation (**14a**).

In the limit, let the applied voltage vary continuously; then, equation (16) becomes

$$D = \kappa_0 (1 + k) G_t - \Delta \kappa \int_{t_0}^{t} \left(\frac{d G_\tau}{d \tau} \right) \phi (t - \tau) d \tau \quad (18)$$

where t_0 is the instant at which the voltage is first applied to the sample. In changing from equation (16) to equation (18), ΔG_τ is divided and multiplied by $\Delta \tau$, and, in the limit, Δ is replaced by d.

In equation (18), ϕ is an assumed function, while G_τ is the impressed stress. It is more convenient to have a derivative of ϕ than of G_τ. Integrating in parts, we get

$$\int_{t_0}^{t} \left(\frac{d G_\tau}{d \tau} \right) \phi (t - \tau) d \tau = G_\tau \phi (t - \tau) \Big|_{t_0}^{t} - \int_{t_0}^{t} G_\tau d_\tau \phi (t - \tau) \quad (19)$$

But

$$G_\tau \phi (t - \tau) \Big|_{t_0}^{t} = G_t \phi (o) - G_{t0} \phi (t - t_0) \quad (20)$$

According to equation (11), $\phi (0) = 1$; moreover, $G_{t_0} = 0$, since, by assumption, t_0 is the instant at which the voltage begins to be applied. Hence, the value of the right-hand side of equation (20) is simply G_t. Using this value in equation (19) and substituting the value of the integral in equation (18), gives

$$D = \kappa_0 G_t + \Delta \kappa \int_{t_0}^{t} G_\tau d_\tau \phi (t - \tau) \quad (21)$$

Using this expression for D in equation (4), we get the following expression for the current density:

$$u = \kappa_0 \left(\frac{d G_t}{d t} \right) + \Delta \kappa \int_{t_0}^{t} G_\tau \left[\frac{d^2 \phi (t - \tau)}{d t \, d \tau} \right] d \tau + \Delta \kappa G_t \left[\frac{d \phi (t - \tau)}{d \tau} \right] \tau = t \quad (22)$$

When taking a total derivative of the definite integral in equation (21), with respect to t, two terms are obtained; viz., one assuming t to be a parameter under the sign of integral, and the other assuming t to be a variable upper limit. Equations (21) and (22) are the fundamental equations in the theory under consideration. In so far as no particular form has been ascribed to the function ϕ, these equations are perfectly general. The next step is to specify the function ϕ in accordance with the observed behavior of solid dielectrics.

3. An Exponential Law of Relaxation

In Fig. 1, the simplest assumption which can be made regarding the shape of the curve, $a\,n$, is that the "deficiency" $w\,s$ is an exponential function of time; that is

$$\phi (t) = \epsilon^{-\alpha t} \quad (23)$$

where α is a *relaxation factor* which characterizes the sample under consideration. Equation (23) proposed by Pellat[5], satisfactorily represents the general shape of the curve $a\,n$ and also satisfies equations (11). On the other hand, substances which show considerable absorption are usually too complicated to be characterized by a single parameter α. Therefore, von Schweidler proposed a generalization of the foregoing formula to

$$\phi (t) = (\Sigma N \epsilon^{-\alpha t}) / \Sigma N \quad . \quad (24)$$

Here the material is supposed to be heterogeneous and to consist of N_1 particles of constant α_1, N_2 particles of constant α_2, etc.

Wagner has further extended this idea and proposed for the relaxation function an expression of the form

$$\phi (t) = \int_0^\infty F (\alpha) \epsilon^{-\alpha t} d \alpha \quad (25)$$

the integration being with respect to α, and not t. His idea was that a piece of heterogeneous dielectric may have some particles with a relaxation constant $\alpha = 0$ (perfect dielectric, no relaxation) and others with $\alpha = \infty$ (conducting particles, instant relaxation). For most particles, α lies between zero and infinity, and the number of particles which have a definite value of α is a function of α. In other words, for a fairly uniform material, α ranges within rather narrow limits for a great majority of particles, and there are comparatively few particles with very large or small values of α, due to admixtures and impurities. A specific form of $F (\alpha)$ will be considered in the next section. We shall first deduce some general expressions which hold true for any function of α. The function $F (\alpha)$ may be called the distribution function, because it shows the relative number of particles having different values of α.

From the physical significance of $F (\alpha)$, we judge that this function remains finite between $\alpha = 0$ and $\alpha = \infty$. Therefore the second equation (11) is satisfied. In order that the first equation (11) be satisfied, the function $F (\alpha)$ must satisfy the condition

$$\int_0^\infty F (\alpha) d \alpha = 1 \quad (26)$$

We shall now apply expression (25) to equations (21) and (22) and deduce some special cases.

General Case of Variable Voltage.

Equation (25) gives

$$\phi (t - \tau) = \int_0^\infty F (\alpha) \epsilon^{-\alpha(t - \tau)} d \alpha \quad (27)$$

5. For literature references see the above mentioned article by Wagner.

so that

$$d_\tau \phi(t-\tau) = \int_0^\infty \alpha F(\alpha)\, \epsilon^{-\alpha(t-\tau)}\, d\alpha\, d\tau \quad (28)$$

and

$$[d^2 \phi(t-\tau)/dt\, d\tau]\, d\tau = -\int_0^\infty \alpha^2 F(\alpha) \epsilon^{-\alpha(t-\tau)}\, d\alpha\, d\tau \quad (29)$$

Substituting expression (28) in equation (21), gives

$$D = \kappa_0 G_t + \Delta\kappa \int_{t_0}^{t} G_\tau\, d\tau \int_0^\infty \alpha F(\alpha)\, \epsilon^{-\alpha(t-\tau)}\, d\alpha \quad (30)$$

The integration with respect to time is independent of that with respect to α. Changing, therefore, the order of integration, the foregoing equation becomes

$$D = \kappa_0 G_t + \Delta\kappa \int_0^\infty \alpha F(\alpha)\, \epsilon^{-\alpha t} \left[\int_{t_0}^{t} G_\tau\, \epsilon^{\alpha\tau}\, d\tau \right] d\alpha \quad (31)$$

Substituting expressions (28) and (29) in equation (22), gives

$$u = \kappa_0 \frac{d G_t}{d t} - \Delta\kappa \int_{t_0}^{t} \int_0^\infty G_\tau\, \alpha^2 F(\alpha)\, \epsilon^{-\alpha(t-\tau)}\, d\alpha\, d\tau + \Delta\kappa G_t \int_0^\infty \alpha F(\alpha)\, d\alpha \quad (32)$$

Equation (32) may also be deduced directly from equation (31) by differentiation; see equation (4).

Continuous Constant Voltage. In this case, $G_t = G_\tau = G$; assume also $t_0 = 0$. We then have for the second integral in equation (31)

$$\int_{t_0}^{t} G_\tau\, \epsilon^{\alpha\tau}\, d\tau = G \int_0^t \epsilon^{\alpha\tau}\, d\tau = \left(\frac{G}{\alpha}\right)(\epsilon^{\alpha t} - 1) \quad (33)$$

Therefore, the first integral in equation (31) becomes

$$G \int_0^\infty F(\alpha)\, \epsilon^{-\alpha t} (\epsilon^{\alpha t} - 1)\, d\alpha = G \int_0^\infty F(\alpha)\, d\alpha - G \int_0^\infty F(\alpha)\, \epsilon^{-\alpha t}\, d\alpha \quad (34)$$

According to equation (26), the value of the first integral on the right hand side is 1. Substituting from equation (34) in equation (31) and dividing by G, gives

$$\kappa_t = \frac{D}{G} = (\kappa_0 + \Delta\kappa) - \Delta\kappa \int_0^\infty F(\alpha)\, \epsilon^{-\alpha t}\, d\alpha \quad (35)$$

Here κ_t may be considered to be the *apparent permittivity* of the sample at the instant t. When $t = 0$, $\kappa_t = \kappa_0$; when $t = \infty$, $\kappa_t = \kappa_0 + \Delta\kappa = \kappa_f$.

The current density u may be obtained directly by differentiating the right-hand side of equation (35) with respect to t, and multiplying the result by G. We then get

$$u = \Delta\kappa G \int_0^\infty \alpha F(\alpha)\, \epsilon^{-\alpha t}\, d\alpha \quad (36)$$

Let γ be the final conductivity of the sample, that is, the conductivity of the fibers c in Fig. 2. Then the *apparent conductivity* at the instant t is

$$\gamma_t = \frac{u}{G} + \gamma_f \quad (37)$$

The first term on the right-hand side corresponds to the displacement current and the second to the real conduction current. Substituting in equation (37) the value of u from equation (36), gives

$$\gamma_t = \Delta\kappa \int_0^\infty \alpha F(\alpha)\, \epsilon^{-\alpha t}\, d\alpha + \gamma_f \quad (38)$$

The initial conductivity, at $t = 0$, is

$$\gamma_0 = \Delta\kappa \int_0^\infty \alpha F(\alpha)\, d\alpha + \gamma_f \quad (39)$$

Thus the function $F(\alpha)$ must satisfy the condition

$$\int_0^\infty \alpha F(\alpha)\, d\alpha = \frac{\gamma_0 - \gamma_f}{\kappa_f - \kappa_0} \quad (40)$$

where the four quantities on the right-hand side characterize the material.

Alternating Voltage. For a sinusoidal applied voltage we can generally put

$$G_\tau = G_m\, \epsilon^{j\omega t} \quad (41)$$

More particularly, at the instant t,

$$G_t = G_m\, \epsilon^{j\omega t} \quad (41a)$$

where G_m is the amplitude of the stress and ω its frequency. It is convenient to put $t_0 = -\infty$ because then the transient term disappears. The second integral in equation (31) becomes

$$G_m \int_{-\infty}^{t} \epsilon^{(j\omega+\alpha)\tau}\, d\tau = \frac{G_m\, \epsilon^{(j\omega+\alpha)t}}{(j\omega + \alpha)} \quad (42)$$

so that, using in equation (31) the value of G_t from equation (41a), we get

$$D = G_m\, \epsilon^{j\omega t} \left[\kappa_0 + \Delta\kappa \int_0^\infty \frac{\alpha F(\alpha)}{(j\omega + \alpha)}\, d\alpha \right] \quad (43)$$

Multiplying the numerator and the denominator of this equation by $(\alpha - j\omega)$, and separating the real from the imaginary part, we get

$$D = G_m\, \epsilon^{j\omega t} \left[\kappa_0 + \Delta\kappa \int_0^\infty \frac{\alpha^2 F(\alpha)\, d\alpha}{(\alpha^2 + \omega^2)} - j\omega\Delta\kappa \int_0^\infty \frac{\alpha F(\alpha)\, d\alpha}{(\alpha^2 + \omega^2)} \right] \quad (44)$$

The sample under consideration may be thought of as a combination of an ideal capacitance, C, in parallel with a conductance, g. The latter is *not* the conductance due to leakage, but the apparent conductance caused by absorption. For such a combination, the current

$$I = E\, \epsilon^{j\omega t} (j\omega C + g) \quad (45)$$

Consequently, the charge varies according to the law

$$Q = E\, \epsilon^{j\omega t} \left(C - \frac{jg}{\omega} \right) \quad (46)$$

because a derivative of equation (46) with respect to t gives equation (45). Equation (44) corresponds to equation (46) for unit volume of the dielectric. Therefore, comparing the two equations term by term, we find that

$$\kappa_\omega = \kappa_0 + \Delta\,\kappa \int_0^\infty \frac{\alpha^2 F(\alpha)\, d\alpha}{(\alpha^2 + \omega^2)} \qquad (47)$$

$$\gamma_\omega = \Delta\,\kappa\,\omega^2 \int_0^\infty \frac{\alpha F(\alpha)\, d\alpha}{(\alpha^2 + \omega^2)} + \gamma_f \qquad (48)$$

In the latter expression, the term γ_f is added to account for the actual leakage conductivity (fibers c in Fig. 2). Thus, with alternating voltages, a dielectric with absorption shows a permittivity and a conductivity both of which are functions of the frequency. Equations (47) and (48) show that the relationship between κ_ω, γ_ω, and ω is quite involved. Nevertheless, it is this relationship that should permit to compare the theory with observed results.

Differentiating equation (44), or directly on the basis of equation (45), we may write for the current density u:

$$u = G_m\, \epsilon^{j\omega t}\, (j\,\omega\,\kappa_\omega + \gamma_\omega) \qquad (49)$$

where κ_ω and γ_ω are determined by equations (47) and (48).

In equation (47), κ_0, by definition, is the initial or instant permittivity; therefore, it is the permittivity which the dielectric should show at an infinite frequency. In fact, by putting $\omega = \infty$, equation (47) gives

$$\kappa_\infty = \kappa_0 \qquad (50)$$

At zero frequency, that is, when $\omega = 0$, equation (47) gives

$$\kappa_{\omega=o} = \kappa_1 + \Delta\,\kappa = \kappa_f \qquad (51)$$

which also agrees with the assumptions made above.

The variable term in equation (48) becomes equal to zero both at $\omega = 0$ and at $\omega = \infty$. This agrees with the physical conception of this term, as giving the apparent time effect of absorption. The power loss per unit volume is $G_{eff}^2\,\gamma_\omega$. Subtracting from this the true conduction loss $G_{eff}^2\,\gamma_f$, gives the dielectric loss per unit volume at frequency ω:

$$P_\omega = G_{eff}^2\,(\gamma_\omega - \gamma_f) \qquad (52)$$

Thus, the observed power loss corrected for true conduction and plotted against ω as abscissas gives some information in regard to the shape of the function $F(\alpha)$.

For the circuit represented by equation (45), we have

$$\tan\psi = \frac{g}{\omega\, C} \qquad (53)$$

where the *loss* or *imperfection angle* ψ is complementary to the phase angle between the voltage and the current. Knowing ψ, the value of sin ψ can be found, and this value is the power factor of the condenser. Applying equation (53) to our case, we have

$$\tan\psi_\omega = \gamma_\omega/(\omega\,\kappa_\omega) \qquad (54)$$

where κ_ω and γ_ω are determined by equations (47) and (48). Knowing ψ_ω, we find,

$$\text{Power factor} = \text{Sin}\ \psi_\omega \qquad (55)$$

Dielectric loss increases considerably with temperature[6]. In the present investigation, the temperature of the sample is assumed to be the same throughout its thickness and, in checking experimental data with theoretical formulas, it is of importance to see that this condition has been at least approximately fulfilled during the tests.

Transient Voltages. The theory developed above for an established direct voltage may be extended to include a short d-c. impulse, or a combination of such impulses, by using the principle of superposition. For example, if a voltage E is applied at the instant t_1 and removed at the instant t_2, the conditions are the same as if the voltage E were continued from $t = t_1$ to $t = \infty$ and a voltage $-E$ applied from $t = t_2$ to $t = \infty$. It is also possible that the Heavisidian operational calculus may be applied to the solution of this problem.

If the applied transient voltage is of the nature of a decremental sine wave, equation (41) may be used for G_τ, in which ω is a complex quantity. The lower limit of τ is no longer $-\infty$ and equation (42) has to be integrated anew. Of course, equations (31) and (32) can be used directly for any transient voltage provided that G_τ is given as a function of τ.

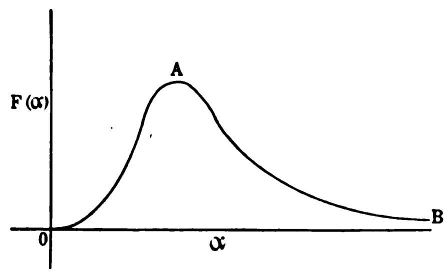

FIG. 5—THE GENERAL CHARACTER OF THE DISTRIBUTION FUNCTION $F(\alpha)$

4. A DISTRIBUTION FUNCTION $F(\alpha)$ AND THE CONDITIONS WHICH ITS PARAMETERS MUST SATISFY

A reasonable shape of the function $F(\alpha)$ for a fairly homogeneous dielectric is shown in Fig. 5. A large number of particles have values of α within the range near the maximum of the curve. There are fewer and fewer particles as one chooses values of α more remote from this range. The curve passes through the origin and may or may not be tangent to the axis of abscissas there; it should approach the axis of abscissas asymptotically at infinity. Probably several analytical functions would give a curve of this shape, and the selection of a particular function, in so far as there are no more valid theoretical grounds, is mainly determined by the following considerations:

a. General simplicity.

b. Ease in the integration of various expressions such as equations (38), (47), etc.

c. A sufficient number of parameters to fit the observed behavior of a given dielectric.

6. See, for example, L. Dreyfus, Mathematische Theorien für den Durchschlag fester Isoliermaterialien; *Schweiz. Elektrot. Verein, Bulletin*, 1924, Vol. 15, p. 321.

As a fundamental empirical expression, we shall take

$$F(\alpha) = H\alpha^{m-1}\epsilon^{-n\alpha} \qquad (56)$$

where H, m, and n, are constants independent of α. These constants are different for different materials and, for a given material, are functions of temperature.

The physical dimension of $\phi(t)$ is a numeric; see its definition, equation (8). According to equation (25), the physical dimension of α is (time)$^{-1}$, because the product αt must be a numeric. Consequently, the physical dimension of $F(\alpha)$ must be "time," because the product $F(\alpha)\,d\alpha$ must be a numeric. In equation (56), $n\alpha$ must be a numeric, hence the dimension of n is "time." The exponent m is a numeric, and the dimension of H is (time)^m. It will be seen later that H is eliminated from the final computations.

Taking a derivative of $F(\alpha)$ with respect to α, we get

$$dF(\alpha)/d\alpha = H\alpha^{m-2}\epsilon^{-n\alpha}(m-1-n\alpha) \qquad (57)$$

With the aid of equations (56) and (57), the limiting values of m and n may be determined as follows:

(a) As α approaches zero, $\epsilon^{-n\alpha}$ approaches unity for any finite value of n. Hence, α^{m-1} should approach zero in order that the curve pass through the origin. This gives the first limiting condition, namely, $m > 1$. But for values of m less than 2, equation (57) gives infinite values of the slope, showing that the curve is tangent to the axis of ordinates. This does not agree with the assumed character of the phenomenon. At $m = 2$, the value of the right-hand side of equation (57) is H.

This may be accepted (at least provisionally) as a possible value, so that

$$m \geqq 2 \qquad (58)$$

(b) At infinity, the term α^{m-1} tends to an infinitely great value, while $\epsilon^{-n\alpha}$ tends to zero, provided that n is positive. Moreover, since an exponential expression ϵ^{α} tends to infinity at a higher rate than any positive power of α, the ratio $\alpha^{m-1}/\epsilon^{n\alpha}$ approaches zero when $\alpha = \infty$.

Equation (57) gives a zero slope at $\alpha = \infty$. Thus, the second limiting condition is

$$n > 0 \qquad (59)$$

(c) The last factor in expression (57) becomes zero when

$$\alpha = (m-1)/n \qquad (60)$$

At this value of α, the function $F(\alpha)$ reaches its maximum. Equation (60) may have some bearing upon the selection of values of m and n, or upon the interpretation of experimentally obtained values.

(d) Substituting expression (56) in equation (26) and integrating, we get[7]

$$H\int_0^{\infty}\alpha^{m-1}\epsilon^{-n\alpha}\,d\alpha = H\,\Gamma(m)/n^m = 1 \qquad (61)$$

from which

$$H\,\Gamma(m) = n^m \qquad (62)$$

7. B. O. Peirce, Short Table of Integrals, formula 493.

where Γ stands for the so-called Gamma Function[8].

Thus, the quantities H, m, n, are not entirely independent of one another, but must satisfy equation (62).

(e) Substituting expression (56) in equation (40) and integrating gives

$$H\int_0^{\infty}\alpha^{m}\epsilon^{-n\alpha}\,d\alpha = H\,\Gamma(m+1)/n^{m+1}$$
$$= (\gamma_0 - \gamma_f)/(\kappa_f - \kappa_0) = \Delta\gamma/\Delta\kappa \qquad (63)$$

from which

$$H\,\Gamma(m+1) = n^{m+1}\,(\gamma_0 - \gamma_f)/(\kappa_f - \kappa_0)$$
$$= n^{m+1}\,\Delta\gamma/\Delta\kappa \qquad (64)$$

This condition imposes another limitation upon the choice of the quantities H, m, and n. There is an additional connection between equations (62) and (64) because

$$\Gamma(m+1) = m\,\Gamma(m)\,{}^{9} \qquad (65)$$

Dividing equation (64) by equation (62), and using expression (65), we get

$$m/n = (\gamma_0 - \gamma_f)/(\kappa_f - \kappa_0) = \Delta\gamma/\Delta\kappa \qquad (66)$$

The function (56) is different from that chosen by Wagner. He used the so-called probability function for the distribution of values of relaxation time[10]. There is no valid theoretical reason for selecting this function in preference to any other, even for a chemically simple and strictly homogeneous material. With actual substances, of complicated molecular structure and with impurities, such a function is totally inadequate, since it has not a sufficient number of parameters to fit experimental curves. Therefore, Wagner had to form a function consisting of a sum of a "finite number" of probability functions of different parameters, each giving a different most probable value of the relaxation time. However, if one has to resort to such a summation, then any other function of reasonable shape, such as equation (56), will do just as well.

The probability function leads to quite complicated integrations, and equation (56) offers considerable advantages in this respect, although two of the integrals also lead to infinite series when m is not an integer. In any event, it seems advisable to carry the theory through on the basis of equation (56), for such practical applications and interpretations of tests as it may lead to.

LIST OF SYMBOLS

A cross-section of a slab of dielectric, perpendicular to the lines of force

a thickness of a slab of dielectric

A, B, values of the integrals defined by equations (67) and (68)

8. For properties and tables of numerical values of Gamma Function see an advanced treatise on the Integral Calculus, for example B. Williamson's.

9. Equation (65) may be extended as follows:

$$\Gamma(m+1) = m(m-1)\,\Gamma(m-1)$$
$$= m(m-1)(m-2)\;\Gamma(m-2) = \text{etc.} \qquad (65a)$$

10. Loc. cit. p. 831.

C ideal capacitance
$C\,i$ integral cosine
col defined by equation (**86**)
D dielectric flux density, or charge per unit area
D' deficiency in the density of displacement
E applied voltage
e a subscript meaning "even"
$F(\alpha)$ distribution function defined by equation (**25**)
f a subscript meaning "final" or at the time $t = \infty$
G voltage gradient or stress
g apparent conductance due to absorption
H a parameter defined by equation (**56**)
I, i current
j $= \sqrt{-1}$
k absorption coefficient
m a subscript meaning "maximum value" or amplitude
m an exponent in equation (**56**)
N number of particles
n an exponent in equation (**56**)
o a subscript meaning "initial," or at the instant $t = t_0$; in application to R means "odd"
P dielectric loss per unit volume
p, q quantities defined by equation (**74**)
p^1, q^1 quantities defined by equation (**81**)
Q dielectric flux or electric charge
R an integral defined by equation (**77**)
$S\,i$ integral sine
sil defined by equation (**87**)
t time
u current density
V, W values of the integrals defined by equations (**69**) and (**70**)
x an auxiliary variable which first enters in equation (**90**)
α relaxation factor defined by equation (**23**)
Γ gamma function
γ conductivity of the material
Δ a finite increment
θ an auxiliary quantity defined by equation (**79**)
κ permittivity or dielectric constant
τ instant of application of a new stress
$\phi(t)$ relaxation function of time
ψ loss angle or imperfection angle, defined by equation (**53**)
ω electric angular velocity, that is, $2\,\pi$ times the frequency.

Methods of High Quality Recording and Reproducing of Music and Speech based on Telephone Research

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Member, A. I. E. E. Associate Member, A. I. E. E.

Synopsis.—*The paper deals with an analysis of the general requirements of recording and reproducing sound, with the nature of the inherent limitations where mechanical records are used, and a detailed description of a solution involving, first, the use of electrical equipment for the purposes of recording and, second, the use of mechanical equipment based on electric transmission methods for reproducing.*

Probably the most useful feature of the paper is the complete description of the application of electrical transmission theory to mechanical transmission systems. A detailed analysis is made of the analogies between the electrical and the mechanical systems.

INTRODUCTION

THE problem with which this paper is concerned, in its broadest sense, may be stated as that of taking sound from the air, storing it in some permanent way and reproducing it again without appreciable distortion. It is immaterial from the general standpoint whether the means used are mechanical or electrical or a combination of the two. The choice of which method to use will depend largely upon the commercial requirements accompanying the specific purpose for which the reproduction is being made. For instance, it is quite probable that the means chosen for reproduction in residences would differ materially from those used in large ballrooms or in the presentation of synchronized motion pictures.

Before considering the methods and results referred to in the title of this paper, it may be well to make a rough division of the problem. The storing or recording of sound requires, first, a mechanical system which will respond faithfully to the sound waves which are to be recorded. Then, there is required some material in or on which this sound may be recorded and an intervening system which permits the sound waves to make the record in this material. In the usual case, and in that with which we are particularly concerned here, there is a mechanical system which will vibrate in response to the sound which is to be recorded and

1. Both members of the technical staff, Bell Telephone Laboratories.

Abridgment of a paper presented at the Midwinter Convention at the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

directly through some mechanical linkage or less directly through an electrical linkage, drive a cutting mechanism which will impress a wax record.

The first consideration, therefore, is the character of the sound which is to be recorded including all of the effects of reverberation and the general questions of studio design. Next to be considered is the manner in which the cutting instrument shall impress this speech or musical record upon the constantly rotating wax disk, which disk is commonly called the wax master. In this connection, there will be discussed also the relative value of the electrical and mechanical linking of the cutting knife with the mechanism which receives the sound waves. Following the discussion of these problems and a brief reference to the state of the prior art, there remains to be considered the reproduction of the sound which is stored in the cuts or grooves of the wax record.

In the case of reproduction also, there is required a mechanical system which will respond to these cuts in the wax and a system which will set up in the air-sound waves essentially identical to those picked up by the first mechanism of the recording system. Between these two systems, a mechanical linkage intervenes in the case under discussion, but reference is made to the relative advantages of this system compared with the use of an electrical linkage.

First to be described, is the character of the sound which is to be recorded and reproduced and the effects of reverberation and transients upon the listener's sensation of this sound.

Studio Characteristics and Transients

Phonographic reproduction may be termed perfect when the components of the reproduced sound reaching the ears of the actual listener have the same relative intensity and phase relation as the sound reaching the ears of an imaginary listener to the original performance would have had. Obviously, it is very difficult, if not impossible, to fulfill all of these requirements with a single channel system, that is, with a system which does not have a separate path from each ear of the listener to the sound source.

The use of two ears, that is, two-channel listening, gives the listener a sense of direction for each of the various sources of sound to which at a given moment he may be listening, and, therefore, he apprehends them in their relative distribution in space. It has been found possible with a single channel system, however, by controlling the acoustic properties of the room in which the sound is being recorded, to simulate to a considerable degree in the reproduced music the effective space relationships of the original. In this case, with a one-channel system, the directional effect is, of course, entirely absent, and the spatial relationship which is apprehended is probably due to the increased apparent reverberation of the instruments situated at the far end of the room as compared with those in the near foreground.

In recording work, therefore, one of the important acoustic characteristics of a room is its time of reverberation. Although it is probable that this is the most comprehensive single factor, experiment has shown that the shape of the room and the distribution and character of the damping surfaces play a part in the excellence of music in such a room.

It has been shown by Sabine[2] that for piano music, studios should have a time of reverberation measured by his method of 1.08 seconds. Experience has indicated that this figure is also very closely correct for other types of music. This figure of Sabine's assumes binaural listening. With single-channel systems, such as most of the present reproduction systems, whether for radio or the phonograph, the ability of the listener to separate the reverberation from the direct music by means of the sense of direction is completely removed and there is thrust upon his attention an apparently excessive amount of room echo. Experiment has shown that a time of reverberation for the recording room ranging from slightly more than ½ to slightly less than ¾ of Sabine's figure affords in the reproduced music the effect of a room with proper acoustics. When this effect is accomplished, the person listening to the reproduced music has the consciousness of the music being played in a continuation of the same room in which he is listening and also has a sense of spatial depth.

Experiment has indicated further that any transients set up by the recording or reproducing system constitute a second cause of apparent increased reverberation. The data obtained thus far are insufficient to permit assignment of quantitative values to the importance of these two factors.

At the present state of the art, the most important requirement of a recording or reproducing system is its frequency characteristic. This involves two factors—intensity versus frequency, and phase distortion versus frequency. The effect of the second of these factors is not thoroughly understood but as it is closely related to the production of transients it has to be considered, as mentioned above. The system to be described is, however, relatively free from violent phase shifts within most of the range covered, but does have some undesirable phase-shift characteristics with small accompanying transients near its limiting cut-off frequencies.

Frequency Requirements

The frequency range which it would be desirable to cover if, it were possible, with relatively uniform intensity for the transmission of speech and all types of music including pipe organ is from about 16 cycles per second to approximately 10,000.

2. Collected papers of W. Sabine.

It may be interesting to examine the record requirements for a band of frequencies this great. For the purpose of this illustration, a lateral cut record will be assumed although in all the factors except the time which the record will run, the arguments apply in a similar manner to the hill-and-dale cut. Since, for mechanical reproduction, the sound at a given pitch is radiated by means of a fixed radiation resistance, it is necessary that the record must be cut with a device the square of whose velocity is proportional to the sound power. Under these conditions, it is seen that for a given intensity of sound the amplitude is inversely proportional to the frequency of the tone, and that a point will be reached somewhere at the low end of the sound spectrum where this amplitude will be great enough to cut from one groove into the adjacent groove, or in case of vertical cut, to cut so deeply that with present materials the wax will tear instead of cut away with a clean surface. This means that there is an inherent maximum amplitude beyond which it is not commercially feasible to go. Similarly the minimum radius of curvature of sine waves of various frequencies cut at constant velocity is inversely proportional to the frequency, so that as higher and higher frequencies are reached the radius of curvature becomes smaller and smaller until finally it becomes too small for the reproducing needle to follow. There is, therefore, an inherent limit at the upper end.

In order to extend these limits, it is necessary in the case of the low end to make the spiral coarser and in the case of the high end to run the record at a higher speed. Both of these changes tend to decrease the time which a record of a given size can be made to play. The only alternative of these methods is to cut the record less loud than is the present standard practise and make the reproducing equipment more sensitive. This could easily be done if it were not for the "record noise" or "surface noise," as it is commonly called. Since this surface noise is already loud enough in comparison with the reproduced music to be somewhat objectionable, no appreciable gain in this direction can be made until the technique of record manufacture has been distinctly improved.

In this connection, there is one other interesting point. It has been suggested that if electric reproduction were used, it would be possible to cut the record with a characteristic other than uniform velocity sensitiveness and correct for the error by an electrical system whose characteristic is the inverse of the characteristic of record. If the change which is made in the recording characteristic tends toward cutting at uniform acceleration sensitiveness, the amplitude varies inversely as the square of the frequency and hence the difficulties at the low end of the scale are greatly enhanced. Similarly, if the records are cut more nearly at constant amplitude, the radius of curvature of the sine waves decreases as the square of the frequency, hence the difficulties are placed at the upper end. In the process which is being described in this paper, these limitations have been met commercially by having a frequency characteristic of the uniform velocity type between the frequencies of 200 and approximately 4000 cycles per second. Below 200 it has been necessary to operate at approximately constant amplitude with a resulting loss in intensity which loss increases as the frequency decreases. Above 4000 it has been necessary to operate at approximately constant acceleration with its consequent slight loss in intensity at the very high overtones. With a characteristic of this type, a range of frequencies from 60 cycles to 6000 can be recorded with reasonable success although the very low and very high range are slightly deficient. (See Fig. 14) With a record having such a frequency characteristic, the inherent limitations are divided between the two ends of the frequency band and where electrical reproduction methods are used, it is possible to employ a reproduction system whose frequency characteristic compensates for that of the record.

It should be pointed out that an attempt to record notes lower than the low cutoff of the above mentioned apparatus would result in recording only those harmonics of the notes which lie above the cut-off. This in no way prevents the listener from hearing the notes, reproduced by means of the harmonics only, as notes with the pitches of the missing fundamentals although it does somewhat change the quality of the tone.[3] If it were not for this ability of the ear to add the fundamental pitch of a note, of which only the harmonics are being reproduced, most of the older phonographs and loud speakers would have been totally useless for the reproduction of speech and music.

Mechanical Versus Electrical Recording

In attacking the recording part of the problem, two ways at once present themselves; first, the direct use of the power, of the sound being recorded, to operate the recording instrument; and second, the use of high quality electric apparatus with vacuum tube amplifiers in order to give more freedom to the artists and better control to the process. The amount of power available to operate the recorder directly from the sound in the recording room is so small as to make it extremely difficult to make records under natural conditions of speaking, singing, or instrumental playing. As the use of high quality electric apparatus with associated amplifiers has a very distinct advantage over the acoustic method, they have been adopted for the recording part of the process. Fig. 1A shows a picture of a group of artists recording by means of the sound power directly, while Fig. 1B shows a record being made by the same artists with the electric process.

3. Physical Criterion for Determining the Pitch of a Musical Tone, H. Fletcher, *Phys. Rev.*, Vol. 23, No. 3, March, 1924.

It will be noticed in Fig. 1A that the artists are grouped very closely about the horn. In the case of the weaker instruments such as violins, it has been possible to use only two of standard construction. The rest of the violins are of the type known as the "Stroh" violin which is a device strung in the manner of a violin but so arranged that the bridge vibrates a diaphragm attached to a horn. This horn is directed toward the recording horn, as shown by the player in the foregound.

Fig. 1A—Picture of an Orchestra Recording for the Acoustic Process. This Picture was Furnished through the Courtesy of the Victor Talking Machine Company, Camden, New Jersey

With such an arrangement of musicians, it is very difficult to arouse the spontaneous enthusiasm which is necessary for the production of really artistic music.

Fig. 1B—Picture of the Same Orchestra Shown in Fig. 1A, but Recording for the Electric Process. This Picture was Furnished through the Courtesy of the Victor Talking Machine Company, Camden, New Jersey

In Fig. 1B the musicians are sitting at ease more nearly in their usual arrangement and all are using the instruments which they would use were they playing at a concert. Furthermore, the microphone is now sufficiently far away from the orchestra to receive the sound in much the manner that the ears of a listener in the audience would receive it. In other words, it picks up the sound after it has been properly blended with the reflections from the walls of the room. It is in this way that the so-called "atmosphere" or "room-tone" has been obtained.

In the old process, it sometimes happened that after the instruments had been arranged in such a manner that the relative loudness of the various parts had been balanced correctly, it was found that the whole selection was either too loud or too weak. This usually meant a complete rearrangement of the players. With the flexibility introduced by the use of electrical apparatus including amplifiers, the control of loudness is obtained by simple manipulation of the amplifier system and is in no way related to the difficulties of the relative loudness of one instrument to another. The only problem for the studio director in this case is to obtain the proper balance among the various musical instruments and artists. The advantages derived from this added ease of control are also made manifest in that it is much easier and less tiresome for the artists and it is usually possible to make more records in a given time.

Mechanical Versus Electrical Reproducing

Where the question of reproduction is concerned, the same two alternatives mentioned for recording present themselves, namely, direct use of power derived from the record itself versus the use of electromechanical equipment with an amplifier. In this case, however, the situation is a little different as the power which can be drawn directly from the record is more than sufficient for home use. Since any method of reproducing from mechanical records by electrical means involves the use of a mechanical device for transforming from mechanical to electrical power and a second such device for transforming from electrical back to mechanical power, that is, sound, it is necessary to use two mechanical systems, one at each end of an electrical system. Where the power which can be supplied by the record, is sufficient to produce the necessary sound intensity, as in the case of home use, it is in general simpler to design one single mechanical transmission system than it is to add the unnecessary complications of amplifiers, power supply and associated circuits. In cases where music is to be reproduced in large auditoriums, the power which can be drawn from the record may be insufficient and some form of electric reproduction using amplifiers becomes necessary.

Brief Description of Recording System

The system used for recording consists of a condenser transmitter, a high quality vacuum tube amplifier and an electromagnetic recorder. Fig. 2 shows the calibration of the condenser transmitter and the associated amplifiers. The condenser transmitter and amplifiers are so designed that the current delivered to the recorder circuit is essentially proportional to the sound pressure at the transmitter diaphragm. The electromagnetic recorder, which will be described later, is designed to work with this type of system.

With the exception of this electromagnetic recorder, apparatus of this type has already been described in the literature.[4] In addition to this equipment which might be called the recording amplifier system, there is a volume indicator for measuring the power which is being delivered to the recorder and also an audible monitoring system. The audible monitoring system consists of an amplifier whose input impedance is high compared with the recorder impedance and a suitable loud speaking receiver. The monitoring amplifier is bridged directly across the recorder and operates the loud speaking receiver so that the operator may listen to the record as it is being made.

In the design of the recording and reproducing systems each part of the system has been made as nearly perfect as possible. Errors of one part have not been designed to compensate for inverse errors in another part. Although this method is the more difficult, its flexibility, particularly as regards the commercial possibilities of future improvements justifies the extra effort.[5] There is, therefore, no distortion in the record whose purpose is to compensate for errors in the reproducing equipment; the only intended distortion in the record being that required by the inherent limitations mentioned above. See Figs. 2, 14 and 20.

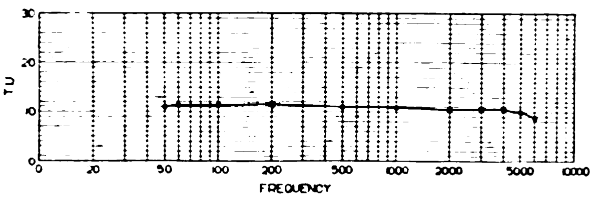

Fig. 2—Calibration of the Condenser Transmitter and Associated Amplifiers

This curve shows merely the relativefrequency sensitiveness of the system, the zero line having been chosen arbitrarily

General Basis of Design

An interesting feature of the development of the mechanical and electromechanical portions of the recording and reproducing system is their quantitative design as mechanical analogs of electric circuits. Both the recording and reproducing systems are good examples of the use of this type of analogy.

The economic need for the solution of many of the problems connected with electric wave transmission over long distances coupled with the consequent development of accurate electric measuring apparatus has led to a rather complete theoretical and practical knowledge of electrical wave transmission. The advance has been so great that the knowledge of electric systems has surpassed our previous engineering knowledge of mechanical wave transmission systems. The result is, therefore, that mechanical transmission systems can be designed more successfully if they are viewed as analogs of electric circuits.

While there are mechanical analogs for nearly every form of electrical circuit imaginable, there is one particular class of electrical circuits whose study has led to ideas of the utmost value in guiding the course of the present development. This class of circuits consists of infinitely repeated similar sections of one or more lumped capacity and inductance elements in series and shunt and are commonly known as filters. The study of filters began with the work of Campbell[6] and a recognition of their importance as frequency selective systems in telephone repeaters, carrier systems, radio, signalling systems, etc., led to their intensive study. In the available literature is to be found a fairly complete statement of their properties and details of their design.[6]

It will be recalled in the case of the telephone circuit that the introduction of inductance coils at regular intervals in the circuit produced a remarkable change in the transmission characteristic. Over a broad band of frequencies the attenuation was reduced and made fairly uniform over that range while beyond a critical frequency called the cut-off frequency the attenuation became very high. In the ideal filters with zero dissipation the transmission characteristics are of the same nature but more clear cut. Structures of this type with infinitely repeated sections will have one or more transmission bands of zero attenuation and one or more bands having infinite attenuation. The impedance characteristics of such a structure measured from certain characteristic points will be pure resistance more or less uniform in the transmission bands, and pure reactance in the attenuation bands. These terminations are

4. Wente, E. C., "Condenser Transmitter as a Uniformly Sensitive Instrument for Measuring Sound Intensity," *Phys. Rev.*, Vol. 10, 1917.

Crandall, I. B., "Air-Damped Vibrating Systems," *Phys. Rev.*, Vol. 11, 1918.

Wente, E. C., "Electrostatic Transmitter," *Phys. Rev.*, Vol. 19, 1922.

Martin, W. H. and Fletcher, H., "High Quality Transmission and Reproduction of Speech and Music," Trans. A. I. E. E., Vol. 43, 1924, p. 384.

Green, I. W. and Maxfield, J. P., "Public Address Systems," Trans. A. I. E. E., Vol. 43, 1923, p. 64.

5. Green, I. W. and Maxfield, J. P., "Public Address Systems," Trans. A. I. E. E., Vol. 42, 1923, p. 64.

6. Campbell, G. A., "On Loaded Lines in Telephonic Transmission," *Phil. Mag.*, March 1903.

Campbell, G. A., U. S. Patents 1,227,113; 1,227,114; "Physical Theory of the Electric Wave Filter," *Bell System Technical Journal*, November 1922.

Zobel, O. J., "Theory and Design of Uniform and Composite Electric Wave Filters," *Bell System Technical Journal*, January 1923.

Peters, L. J., "Theory of Electric Wave Filters Built up of Coupled Circuit Elements," Trans. A. I. E. E., May 1923.

Carson, J. R. and Zobel, O. J., "Transient Oscillations in Electric Wave Filters," *Bell System Technical Journal*, July 1923.

Zobel, O. J., "Transmission Characteristics of Electric Wave Filters," *Bell System Technical Journal*, October 1924.

Johnson, K. S., and Shea, T. E., "Mutual Inductance in Wave Filters with an Introduction on Filter Design," *Bell System Technical Journal*, January 1925.

Johnson, K. S., "Transmission Circuits for Telephonic Communication," D. Van Nostrand, 1925.

mid-series; that is, the entering element being a series one of half the normal series element; or mid-shunt; that is, the entering element being twice the impedance of the normal shunt element. The corresponding impedances are called the mid-series and mid-shunt characteristic or iterative impedances.

If we retain the first few sections of such a structure

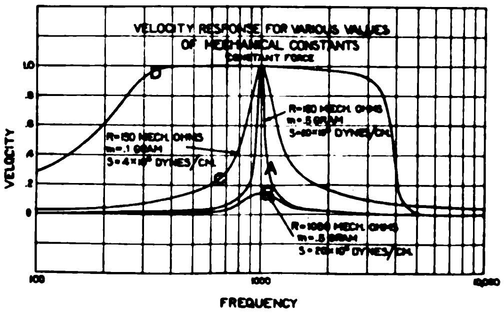

FIG. 9—VELOCITY. RESPONSE FOR VARIOUS VALUES OF MECHANICAL CONSTANTS

and terminate them with a resistance which is equal to the resistance impedance of the infinite line from which they were taken, the characteristics are substantially unchanged. It is understood, of course, that this resistance equals approximately the resistance impedance of the remainder of the infinite line at most of the frequencies in the transmission band in which we are interested.

The presence of small amounts of damping in the various elements also has but slight effect on the general characteristics. These results could in general be readily applied to the various telephone transmission problems because the source and load between which the filter system was inserted generally had or could be made to have a nearly resistance impedance equalling the mid-series or mid-shunt impedance of the filter within the transmission band. The filter and terminating impedances may then be said to be matched. Where adjacent sections in the filter have impedances similar in character but different in absolute magnitude they may be joined by a suitable transformer.

Many early attempts were made to design mechanical transmission systems having a wide frequency range in which highly damped single or multi-resonant systems were employed. In these attempts both of the obvious methods of increasing the damping were used, namely, that of adding a resistance to the system and that of increasing the value of the compliance and decreasing mass in such proportion as to maintain the same natural frequency. The former of these methods reduces the sensitivity of the system at the point where it is most efficient, (See Fig. 9), while the second method increases the response at the points where the system is less sensitive, namely, away from its resonance point. Fig. 9 shows four curves—first, a singly resonant system, Curve A; second, the same system with friction added, Curve B; third, the same system without the added friction but with an increase in compliance and a decrease in mass such that the natural period remains the same; Curve C, and fourth, a band pass type of circuit whose resistance impedance is the same as that of the system shown in Curve A. (See Curve D.)

The results of filter theory have shown how these resonances should be coordinated so that when a proper resistance termination is used high efficiency and equal sensitivity are obtained over a definite band of frequencies by elimination of response to all frequencies outside the band. With the electrical case of a repeated filter, each section considered by itself resonates at the same frequency but when combined into a short-circuited filter of n sections, there will be n natural frequencies. However, when such a system is terminated with a resistance which equals the nominal characteristic impedance in the transmission band, uniform response in the terminating resistance is obtained over the entire band.

DETAILED ANALYSIS OF MECHANICAL AND ELECTRICAL ANALOGS[7]

Before going on with a detailed treatment of the electrical analogues of the mechanical structures used in the problem of phonographic reproduction, a list of the corresponding quantities used in the two systems will be given, together with the symbols employed.

Mechanical		Electrical	
Force	= F (dynes)	Voltage	= E (volts)
Velocity	= v (cm./sec.)	Current	= i (amperes)
Displacement	= s (cm.)	Charge	= q (coulombs)
Impedance or mechanical ohms)	= z (dyne sec./cm.	Impedance	= Z (ohms)
Resistance	= r (dyne sec./cm.)	Resistance	= R (ohms)
Reactance	= x (dyne sec./cm.)	Reactance	= X (ohms)
Mass	= m (gms)	Inductance	= L (henries)
Compliance	= c (cm./dyne)[8]	Capacity	= C (farads)

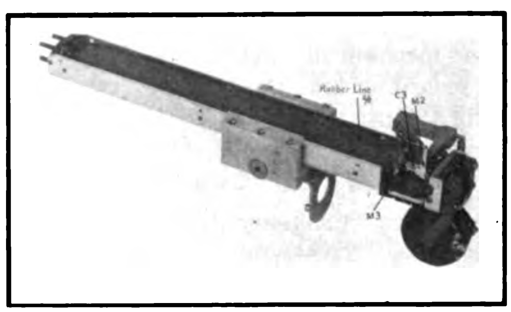

FIG. 10—THIS FIGURE SHOWS AN ELECTROMAGNETIC RECORDER COMPLETE EXCEPT FOR THE BOTTOM OF THE CASE

7. The authors wish to express their appreciation to Mr. E. L. Norton for his courtesy in working out the mathematics of the mechanical and electrical analogs which are shown in this paper.

8. H. W. Nichols, "Theory of Variable Dynamical Electrical Systems," *Phys. Rev.* Vol. 10, 1917.

General Design of Mechanical Systems

In designing mechanical systems of the band pass type, the problem is three fold—first, that of arranging the masses and compliances such that they form repeated filter sections; second, determining the magnitude of these quantities so that with or without transformers the separate sections all have the same cut-off frequencies* and characteristic impedances; third, to provide the proper resistance termination. Where the transmitted mechanical power has not been radiated as sound this third part has been one of the most difficult to fulfill.

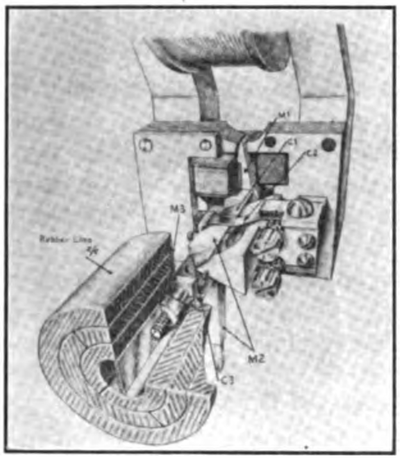

Fig. 11—Detailed Drawing of the Mechanical Filter of an Electromagnetic Recorder. (Lettering Same as in Fig. 12)

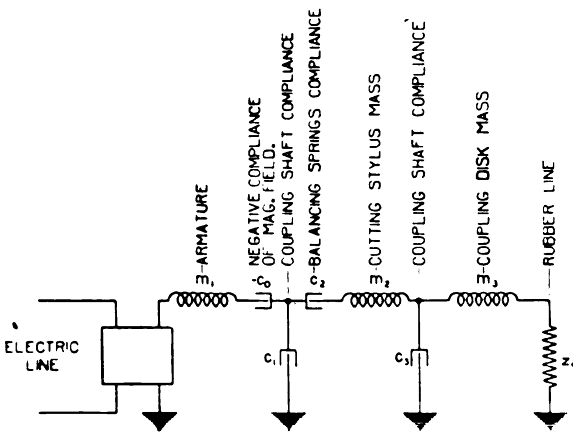

Fig. 12—Equivalent Electric Circuit of the Electromagnetic Recorder

In designing these systems, practical difficulties arose—first, the difficulty of insuring that the parts vibrated in the desired degrees of freedom only, and second, the difficulty of determining the magnitudes of the various effective masses, compliances and resistances. Before the work to be described could be carried out practically it became necessary to develop a method of measuring mechanical impedances[10]. This method of measurement has been very useful not only in determining the magnitudes of the impedances in the degrees of freedom in which it is desired that they shall operate, but in determining the impedances to motion of the various parts in directions in which they should not be permitted to vibrate. In connection with the measurement of the magnitudes of the parts in the desired degrees of freedom this method enables us to determine the constants of the mechanical networks under their conditions of operation. Experience so far has indicated that when all the degrees of freedom have been taken into account and when the dynamic axes of vibration have been properly chosen, the static and dynamic constants of the parts are the same, and it is then possible to check the parts by simple static measurements. In the early attempts to build these systems very large discrepancies between the static and dynamic characteristics were found.

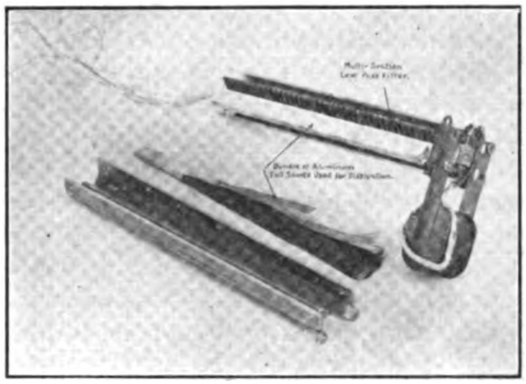

Fig. 13—Electromagnetic Recorder using Lumped Loaded Termination

The method of furnishing dissipation to the lumped loaded line is shown

The Recorder

One of the early practical phonographic applications of electric filter design to mechanical problems was the development of an electromagnetic recorder. The instrument as finally constructed is essentially a properly terminated three-section mechanical filter in which the recording stylus and its holder constitute the series mass in the second section. Since a filter of this type appears at its input end as approximately a pure resistance within the transmission band, the current in the series inductances, that is, in the mechanical

*It is of course permissible to have a section having a higher cut-off than the others provided its characteristic impedance is the same as that of the others over the transmission band of those having the lower cut-off.

10. Kennelly, A. E. and Affel, H. A., "The Mechanics of Telephone Receiver Diaphragms, as Derived from their Motional Impedance Circles," *Proc.* A. A. A. S., Vol. 51, No. 8, November, 1915.

Kennelly, A. E. and Pierce, G. W., "The Impedance of Telephone Receivers as Affected by the Motion of their Diaphragms," *Proc.* A. A. A. S., Vol. 48, No. 6, September, 1912.

case, the velocity of the series masses is proportional to the driving force.

Figs. 10, 11 and 12 show respectively, a complete recorder, a drawing of the mechanical filter of such a recorder and a diagram of the equivalent electric circuit.

Referring to Figures 11 and 12, all of the equivalents can readily be seen with the exception of the terminating resistance and the negative compliance, c_0. The reason for using the type of termination shown lies in the fact that most of the known mechanical resistances have values which are functions of frequency or of amplitude or of both. Also in most cases, the mechanical resistance is accompanied by either a mass or compliance reactance. By using a continuous transmission line (shown completely in Fig. 10 and partially in Fig. 11) which line is sufficiently long so that a wave entering it will be essentially absorbed before it has reached the far end, been reflected and returned to the entering end, it has been possible to use imperfect types of damping for this line and still

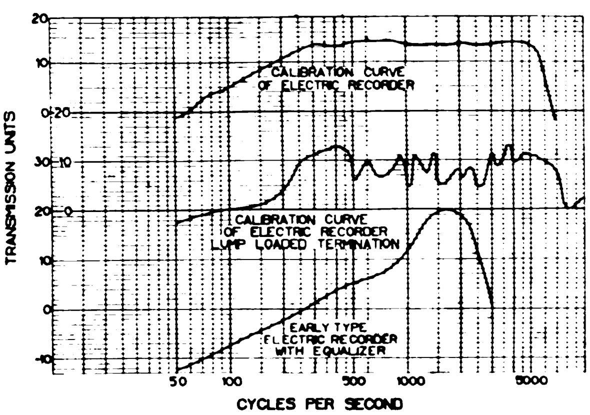

FIG. 14—CALIBRATION CURVE OF THREE TYPES OF ELECTROMAGNETIC RECORDERS

obtain over the desired band, an essentially pure resistance at the input end.

Fig. 14 shows calibration curves of three types of recorders. The bottom curve shows an early type of highly damped singly resonant system. The middle curve is a calibration of a low pass mechanical filter type using lumped loading in the resistance line.* The upper curve shows the calibration of the recorder shown in Fig. 10.

The compliance $-c_0$ is a mechanical quantity for which there is no simple electric analog. In a balanced armature type of structure such as that shown in Fig. 11, the action of the field on the armature, when it is at its center point, is balanced. If, however, the armature be deflected, a small distance from this equilibrium, there is exerted by the magnetic field a torque tending to pull the armature further away from its center position. The value of this torque for small amplitudes is proportional to the angular displacement. It is therefore seen that this quantity is of the nature of a compliance but that the back force is in a reverse direction to that required for a positive compliance.

*For a description of this, see the complete paper available in pamphlet form upon request.

DESIGN OF THE REPRODUCING APPARATUS

As the analogy between the mechanical and electrical filter is more perfectly shown in the case of the reproducing equipment, the detailed quantitative descrip-

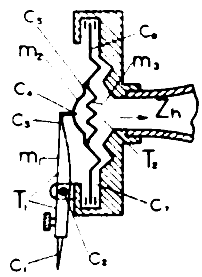

FIG. 15—DIAGRAMMATIC SKETCH OF THE MECHANICAL SYSTEM OF THE PHONOGRAPH

tion will be given in this connection. Figs. 15 and 16 show respectively a diagram of the reproducing system and its equivalent electric circuit. From these diagrams it is evident which units in the mechanical system correspond to the various electrical parts. As the series compliances c_2, c_4 and c_6 have been made so large that the low frequency cut-off caused by them lies well below the low frequency cut-off of the horn, an inappreciable error is introduced in using for design

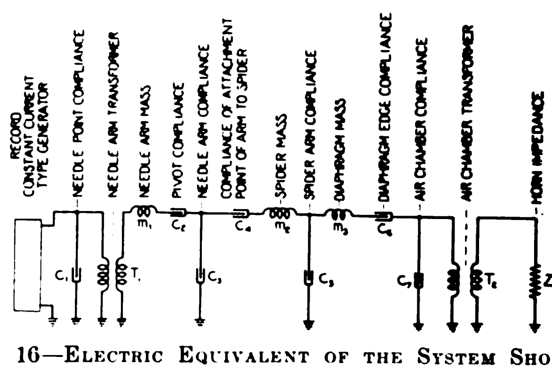

FIG. 16—ELECTRIC EQUIVALENT OF THE SYSTEM SHOWN IN FIG. 15

purposes formulas of low pass filters[11]. The two formulas which will be used are as follows:

$$f_c = \frac{1}{\pi} \sqrt{\frac{1}{m\,c}} \qquad (12)$$

Where

f_c = cut-off frequency of a lumped transmission system in cycles per second

11. Campbell, G. A., "On loaded lines in Telephonic Transmission," *Phil. Mag.*, March, 1903.

c = shunt compliance per section in centimeters per dynes

m = series mass per section in grams

$$z_0 = \sqrt{\frac{m}{c}} \qquad (13)$$

Where z_0[12] is the value of characteristic impedance over the greater part of the band range.

Equations (**12**) and (**13**) which form the basis of the design work contain four variables, f_c, c, m and z_0. It is, therefore, necessary to determine two of them by the physical requirements of the problem after which the other two are determined. The upper cut-off frequency f_c was arbitrarily chosen at 5000 pps. as a compromise between the highest frequency occurring on the record and the increase in surface noise as the cut-off is raised. The choice of the other arbitrarily set variable came after considerable preliminary experimenting and was fixed by the difficulty of obtaining a diaphragm which is light enough and has a large enough area. Hence the effective mass of the diaphragm m_3, (Figs. 15-16) was fixed at 0.186 grams which value can be obtained by careful design. The effective area can be made as large as 13 square centimeters. For convenience let the arbitrary value chosen for $f_c = \bar{f}_c$ and the value of $m = \bar{m}_3$.

Solving Equations (**12**) and (**13**) for c and z_0, we get

$$c = \frac{1}{\pi^2 \bar{f}_c^2 \bar{m}_3} \qquad (14)$$

$$z_0 = \pi \bar{f}_c \bar{m}_3 \qquad (15)$$

also

$$z_0 = \frac{1}{\pi c \bar{f}_c} \qquad (16)$$

In order to obtain the low value of mass mentioned, with a large enough area, it was necessary to make the diaphragm of a very stiff light material. An aluminum alloy sheet 0.0017 in. thick was chosen and concentrically corrugated as shown in Figs. 17 and 18. These corrugations are spaced sufficiently close so that the natural periods of the flat surfaces are all above $\bar{f}_c$. To insure that this central stiffened portion should vibrate with approximate plunger action, which is more efficient than diaphragm action, it is driven at six points near its periphery.

Reference to Figs. 15 and 16 and Equation (**14**) shows that the compliance of the air chamber c_7, of the spider legs c_5 and shunt tip of the needle arm c_3 are determined. Also the mass of the spider m_2 and the effective mass of the needle arm m_1, as viewed at the point where it is attached to the spider, are determined.

The impedance looking into the system from the record is determined by the rate at which it is necessary to radiate energy in order that the reproduction may be loud enough. The power taken from the record is approximately $v^2 z_0$ since z_0 is a resistance over most of the band. Experiment has shown this value of z_0 to be approximately 4500 mechanical ohms.

But substituting in Equation (**13**) the value of $\bar{m}_3$, and from Equation (**14**) the value of c_5, we find that the impedance is only 2920 mechanical ohms. It is, therefore, necessary to use a transformer whose impedance ratio is $\frac{4500}{2920}$. From this and a knowledge of filter structures the needle-point compliance can be determined. The value obtained is easily realized with commercial types of needle.

It will be noted that the record is shown in Fig. 16 as a constant current generator, *i. e.*, a generator whose impedance appears high as viewed from the needle point. That this is necessary is obvious when it is remembered that, if the impedance looking back into the record were to equal the impedance of the filter system, the walls of the record would have to yield an amount comparable with one-half the amplitude of the lateral cut. This would cause a breakdown of the record material with consequent damage.

The design of the system is, therefore, complete except for the resistance termination which is supplied by the horn for all frequencies above its low frequency cut-off. The characteristics of the horn will be dealt with later. The resistance within the band looking in at the small end of the horn is $G A_2$ where G = mechanical ohms per square centimeter of an infinite cylindrical tube of the same area, and A_2 = area in square centimeters of the small end of the horn.

Let A_1 = the effective plunger area of the diaphragm (as previously mentioned this is 13 sq. cm.). The impedance looking back at the diaphragm is

$$z_0 = \pi \bar{f}_c \bar{m}_3 = 2920 \text{ mechanical ohms}$$

from Equation (**15**), and the impedance looking at a horn whose small end area equals A_2 is

$$z_h = r_0 = A_2 G \qquad (17)$$

Substituting

A_2 = 13 sq. cm.

G = 41 ohms per cm.^{2} we get

$z_h = r_0$ = 533 mechanical ohms

This is entirely insufficient so that the air-chamber transformer becomes necessary.

To calculate the necessary ratio of areas on the two sides of the air-chamber transformer, the following formula is needed. The formula assumes the chamber to be relatively small compared with all wave lengths of the

12. z_0 may be called nominal mid-shunt or mid-series impedance. Their actual values in the transmission band being at any frequency f.,

$$\text{mid-series} = z_0 \sqrt{1 - \left(\frac{f}{f}\right)^2}$$

$$\text{mid-shunt} \quad \frac{z_0}{\sqrt{1 - \left(\frac{f}{f_c}\right)^2}}$$

sound to be transmitted, that is, the pressure changes throughout the chamber are substantially in phase.

$$\frac{z_0}{z_h} = \frac{A_1^2}{A_2^2} \qquad (18)$$

Where

z_0 = the impedance of the primary side of the transformer in mechanical ohms

z_h = the impedance on the secondary side of the transformer in mechanical ohms, *i. e.*, the horn impedance

Solving this equation with the aid of Equations (**15**) and (**17**), we get

$$A_2 = \frac{G\,A_1^2}{\pi\, f_c\, m_3} \qquad (22)$$

(A more complete description of this part of the design is given in the complete paper which will be published in the A. I. E. E. TRANSACTIONS for 1926.)

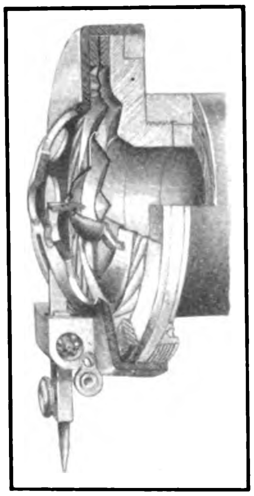

FIG. 18—SECTIONAL DRAWING SHOWING CONSTRUCTION OF THE SYSTEM SHOWN IN FIG. 17

The horn which has been used as a terminating resistance to the mechanical filter structure is a logarithmic one. The general properties of logarithmic horns have been understood for some time.[13]

There are two fundamental constants of such a horn—the first is the area of the large end and the second the rate of taper. The area of the mouth determines the lowest frequency which is radiated satisfactorily. The energy of the frequencies below this is largely reflected if it is permitted to reach the mouth.

From the equations given by Webster,[13] it can be shown that all logarithmic horns have a low frequency cut-off which is determined by the rate of taper. If the rate of taper is so proportioned that its resulting cut-off prevents the lower frequencies from reaching the horn mouth, the horn will then radiate all frequencies reaching its mouth and very little reflection will result.[14] It is, therefore, possible to build a horn having no marked fundamental resonance.

Since the characteristics of the horn are determined by the area of its mouth and by its rate of taper the length of the horn is determined by the area of the small end. This area is determined in turn by the mechanical impedance and effective area of the system

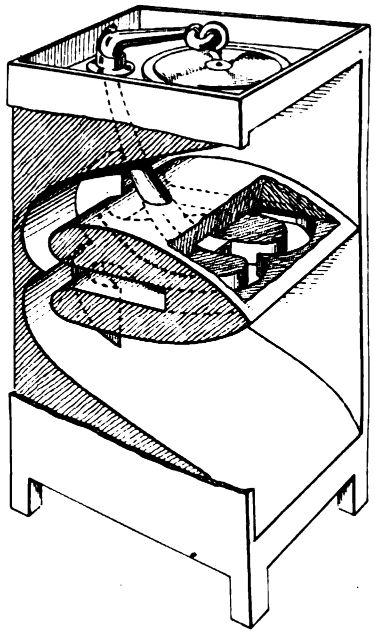

FIG. 19—SECTIONAL VIEW OF THE FOLDED HORN SHOWING THE AIR PASSAGE

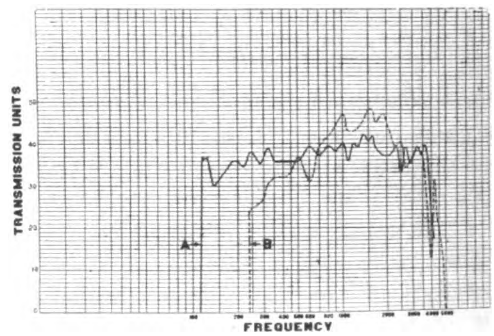

FIG. 20—RESPONSE FREQUENCY CHARACTERISTIC OF TWO PHONOGRAPHS. CURVE *A* SHOWS THE CHARACTERISTIC OF THE BAND PASS FILTER TYPE DESCRIBED. CURVE *B* SHOWS THE CHARACTERISTIC OF ONE OF THE BEST COMMERCIAL MACHINES PREVIOUSLY ON THE MARKET

13. Webster, A. G., "Acoustical Impedance and Theory of Horns and Phonograph," *Proc.* Nat. Acad. of Sci., 1919.

14. The authors wish to express their appreciation in this connection of the work of Mr. P. B. Flanders who carried out the mathematical investigation of these relationships and to Mr. A. L. Thuras who checked experimentally the mathematical theory.

which it is terminating, as shown in Equation (22). It is seen, therefore, that the length of the horn should not be considered as a fundamental constant. A paper describing the design of horns based on these principles is being prepared.

An interesting feature of the horn which has been built commercially is its method of folding. The sketch in Fig. 19 shows a shadow picture of the horn. It will be noticed that the sound passage is folded only in its thin direction, which permits the radius of the turns to be small and thereby makes the folding compact.

Fig. 20 shows the frequency characteristic of a phonograph designed as shown above with a logarithmic horn whose rate of taper and area of mouth opening place the low cut-off at about 115 cycles. It also shows the characteristics of one of the best of the old style phonographs. Curve *A* represents the new machine, while Curve *B* represents the old style standard machine.

Development and Application of Loading for Telephone Circuits

BY THOMAS SHAW[1] and WILLIAM FONDILLER[2]
Member, A. I. E. E. Member, A. I. E. E.

***Synopsis.**—A review of the art of loading telephone circuits as practised in the United States. The introductory section briefly reviews the theory of coil loading, and summarizes the principle characteristics of the first commercial standard loading coils and loading systems, thereby serving as a background for the description of the various improvements of outstanding importance which have been made in the loading coils and loading systems during the past fifteen years to meet the new or changing requirements in the rapidly advancing communication art.*

These major improvements are described in detail under the appropriate headings (1) Phantom Group Loading, (2) Loading for Repeatered Circuits, (3) Incidental Cables in Open-Wire Lines, (4) Cross-talk, (5) Telegraphy over Loaded Telephone Circuits, (6) Loading for Exchange Area Cables, and (7) Submarine Cables. The discussion of these various developments sets forth the relations between the loading features and the associated phases of telephone development, such as the cables, repeaters, telegraph working, and carrier telephone and telegraph systems.

The concluding part of the paper gives some general statistics regarding the extent of the commercial application of loading in the United States, and a brief statement indicative of the large economic importance of loading to the telephone using public.

INTRODUCTION

THE purpose of this paper is to present a review of the art of loading telephone circuits by means of inductance coils inserted at periodic intervals, as practised in the United States. In a paper[3] presented before the Institute in 1911, Mr. B. Gherhardi described the developments in loading up to that time and gave a comprehensive statement of the results obtained. The present paper, therefore, deals primarily with the subsequent developments in the art and their application. The more important improvements which will be considered here, are as follows:

Phantom Group Loading
Loading for Repeatered Circuits
Incidental Cables in Open-Wire Lines
Crosstalk
Telegraphy over Loaded Telephone Circuits
Loading for Exchange Area Cables

1. American Telephone & Telegraph Company, New York, N. Y.

2. Bell Telephone Laboratories, Inc., New York, N. Y.

3. *Commercial Loading of Telephone Circuits in the Bell System*, B. Gherardi, TRANS. A. I. E. E., Vol. XXX, 1911.

Abridgment of paper presented at Midwinter Convention of the A. I. E. E., February 8-11, New York, N. Y. Complete copies to members on application.

THEORY

Viewed from the standpoint of the power engineer, the general effect of loading is to raise the line impedance and improve the power factor. This makes it possible to transmit a given amount of power corresponding to speech sounds at a higher line potential and with a lower value of line current than would be possible without the loading. In the non-loaded line, which is inherently a low impedance line, the series dissipation losses which are proportional to the square of the line current are ordinarily very large relative to the shunt dissipation losses which are proportional to the square of the line potential. Consequently, when the line impedance is increased by a suitable amount, the reduction in series losses is much greater than the increase in shunt losses, and a substantial improvement in line efficiency is obtained. The optimum impedance for minimum line loss is that which results in the shunt and series losses being equal. Ordinarily, it is not economical to apply a sufficient amount of loading to reach this condition.

In general, commercial power lines are electrically short in terms of the wave length of the transmitted frequency, and consequently the sending-end impedance is very largely influenced by the receiving-end impedance. This allows high impedance lines to be

obtained by using high ratio transformers at the receiving end to step up the terminal impedance. On the other hand, telephone lines which are of interest from the loading standpoint are electrically long, and their sending-end impedance is practically unaffected by the terminal impedance. Consequently, the addition of series inductance to the line is the most

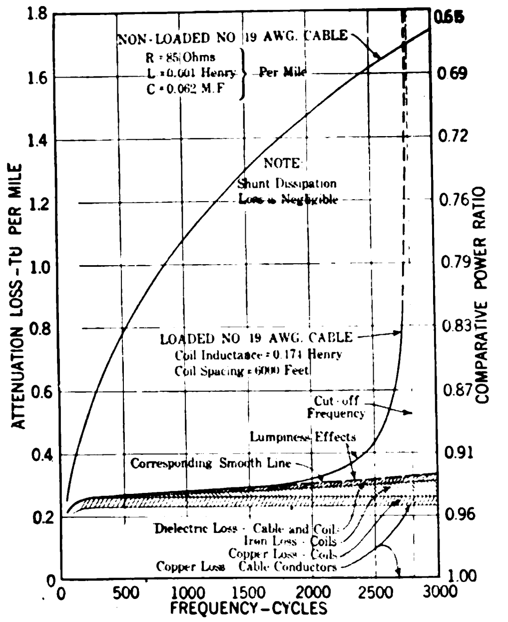

FIG. 1—ATTENUATION-FREQUENCY CHARACTERISTICS OF LOADED AND NON-LOADED NO. 19 A. W. G. CABLE

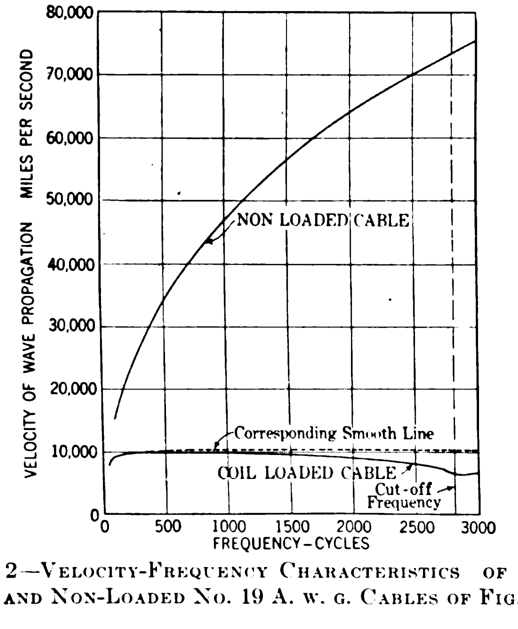

FIG. 2—VELOCITY-FREQUENCY CHARACTERISTICS OF LOADED AND NON-LOADED NO. 19 A. W. G. CABLES OF FIG. 1

practical way of increasing the telephone line impedance.

Besides reducing the line losses and the velocity of propagation, the addition of series inductance makes the attenuation and velocity substantially independent of frequency over the frequency range where the inductive reactance is large relative to the line resistance. This reduction of frequency distortion is especially important in cable circuits, since non-loaded cables have a negligible amount of distributed inductance.

Investigating the question of concentrating the line inductance at uniformly spaced intervals, Professor Pupin gave his famous solution in a paper[4] presented before the Institute in May 1900. Doctor G. A. Campbell, in his paper[5] of March 1903, also gave a mathematical development of the loading theory along somewhat different lines. These early investigations showed the beneficial effects of the lumped inductances and pointed out that these desirable effects hold up to a certain critical frequency which is known as the cutoff frequency, since at this frequency and higher frequencies the attenuatian loss amounts practically to a suppression, due to internal reflection effects. The cutoff

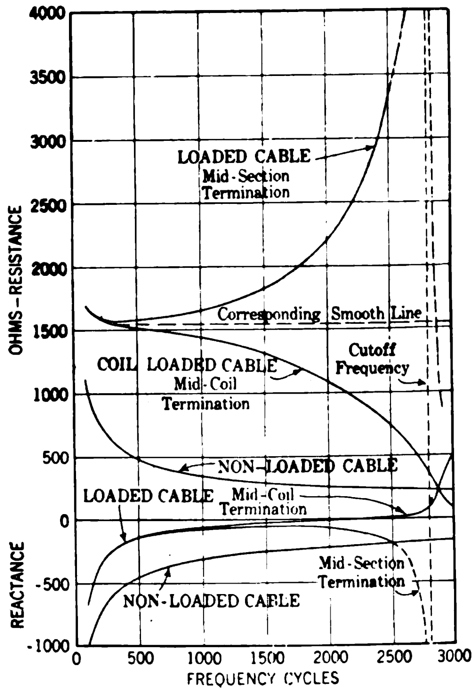

FIG. 3—IMPEDANCE-FREQUENCY CHARACTERISTICS OF LOADED AND NON-LOADED NO. 19 A. W. G. CABLES OF FIG. 1

frequency of a coil loaded line having zero distributed inductance is given by the expression:

$$f_c = \frac{1}{\pi \sqrt{L s C}}$$

in which

f_c = cut-off frequency
L = coil inductance
s = coil spacing
C = line capacitance per unit length

At the cut-off frequency there are two coils per actual

4. *Wave Transmission over Non-Uniform Cables and Long Distance Air Lines*, M. I. Pupin, TRANSACTIONS A. I. E. E., Vol. XVII, 1900, p. 445. Refer also to Pupin U. S. Patents Nos. 652, 230 and 652, 231, June 19, 1900.

5. *On Loaded Lines in Telephone Transmissions*, G. A. Campbell, *Philosophical Magazine*, March 1903.

wave length, and π coils per wave length in terms of the velocity of the corresponding smooth line. At frequencies above 75 per cent. of the cut-off frequency, the internal reflection effects, sometimes known as "lumpiness effects," are of appreciable magnitude and increase rapidly with rising frequency as the cut-off frequency is approached. At the cut-off frequency, abrupt changes also occur in the velocity and impedance characteristics.

Figs. 1, 2 and 3 illustrate the differences in attenuation, velocity, and impedance characteristics of a typical telephone cable, with and without loading. It is interesting to note that the standard type of loading illustrated in these diagrams so increases the transmission efficiency of No. 19 A. w. g. cable wires that the loaded circuits can be used for distances four times the permissible length of the non-loaded circuits. To obtain this increased transmission range without loading would require wires about eight times as heavy; *i. e.*, No. 10 A. w. g.

Phantom Group Loading

Loading Methods. The Bell System standard methods[6] for loading phantom circuits and side circuits of phantoms are illustrated in Fig. 4.

The loading problem is to introduce the desired inductance into each of the three circuits of a phantom group without causing unbalances which would result in objectionable overhearing or crosstalk effects. The method illustrated in Fig. 4 involves individual loading coils for each telephone circuit, the designs being such that the side circuit coils are substantially non-inductive to the phantom circuit, while the phantom loading coil is substantially non-inductive to each of the side circuits.

Cable Loading. Data regarding the general characteristics of the first phantom group loading systems standardized for use on quadded telephone cables are given in Table V, as follows:

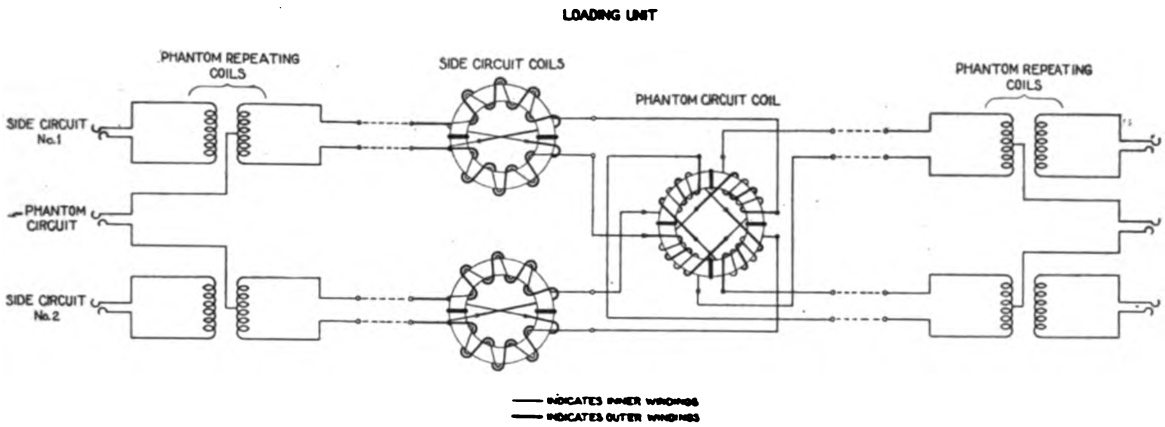

Fig. 4—Bell System Standard Method of Loading Phantom Circuits and Their Side Circuits

TABLE V
FIRST LOADING STANDARDS FOR QUADDED TOLL CABLES

Item	Loading Designation	Type Circuit	Coil Inductance (Henrys)	Coil Spacing (Miles)	Nominal Impedance (Ohms)	Attenuation Loss—TU per mile 19 A. w. g.	16 A. w. g.	13 A. w. g.	10 A. w. g.
1	Medium-Heavy	Side	0.210	1.4	1500			0.085	0.050
2	" "	Phantom	0.130	1.4	950			0.069	0.040
3	Heavy	Side	0.250	1.25	1850			0.081	0.050
4	"	Phantom	0.155	1.25	1150			0.066	0.042
5	Heavy	Side	0.250	1.25	1850	0.24	0.14		
6	"	Phantom	0.155	1.25	1150	0.20	0.12		
7	Medium	Side	0.175	1.75	1300	0.31	0.17		
8	"	Phantom	0.106	1.75	800	0.26	0.14		

Notes: A capacitance of 0.062 μf. per mile is assumed in side circuits and 0.100 μf. per mile in the phantom circuit. The pair capacitance value is smaller than that assumed in Table II. due to improvements in the cables.
All of the above loading systems have a cut-off frequency of about 2300 cycles.

Loading Coils. Table VII gives general information regarding the first standard side circuit and phantom coils used in the phantom group loading systems listed in Table V. The coils designed for No. 10 A. w. g. cable had 65-permeability wire cores and stranded copper windings. The coils designed for No. 13 A. w. g. cables had 65-permeability wire cores and non-stranded copper windings. The coils for Nos. 16 and 19 A. w. g. cables had 95-permeability wire cores.

Loading for Repeatered Circuits

General. In the development of telephone repeaters to the point where they could be used for commercial

6. U. S. Patents No. 980,021, *Loaded Phantom Circuit*, G. A. Campbell and T. Shaw, and No. 981,015, *Phantomed Loaded Circuit*, T. Shaw.

service in extending the range of telephone transmission, the adaptation of the lines to the requirements of repeater operation was secondary in importance only to the development of satisfactory repeater elements and circuits for associating the repeater elements with the lines[7].

TABLE VII
FIRST STANDARD LOADING COILS FOR PHANTOM WORKING

Type Line	Inductance (Henrys)	Coil Code No.	Type Circuit	Average Resistance-Ohms D-C.	Average Resistance-Ohms 1000 cycles	Overall Dimensions Diameter (In.)	Overall Dimensions Height (In.)
Open-Wire	0.265	512	Side	5.0	8.4	9.0	4.0
	0.163	511	Phantom	2.5	4.4	11.0	4.9
10-A. w. g. Cable	0.210	520	Side	3.8	6.6	8.5	3.5
	0.130	519	Phantom	1.9	3.4	10.4	4.0
	0.250	532	Side	4.1	7.8	8.5	3.5
	0.155	531	Phantom	2.1	3.9	10.4	4.0
13-A. w. g. Cable	0.205	538	Side	6.0	9.2	5.7	2.5
	0.130	521	Phantom	3.0	4.5	7.9	3.0
	0.250	534	Side	6.6	10.7	5.7	2.5
	0.155	533	Phantom	3.3	5.3	7.9	3.0
16 and 19-A. w. g. Cable	0.250	515	Side	8.9	23.1	4.6	2.4
	0.155	530	Phantom	4.4	11.9	5.9	2.9
	0.175	514	Side	5.4	14.4	4.6	2.4
	0.106	513	Phantom	2.7	7.1	5.9	2.9

NOTE. The resistance data apply to circuits of a complete phantom group: *i. e.*, the side circuit data include effects of the phantom coils, and phantom circuit data include effects of the side circuit coils. Effective resistance values correspond to line current of 0.002 ampere.

Early Work—Reduction of Line Irregularities. Commercial telephony, requiring two-way transmission, imposes severe balance requirements on repeater circuits over the entire band of frequencies which the repeater is designed to transmit. The solution of this problem required (a) the construction of lines having extremely regular impedance features, (b) the development of balancing networks[8] capable of accurately simulating the impedance characteristics of the improved lines throughout the working frequency range, and (c) the use of electric wave filters[9] in the repeater sets which cut off somewhat below the cutoff frequency of the loading.

In loaded lines, the uniformity requirements call for the loading coils to have very closely the same inductance value and to be capable of resisting the magnetizing effects of abnormal service conditions; also the sections of line between loading coils should have closely the same value of capacitance.

Transcontinental Lines—High Stability Loading Coils. The inauguration of commercial transcontinental telephone service over the New York-San Francisco line in January 1915 marked the first commercial application of the general improvements in regularity of line construction, including the use of an improved type of loading coil having a very high degree of magnetic stability.

In the development of the improved coils the requirement laid down was that the inductance to speech currents should not be changed more than about two per cent when a magnetizing current of two amperes was passed through any of its line windings. In the older types of coils, this severe magnetization condition caused a drop of about 30 per cent in the coil inductance: The new design which was adopted involved the use of two air gaps at opposite points in the (iron wire) cores of loading coils[10], suitable clamping means being provided to hold the coil halves in proper alignment. Data regarding these coils are given in Table VIII. To assist in getting a maximum degree of line regularity, these coils were adjusted in the factory to meet ± 1 per cent inductance limits. In the older types of coils ± 5 per cent deviations had been allowed.

In the case of coarse gage cable circuits, installed prior to the advent of repeaters, the new requirements were met by the design of an air-gap type of wire core coil on which data are given in Table VIII.

TABLE VIII
HIGH STABILITY COILS HAVING WIRE CORES WITH AIR GAPS

Type Loading	Coil Code No.	Type Circuit	Inductance henrys	Average Resistance Ohms D-C.	Average Resistance Ohms 1000-Cycles	Overall Dimension Inches Diameter	Overall Dimension Inches Hgt.
Open Wire	550	Side	0.245	5.4	11.1	8.1	3.9
" "	549	Phantom	0.150	2.7	6.4	10.0	4.0
10 and 13 A. w. g. Cable	556	Side	0.255	7.0	14.0	5.6	2.9
	555	Phantom	0.155	3.5	7.0	7.5	3.6
10 and 13 A. w. g. Cable	558	Side	0.200	6.2	10.9	5.6	2.9
	557	Phantom	0.135	3.1	5.9	7.5	3.6

NOTES. Open-wire coils used in Loading Systems, Tables III and VI. Cable coils used in Loading Systems, Table V.
Resistance data apply to side circuits and phantom circuits of complete phantom groups. Effective resistance values are for 0.002 ampere line current.

Compressed Powdered Iron Core Loading Coils. The use of telephone repeaters made it possible in new cable installations to supersede the No. 10 and No. 13 A. w. g. gage conductors by No. 16 and No. 19 A. w. g. conductors. This development greatly increased the need for an efficient and stable loading coil of lower cost than the air-gap wire core coil. To meet this need there was standardized early in 1916 a new magnetic material, compressed powdered iron, which has been of the utmost value in loading coil design[11]. Briefly,

7. *Telephone Repeaters*, B. Gherardi and F. B. Jewett, TRANS. A. I. E. E., Vol. XXXVIII, 1919.

8. R. S. Hoyt "Impedance of Loaded Lines and Design of Simulating and Compensating Networks," Bell System *Technical Journal*, July, 1924.

9. U. S. Patent Nos. 1,227,113 and 1, 227,114 G. A. Campbell.

10. U. S. Patents Nos. 1,289,941 and 1,433,305, Shaw and Fondiller.

11. U. S. Patents Nos. 1,274,952 B. Speed, 1,286,965 G. W. Elmen, 1,292,206 J. C. Woodruff.

the method of production consists of grinding electrolytically deposited iron to the desired fineness, insulating the particles, and finally compressing these insulated particles in steel dies at very high pressures. The compressed powdered iron core by virtue of its very numerous, though extremely small distributed air gaps, has a very high degree of magnetic stability[12].

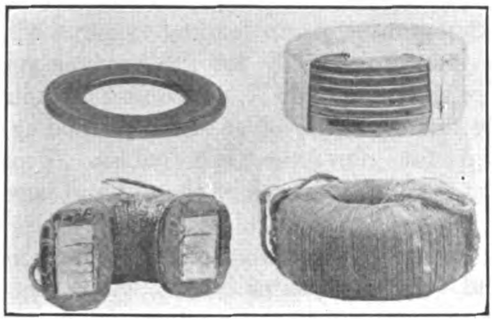

Fig. 6—Compressed Powdered Iron Core Loading Coil

Fig. 6 gives photographs of (a) a standard compressed iron powder core ring such as is used in the cores of toll cable loading coils: (b) a completely assembled core with part of the core taping removed: (c) a completely wound coil of the side circuit type: and (d) a coil in cross-section.

The first standard powdered iron cores had an

TABLE IX
TYPICAL COMPRESSED POWDERED IRON CORE LOADING COILS

Coil Code No.	Core Permeability	Inductance (henrys)	Type Circuit	Resistance Ohms D-C.	Resistance Ohms 1000-Cycles	Dimensions Inches Diameter	Dimensions Inches Height
562	60	0.250	Side	11.4	25.8	4.5	2.1
561	60	0.155	Phantom	5.7	11.7	6.3	3.0
564	60	0.175	Side	6.6	15.4	4.5	2.1
563	60	0.106	Phantom	3.3	6.7	6.3	3.0
582	35	0.250	Side	15.9	21.8	4.7	2.4
581	35	0.155	Phantom	8.0	10.0	6.7	3.1
584	35	0.175	Side	10.8	14.1	4.7	2.4
583	35	0.106	Phantom	5.4	6.6	6.7	3.1
584	35	0.175	Side	12.1	15.3	4.7	2.4
587	35	0.063	Phantom	6.1	7.0	4.7	2.8
590	35	0.044	Side	4.0	4.6	4.7	2.4
591	35	0.025	Phantom	2.0	2.0	4.7	2.8

Note. Resistance values apply to side circuits and phantom circuits of complete phantom groups. Effective resistance corresponds to 0.002-ampere line current.

These coils are used in the loading systems listed in Tables V and X.

effective permeability of about 60. Further developments resulted in the standardization of an improved grade of compressed powdered iron core having a permeability of 35. Coils having this new material 60-permeability compressed core coils were restricted to interoffice trunks and to short toll cables operated without superposed telegraph. Data on these two types of coils are given in Table IX.

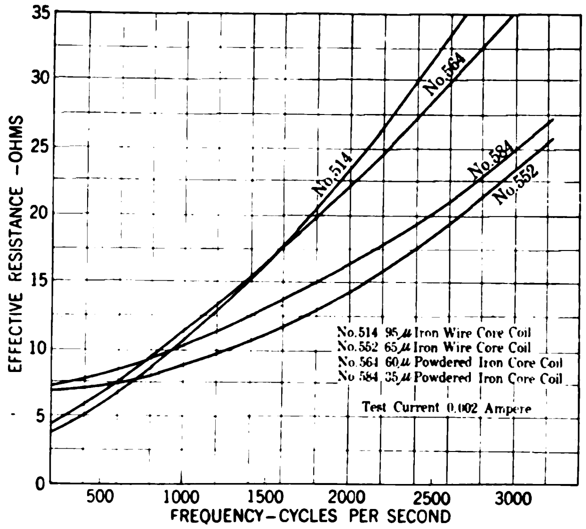

Fig. 7—Effective Resistance-Frequency Characteristics Toll Cable Loading Coils

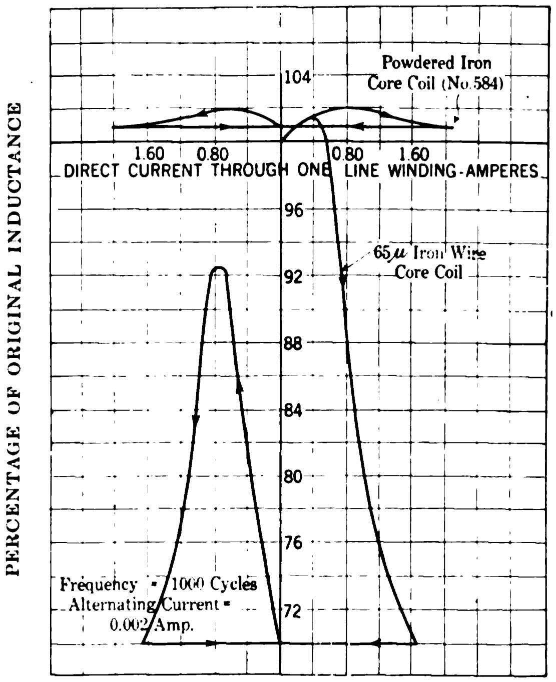

Fig. 8—Residual Magnetization Characteristics of Compressed Powdered Iron Core and Iron Wire Core Loading Coils

The effective resistance-frequency characteristics of 60-permeability and 35-permeability compressed powdered iron core coils and the older 95-permeability and 65-permeability wire core coils having the same inductance (0.175 henry) and the same overall size, are given in Fig. 7. The large improvement as to freedom from residual magnetization effects afforded by the 35-

12. *Magnetic Properties of Compressed Powdered Iron*, B. Speed and G. W. Elmen, Trans. A. I. E. E., Vol. XL, 1921.

permeability powdered iron core, compared with the old standard 65-permeability wire core coil is evident from the curves of Fig. 8.

The value of the compressed powdered iron core coil in the modern loading art has been recognized to the extent of its adoption as an international standard for repeatered circuits[13].

New requirements for Cable Loading Systems. The completion of the development of a satisfactory commercial type of telephone repeater marked the beginning of a long period of experimental work for the purpose of determining the commercial possibilities of the use of repeaters over long cable circuits. During these experiments, as the lengths were increased, echo and velocity distortion effects became increasingly troublesome, and it became apparent that improved loading would be necessary in order to realize the full possibilities of the use of repeaters.

Echoes. Echoes are due to unbalance currents, *i. e.*, to reflections of electrical energy at points of impedance irregularity in the circuits. When the circuit is so long that the time of transmission from the point of reflection to the disturbed subscriber station is appreciable, there will be echo effects, unless the losses in the circuit are so large as to cause the reflected energy to become inappreciably small.

Velocity Distortion. The velocity distortion in long lines is noticeable during the building up and dying down periods, when it manifests itself as transient distortion. The duration of transient distortion depends, among other factors, upon the length of the line, the nominal velocity, and the cut-off frequency of the loading. A substantial reduction in the transient distortion has been obtained in the new standard loading systems by raising the cutoff frequency as well as the velocity of the loading.

Experimental data regarding transient distortion is given in an Institute paper[14] by Mr. A. B. Clark and the results of theoretical studies are given in an earlier Institute paper[15] by Mr. J. R. Carson.

Characteristics of Improved Cable Loading Systems. The principal electrical features of the H-44-25 and H-174-63 phantom group loading systems which have been developed primarily for use on long repeatered cables are given in Table X, which also includes corresponding details of the older standard loading systems developed for non-repeatered cables. Typical attenuation-frequency curves of the old and new loading systems are given in Fig. 10.

Table XI lists the combinations of loading, conductor gage and type of repeater circuit which are used in meeting the wide range of commercial requirements. The position of the facility item in the table indicates the sequence of transmission excellence, item (*i*) being the highest grade facility in this respect.

For a further discussion of the use of repeatered loaded lines the reader is referred to recent papers presented before the Institute by Mr. J. J. Pilliod[16] and Mr. H. S. Osborne[17].

Attenuation—Frequency Distortion. In addition to their improved velocity and cut-off frequency characteristics, the H-44-25 and H-174-63 loading systems

TABLE X

LOADING SYSTEMS—SMALL GAGE REPEATERED TOLL CABLES

Item	(*a*) Loading System	Circuit	(*b*) Coil Code No.	Nominal Impedance (Ohms)	Nominal Cut-off Frequency (Cycles)	Transmission Velocity Miles-per Second	(*c*) Attenuation Loss TU per Mile at 1000 Cycles 19 A. w. g.	16 A. w. g.	(*d*) Maximum Geographical Length (Miles)
(1)	H- 44-25	Side	590	800	5600	19000	0.48	0.25	5000
(2)	"	Phantom	591	450	5900	20000	0.40	0.21	5000
(3)	H-174-63	Side	584	1550	2800	10000	0.28	0.16	500
(4)	"	Phantom	587	750	3700	13000	0.28	0.16	1500
(5)	H-174-106	Side	584	1550	2800	10000	0.28	0.16	500
(6)	"	Phantom	583	950	2900	10000	0.22	0.13	500
(7)	H-245-155	Side	582	1850	2400	8000	0.25	0.16	250
(8)	"	Phantom	581	1150	2400	8000	0.20	0.12	250

Notes: (*a*) Nominal coil spacing is 6000 feet in cable having a capacitance of 0.062 μf per/mile in the side circuits and 0.100 μf per mile in the phantom circuit.

(*b*) The loading coil data are given in Table IX.

(*c*) These attenuation values apply at 55 deg. fahr. Under extreme temperature conditions, the actual attenuation may be approximately 12 per cent larger or smaller, due principally to changes in conductor resistance with temperature. In long repeatered cable circuits these variations of attenuation with temperature require special corrective treatment by means of automatic transmission regulators.

(*d*) The length limitations are set by transient distortion effects; echo currents may limit circuit lengths to lower values, depending on the grade of balance of the lines and the permissible over-all loss.

13. Minutes of Second Conference of Permanent Commission, Le Comité Consultatif Internationale de Communications Telephonique a Grande Distance, Page 55 (Page 119 of English Version.)

14. *Telephone Transmission over Long Cable Circuits*, A. B. Clark, TRANS. A. I. E. E., Vol. XLII, 1923.

15. *Theory of the Transient Oscillations of Electrical Networks and Transmission Systems*, J. R. Carson, TRANS. A. I. E. E., Vol. XXXVIII, 1919.

16. *Philadelphia-Pittsburgh Section of New York-Chicago Cable*, J. J. Pilliod, TRANS. A. I. E. E., Vol. XLI, 1922.

17. "Telephone Transmission over Long Distances" H. S. Osborne, TRANS. A. I. E. E., Vol. XLII, 1923.

have an important advantage from the standpoint of attenuation-frequency distortion effects, as is illustrated in Figs. 10 and 11. The heavy line curves in Fig. 11 apply to a 500-mile No. 19 A. w. g. cable circuit, assuming that repeaters which give the same gain at all frequencies are used in each case to reduce the total line loss to 10 *T U* at 1000 cycles. The dotted lines in

TABLE XI
TYPES OF TOLL CABLE FACILITIES

Item No.	Length Circuit	Cable Gage	Type of Loading	Type Circuit	Type Repeater
(a)	(short)	19	H-174-63	2-wire	—
(b)		16	"	"	—
(c)		19	"	"	21
(d)		16	"	"	21
(e)		19	"	"	22
(f)		16	"	"	22
(g)		19	"	4-wire	44
(h)		16	H- 44-25	2-wire	22
(i)	(very long)	19	"	4-wire	44

Fig. 11 give corresponding curves for non-repeatered cables (No. 19 A. w. g.) having the same types of loading as before, in each case the length being chosen so that the circuits have a 10 *T U* loss at 1000 cycles.

In very long lines, the line losses, even with the best grade of loading, may cause sufficient distortion to require the use of correcting devices. The improvement obtainable by suitably designed repeaters is illustrated by an appropriately marked dot-dash curve in Fig. 11 which gives the attenuation-frequency characteristic of a 500-mile H-44-S circuit (No. 19 A. w. g.) as set up for commercial service.

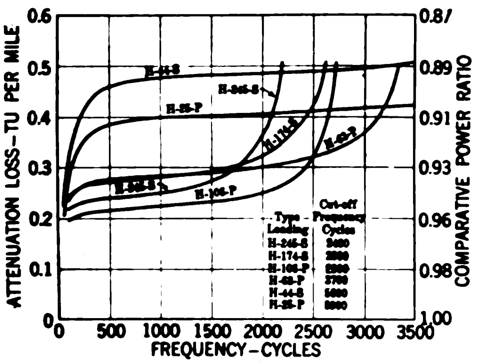

Fig. 10—Attenuation-Frequency Characteristics of Toll Cable Loading

In connection with the foregoing discussion, it is important to keep in mind the fact that coil loading substantially improves the attenuation and substantially reduces the frequency distortion at a cost which is much lower than the cost of the additional repeaters and distortion corrective networks which would be required to give the same grade of transmission without using loading.

Cost considerations make it desirable to use aerial cable in the long toll cable installations. On the main trunk cables an aerial fixture capable of supporting 4 or 6 large coil pots is required. A fixture of this type is illustrated in Fig. 12.

Long Repeatered Open-Wire Lines. The use of improved types of repeaters now makes it economical to secure better transmission results in long open-wire circuits without loading, than can be secured in loaded repeatered lines. This is because in non-loaded open-wire lines the distributed inductance is sufficiently large to keep the frequency distortion low; also, the transmission velocity is relatively very high.

Loading is now being removed from the important lines and it is expected that new applications of loading will generally be limited to isolated cases of short lines,

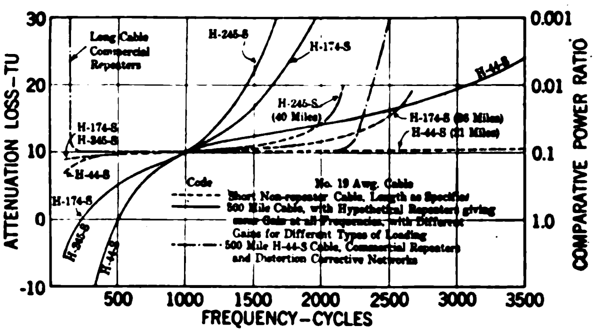

Fig. 11—Attenuation-Frequency Characteristics of Short and Long Loaded Toll Cable Circuits having a Net Attenuation Loss of 10 *TU* at 1000 Cycles

where carrier telephone or telegraph systems are not contemplated or where the maintenance and operating conditions are unfavorable to the use of telephone repeaters.

Loading for Incidental Cables in Open-wire Lines

In the loading application discussed in the other sections, the primary purpose of the loading is to reduce

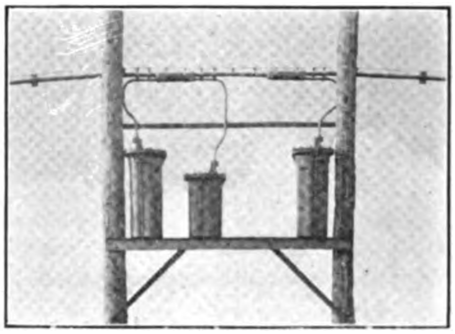

Fig. 12—Installation of Aerial Toll Cable Loading on 4-Case "H" Fixture

line attenuation losses and frequency distortion effects. In the case of incidental pieces of cable in open-wire lines, however, the primary function of the loading is to give the inserted cable approximately the same characteristic impedance as the open-wire line, in order to minimize junction reflection effects. This particular type of loading is becoming increasingly important because of the rapidly increasing use of repeaters on open-wire lines.

In incidental cables associated with loaded open-wire

lines, the primary requirements for matching impedance, are that the nominal impedance ($\sqrt{L/C}$) and the cut-off frequency of the loaded cable and of the loaded line should be closely the same. The E-248-154 phantom group cable-loading system listed in Table XII meets these general requirements.

The loading problem for an incidental cable in a non-loaded open-wire line requires an impedance match between a smooth line and a lumpy line, and therefore involves some degree of compromise, because

TABLE XII
TYPICAL LOADING SYSTEMS FOR TOLL ENTRANCE AND INTERMEDIATE CABLES

Loading System Designation	Type Circuit	Coil Inductance Henrys	Coil Spacing Miles	Nominal Impedance Ohms	Cut-off Frequency Cycles	Attenuation Loss TU per Mile at 1000 Cycles	
E-28-16	Side	0.028	1.09	650	7200	0.15	(13 A.w.g.)
	Phantom	0.016	1.09	400	7800	0.13	
CE-4.1-12.8	Side	0.0041	0.176	600	45000	0.22	(13 A.w.g.)
	Phantom	0.0128	1.09	400	8500	0.19	
M-44-25	Side	0.044	1.66	650	4600	0.29	(16 A.w.g.)
	Phantom	0.025	1.66	400	4900	0.24	
E-248-154	Side	0.250	1.09	1950	2400	0.081	(13 A.w.g)
	Phantom	0.155	1.09	1200	2500	0.070	

NOTE. Cable capacitance is assumed to be 0.062 μf per mile for side circuits, and 0.100 μf per mile for phantoms.

of the dependence of the impedance of a coil-loaded cable upon the loading termination, as illustrated in Fig. 3. At frequencies above approximately 500

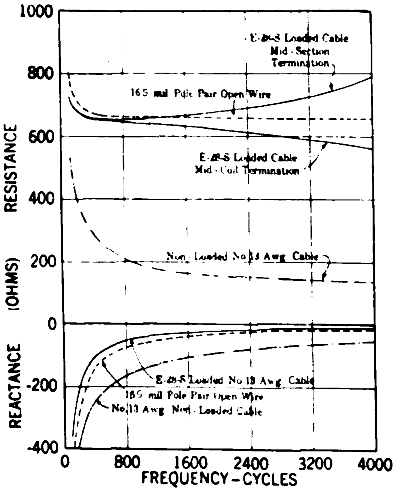

FIG. 14—TYPICAL IMPEDANCE-FREQUENCY CHARACTERISTICS OF LOADED AND NON-LOADED ENTRANCE CABLE AND NON-LOADED OPEN-WIRE LINE

cycles, the impedance of the non-loaded open-wire line is practically a non-inductive resistance, constant with frequency. On the other hand, with mid-section and mid-coil terminations, the impedance of the coil-loaded cable is substantially that of a non-inductive resistance as illustrated in Fig. 3. The higher the cut-off frequency of the loading, the more closely do these resistance-frequency curves approach the flat resistance-frequency curve of the non-loaded line, over the range of frequencies which the telephone repeaters are designed to transmit; provided, of course, that the cable loading also has the same nominal impedance as the non-loaded line. For plant simplicity and economy, it is desirable to use the same coil spacing in the different types of incidental cable-loading systems.

The above general considerations have led to the standardization of the E-28-16 loading system for use on cables associated with non-loaded open-wire lines. General data regarding this system are given in Table XII, and impedance frequency curves are given in Fig. 14.

Carrier-Frequency Loading. Special types of loading typified by the "CE-4.1-12.8" system in Table XII have been developed for use on incidental cables in non-loaded open-wire lines on which carrier telephone or carrier telegraph systems are superposed. The

TABLE XIII
CARRIER FREQUENCY LOADING

Frequency Kilocycles	Attenuation Loss - TU per Mile (13 A. w. g. Cable) Non-Loaded	C-4.1 Loading	Resistance-Ohms per Carrier Loading Coil
1	0.49	0.23	1.5
5	0.78	0.27	1.6
10	0.90	0.33	1.9
20	1.14	0.52	4.1
30	1.37	0.90	8.1

present standard carrier telephone systems operate up to frequencies of the order of 30,000 cycles.[18] Data regarding attenuation losses in a No. 13 A. w. g. cable with and without carrier loading are given in Table XIII.

The high-frequency loading is used only on the side circuits, since at the present time it is not customary to operate carrier telephone systems over phantom circuits. Carrier operation imposed upon the carrier-frequency coils involves new requirements as regards freedom from intermodulation between channels, and low energy losses at carrier frequencies. These requirements were met by using toroidal-type wood core coils with finely stranded copper windings. Typical resistance-frequency data are included in Table XIII.

CROSS-TALK

One of the greatest practical difficulties which has been encountered in extending the commercial range of long distance telephone service is that of keeping at a tolerably low value the speech overhearing known as cross-talk which occurs between adjacent telephone circuits whenever there is an appreciable amount of

18. "Carrier Current Telephony and Telegraphy," Colpitts and Blackwell, TRANS. A. I. E. E., Vol. XL, 1921, p. 205.

electromagnetic or electrostatic coupling between them. This difficulty is in part due to the fact that as the length of the line increases, there are more and more opportunities for unbalances in the lines and in the associated apparatus. Moreover, the repeaters amplify the cross-talk as well as the speech transmission. From the service standpoint, however, it is necessary that the cross-talk in the very long lines should be within the limits set for the shorter lines.

The problem of keeping cross-talk low between the individual circuits of a phantom group is by far the most difficult phase of the general cross-talk problem in long repeatered cables. The unbalances in the cable quads are reduced to small values by exercising great care in manufacture and by selective splicing at the time of installation. By design, the loading coils are substantially free from inherent unbalances, and great care is exercised in manufacture to realize the benefits of this inherent symmetry of design.

When repeaters came into general use it was found necessary to obtain much more refined adjustments than those previously made; so further improvements were worked out in several manufacturing processes. As a result of these various improvements, the unbalances in the loading coils are now only about one-fourth of the earlier values. For instance, the average cross-talk in the coils used for H-44-25 loading is now about 20 millionths of the disturbing current. This corresponds to an attenuation of about 95 *T U*.

To assist in visualizing the real achievement which this minute value of phantom-to-side cross-talk represents, Table XIV gives information regarding the cross-talk effects of different elementary types of unbalance in H-44-25 loading coils:

TABLE XIV
CROSSTALK DUE TO UNBALANCE IN H-44-25 LOADING COILS

Type of Unbalance	Amount of Cross-talk
1 ohm resistance	400 millionths (68 TU)
1 micro-henry inductance	2.5 " (112 TU)
1 turn of winding	280 " (71 TU)
1 micro-microfarad capacitance	0.94 " (121 TU)

The cross-talk current caused by electromagnetic unbalances flows around the two ends of the disturbed circuit in series. On the other hand, the cross-talk current caused by electrostatic unbalances divides and flows from its point of origin in opposite directions around the two ends of the circuit in parallel. Consequently, when electrostatic and electromagnetic cross-talk currents are in phase at one end of the circuit, they tend to be in phase opposition at the other end of the circuit. The special cross-talk adjustments are made in such a way as to obtain the maximum benefit from the phase-opposition effects at the particular end of the circuit where these reductions are more important, *viz.*, at the "near-end" for two-wire circuits and at the "far end" for four-wire circuits.

Unbalances in loaded circuits which contribute to noise due to induction from power transmission and distribution circuits are similar in nature to those contributing to cross-talk. The precautions which are taken in the design, manufacture, and installation of loaded circuits to reduce unbalances have the effect, therefore, of reducing both cross-talk and noise.

Telegraphy Over Loaded Telephone Circuits

After the introduction of loading it was desirable to continue superposing d-c. ground return telegraph currents on telephone circuits. As the lengths of the loaded circuits increased, the interaction between the telegraph and telephone currents which has been designated in an Institute paper[19] as "flutter," was aggravated and serious distortion of speech resulted. Considerable study was given to the flutter problem, and important improvements were made by changes in the design of the magnetic circuit and improved core materials.

The increasing use of long repeatered toll cables brought about a need for further reduction in flutter distortion which was met by the development of a metallic telegraph system in which the amplitude of telegraph currents is of the same order of magnitude as the telephone current[20].

More recently the development of a voice-frequency carrier telegraph system[21] providing ten or more independent channels over a loaded four-wire cable circuit has made it economical to concentrate a large part of the telegraph service over the long repeated cables on a special group of wires which is not used simultaneously for telephone purposes.

Recent Improvements in Loading for Exchange Area Cables

The first important change in the exchange area loading standards occurred about 1916, when compressed powdered-iron core coils came into general use in place of the old standard wire core coils. In the period 1922-24, the use of new types of fine wire cables had reached a point which required changes in the loading systems and accordingly, a new series of improved loading systems having a considerably higher cut-off frequency, were developed.

Cable Development. Notable advances have been made in the art of cable manufacture during the last decade, including the standardization of 450-pair No. 19 A. w. g. cable, 900-pair No. 22 A. w. g. cable, and 1200-pair No. 24 A. w. g. cable, all within standard full-

19. "Hysteresis Effects with Varying Superposed Magnetizing Forces," W. Fondiller and W. H. Martin, Trans. A. I. E. E. Vol. XL, 1921, p. 553.

20. "Metallic Polar-Duplex Telegraph System for Cables," Messrs. Bell, Shanck and Branson, presented at Midwinter Convention of the A. I. E. E., Feb., 1925, Abridgment published in Journ. A. I. E. E., April, 1925, p. 378.

21. "Voice-frequency Carrier Telegraph Systems for Cables," Messrs. Hamilton, Nyquist, Long and Phelps, Journ. A. I. E. E., March, 1925, p. 213.

sized sheaths (2 5/8 in. outside diameter). The 50 per cent increase in the number of circuits over the older cable designs was accompanied by a substantial increase in the mutual capacitance.

The use of the old standard loading systems on the new types of cables would have resulted in an objectionable impairment of quality, due to the reduction of the cut-off frequency resulting from the increased cable capacitance. Also the types of loading coils available were more expensive than could be justified for permanent standards on the low cost fine wire cables.

Determination of New Cut-off Frequency Standard. A coil design cost-balance study was taken up as one phase of a general transmission-cost study of exchange area transmission, which also included a theoretical investigation of cut-off frequency standards.

It was found that an increase in the cut-off frequency of exchange area loading up to about 3000 cycles could be justified; the increased costs for materially higher cut-off frequencies would have been unduly large in proportion to the resultant improvement in transmission.

New Standard Loading System. The new standard exchange area loading systems make as much use as is practicable of the old standard coil spacings and inductance values, in order to minimize the expense of rearranging the existing loading to conform to the new standards, and at the same time make full use of the large number of available loading vaults and manholes. General data regarding these new standards are given in Table XV.

TABLE XV
NEW LOADING STANDARDS FOR EXCHANGE AREA TRUNKS

Loading Designation	Coil Spacing Feet	Coil Code Nos.	Approx. Cut-off Frequency Cycles: High Capacitance Cable	Approx. Cut-off Frequency Cycles: Low Capacitance Cable
M-88	9000	602	2900	3200
H-135	6000	603	2800	3200
H-175	6000	574	——	2800
D-175	4500	574	2900	3200

NOTE. High capacitance cable has approximately 0.083 μ per mile. Low capacitance cable has approximately 0.066 μf per mile.

The M-88 system is especially suitable for the shorter lengths of fine wire trunk cables which will constitute the bulk of the exchange area trunk mileage. In longer trunks, the other more expensive loading systems find their field of service. The H-175 system is limited to low capacitance cables because of the lower cut-off effects on high capacitance cables, but has considerable commercial importance because of the large number of low capacitance cables now in the plant.

Table XVI gives some general transmission data on typical exchange area trunks using the new loading systems, including also non-loaded trunks. Attenuation-frequency curves of some of these trunks are given in Fig. 15, which includes also a dotted line curve for the old standard medium loading when used on 0.065 m. f., No. 19 A. w. g. cable.

In the application of the new standard loading systems, the same standards of over-all attenuation loss are adhered to, as in the older loading systems.

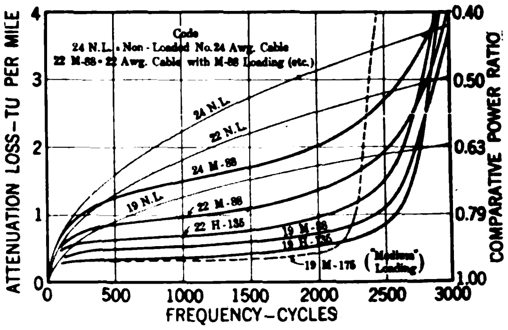

FIG. 15—ATTENUATION-FREQUENCY CHARACTERISTICS OF TYPICAL EXCHANGE AREA LOADED AND NON-LOADED CABLES

In consequence, there is an appreciable improvement in the intelligibility of transmission, due to the ability of the new loading systems to transmit efficiently a range of high-frequency voice over-tones which were suppressed by the old standard 2300-cycle cut-off systems. Along with this improvement in service,

TABLE XVI
TRANSMISSION CHARACTERISTICS OF TYPICAL EXCHANGE AREA TRUNKS

Cable Conductor A. w. g.	Capacitance μf./Mile	System	Coil Code No.	Cut-off Frequency Cycles	Circuit Impedance Ohms	Attenuation Loss TU per Mile
24	0.079	Non-loaded	—	—	740	2.2
22	0.083	" "	—	—	570	1.8
24	0.079	M-88	602	2900	900	1.48
22	0.083	M-88	602	2900	990	0.96
22	0.083	H-135	603	2800	1300	0.68
19	0.085	Non-loaded	—	—	400	1.27
22	0.083	D-175	574	2900	1690	0.53
19	0.083	M-88	602	2800	860	0.51
19	0.085	H-135	603	2800	1280	0.38
19	0.066	H-175	574	2800	1640	0.29
19	0.085	D-175	574	2800	1680	0.30
16	0.066	M-88	602	3200	960	0.24
16	0.066	H-135	603	3200	1420	0.20
16	0.066	H-175	574	2800	1640	0.17

NOTE. The impedance and attenuation figures hold at 1000 cycles. Impedance values for loaded circuits assume mid-section termination.

the new loading systems substantially reduce the plant cost, partly due to the economies which result from the extension of the transmission range of the new types of fine wire cables and partly because of the use of materially less expensive types of loading coils.

Loading Coils and Cases. Table XVII gives general data for the coils used in the new exchange area loading systems.

The standardization of the small size Nos. 602 and 603 loading coils has made it possible to design containing cases and assembly methods which permit

larger numbers of coils—up to 300—to be enclosed in the loading cases. Fig. 17 illustrates the operation of assembling the loading coils, previously spliced to the cable stub, into a 300-coil pot. The use of these larger potting capacities will be of considerable value in reducing the space congestion in the loading vaults in "downtown" districts of the larger metropolitan areas.

TABLE XVII

COILS FOR LOADING EXCHANGE AREA CABLES

Coil Code No.	Inductance (Henrys)	Core Permeability	Resistance-Ohms D-C.	Resistance-Ohms 1000 Cycles	Over-all Dimensions Inches Diameter	Over-all Dimensions Inches Height
602	0.088	35	8.9	10.5	3.6	1.3
603	0.135	35	12.8	14.1	3.6	1.3
574	0.175	60	4.6	10.6	4.5	2.1

Effective resistance values are for a line current of 0.001 ampere.

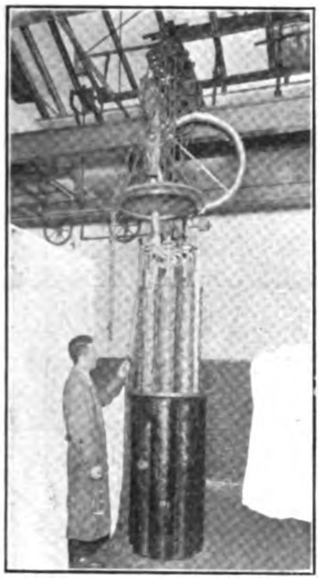

FIG. 17—ASSEMBLY OF 300-COIL CASE

Lowering loading coils into case after coil spindles have been mounted on frame and coil terminals spliced to stub cable conductors

In general, exchange area loading is installed in underground vaults or manholes. Fig. 18 shows a typical installation in a "double-deck" vault in New York City.

EXTENT OF COMMERCIAL APPLICATION

Conservative estimates set the total number of loading coils in service in the Bell System, as of January 1, 1926, at 1,250,000. These coils provide loading for about 1,600,000 miles of cable circuits and 250,000 miles of open-wire. In round numbers, 500,000 coils are installed on non-quadded local area trunk cables and 700,000 in toll entrance and toll cables (the bulk of these being quadded cables). Nearly two-thirds of the total number of coils have compressed-iron powder cores, all of these being installed on cable circuits. Recent estimates of the loading coil requirements for the next five years indicate an annual demand which will double the total number of loading coils in service by about 1930.

CONCLUSION

It will be appreciated from the foregoing account that the invention of coil loading was the beginning of an era of intensive development which has been marked by enormous advances in the design of telephone transmission lines, nor is there any slackening of the inventional or development activity devoted to this subject.

In conclusion, it may be of interest to note what the development and use of loading has meant to the telephone using public from an economic standpoint. Leaving out of consideration altogether loading on long toll cables—where the interdependence of repeaters and loading is such that it is impracticable to assign to each its share of the savings—and taking into consideration only the loading of interoffice trunks and toll open-wire circuits, it has been estimated that the larger wires which would have been required to give the present grade of transmission if loading had not been available, together with the heavier pole lines and additional underground ducts, would have entailed an additional investment in Bell System telephone plant of over $100,000,000.

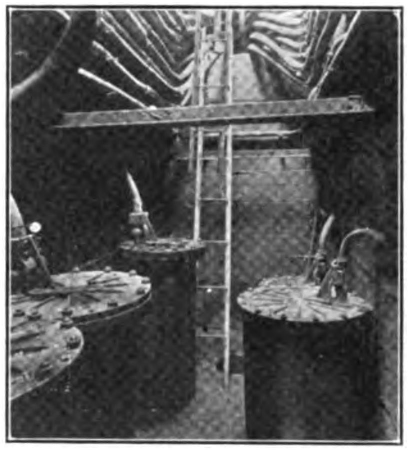

FIG. 18—UNDERGROUND CABLE LOADING COIL INSTALLATION IN METROPOLITAN AREA. DOUBLE-DECK VAULT HAVING ULTIMATE CAPACITY OF 14 LARGE COIL CASES

METHODS OF HARDENING HIGH-SPEED ROUGHING TOOLS

Since the discovery some 20 years ago of the benefits derived by subjecting certain chormium-tungsten or so-called high-speed steels to exceedingly high temperatures in hardening, much discussion has centered upon the best procedure and equipment for this heat treatment.

Some roughing lathe tool tests were recently made at the Bureau of Standards to determine whether or not such claims were justified. It was found that comparable performance was obtained when tools were raised to approximately equal temperatures for equal times in hardening.

No-Load Copper Eddy-Current Losses

BY THOMAS SPOONER[1]

Member, A. I. E. E.

***Synopsis.**—One of the factors which is sometimes responsible for very considerable losses in rotating machines is that of eddy-current losses in the copper conductors resulting from slot leakage flux produced by the main flux. These losses occur at no-load as well as under load and should not be confused with the copper losses resulting from the slot leakage flux produced by the load current. These no-load copper losses occur in salient pole machines, both d-c. and a-c., and in induction motors.*

This paper is an attempt to remove the calculation of no-load copper eddy-losses from the field of empiricism where it has previously been and to place it on a firm theoretical foundation. Test results are presented which show that the theoretical formulas which have been developed are correct.

Some of the consequences of this analysis are rather unexpected where the frequencies are sufficiently high to produce large skin effect. For instance, laminating the copper may produce increased or decreased losses, depending upon the conditions.

* * * * *

Introduction

The design of electrical apparatus is becoming so standardized, and the efficiencies so high, that further improvements in performance will probably come largely through attention to details which previously have been considered of somewhat minor importance. This paper considers one of these details which has, perhaps, not received as much attention as its importance under certain conditions would warrant.

When a copper conductor in the slot of a rotating machine carries alternating current there are produced slot leakage fluxes which may induce sufficiently large eddy currents in the conductor copper to result in very appreciably increased losses. This type of loss has been quite adequately dealt with by Field, Gilman, and others. The type of copper eddy-current loss with which this paper deals has a different origin and is the result of slot leakage fluxes caused by the main flux. These losses are often nearly as large at no-load as at full load, and are of importance in connection with both salient pole machines and induction motors.

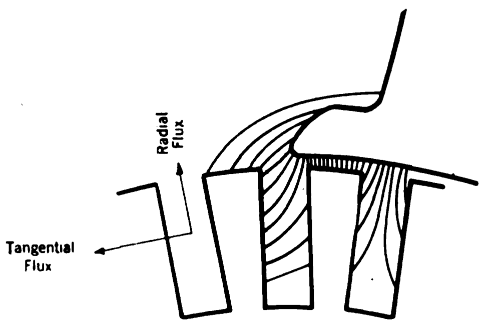

Fig. 1—Slot Leakage for Salient Pole Machine

Cause and Nature of Losses

Fig. 1 illustrates the nature of the slot-leakage flux for a salient pole machine. As a slot comes out from under the pole tip there is a rapid decrease in the radial component of slot-leakage flux and a rapid generation and then dying out of the tangential component of slot-leakage flux as shown by Fig. 2, which is from test data obtained on a small d-c. railway motor with unsymmetrical pole tips. It will be seen that the radial leakage flux consists chiefly of the fundamental, while

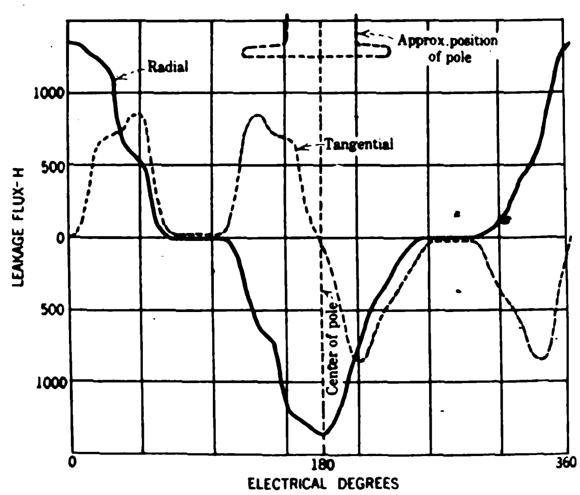

Fig. 2—Slot Leakage Fluxes for D-C. Railway Motor

the tangential flux has a larger third harmonic than it has fundamental. Some of the other harmonics for the tangential flux are also quite large. These results are typical.

Fig. 3 shows the nature of the slot-leakage fluxes for an induction motor. It will be seen that there are

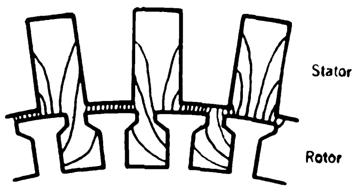

Fig. 3—Slot Leakage for Induction Motor

leakage fluxes in the rotor slots having both radial and tangential components. The radial components pulsate in amplitude but do not change sign while under a given pole. The tangential components reverse in sign twice during the interval required for a rotor tooth to

1. Research Engineer, Westinghouse Electric & Mfg. Co.

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pass over a distance equal to one stator slot pitch. The slot-leakage fluxes, both tangential and radial, therefore, have a frequency equal to the number of stator teeth per pair of poles, multiplied by the rotor frequency, the latter frequency being in general nearly equal to the applied fundamental frequency. These leakage fluxes are small in magnitude but high in frequency and are often of importance. In the ordinary construction, consisting of nearly closed rotor slots, the pulsations of leakage flux in the stator slots are usually negligible.

These slot-leakage fluxes are appreciable only when the teeth begin to saturate. In salient pole machines, tooth inductions of the order of 120 kilolines per sq. in. are necessary before noticeable eddy losses in the copper conductors begin to be produced. For induction motors the tooth inductions must reach about 70 kilolines per sq. in. before copper eddy losses of noticeable magnitude appear. The reason for the lower inductions for the induction motors is because of the much higher frequency of the slot-leakage fluxes. In the case of the salient pole machines the radial fluxes produce very little loss as a rule, because the frequency is so low and because the copper is usually narrow tangentially. The tangential leakage fluxes, however, may produce very considerable losses, and consequently heating, due to their higher-frequency components and the fact that the radial dimensions of the copper are usually fairly large. In the induction motor, both components of the leakage flux may be quite effective in producing copper eddy losses.

Calculation of Copper Eddy Losses

A number of formulas have been devised for calculating this type of loss, but they all contain empirical constants and all neglect certain essential factors. For instance, one of Mr. Lamme's formulas,[2] which was designed for use with large salient pole machines and was very satisfactory for the particular conditions, gave calculated losses which were from 6 to 10 times the true values when applied to a certain small railway motor. The formulas which will be proposed in this paper are based on fundamental considerations only and were devised without reference to any test data.

If the copper bars in a slot are narrow radially or the frequency is sufficiently low, the no-load eddy losses in the copper may be calculated by the following simple formula:

$$W_e = \frac{\pi^2}{6} \times \frac{W^2}{\rho} f^2 H^2 10^{-7} \qquad (1)$$

(See list of symbols below.)

If, however, the bars are wide (this refers to radial width when considering tangential slot leakage flux) or the frequency high, the above formula will no longer apply, due to the fact that the eddy currents in the copper produce a damping effect on the flux, thus making the losses less than would otherwise occur. This is the well-known skin effect. Under these conditions the flux in the region of the center of the bars is damped out. (See Fig. 4.) The eddy currents are greater in magnitude as the bottom and top of the bars are approached and there are no appreciable currents in the center; that is, if the center portions of the copper were removed there would be no change in the eddy losses.

Some time ago we developed the following formula for calculating eddy losses under the conditions of appreciable skin effect:

$$W_e = \frac{\pi^2 f^2 H^2}{m^3 \rho W 10^7} \; \frac{\sinh m W - \sin m W}{\cosh m W + \cos m W} \qquad (2)$$

The method of developing this formula was similar to that used by Latour for his formulas dealing with losses in laminated steel at radio frequencies.[3] Dr. J. Slepian assisted in the development of this formula. For no skin effect the results are identical with those obtained

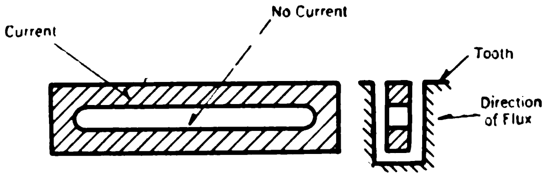

Fig. 4—Copper Eddy-Current Losses, Illustrating Skin Effect

by the simple formula (1). In the use of either formula, the eddy losses have to be calculated for each frequency; namely, for salient pole machines the magnitude of the various important harmonics has to be determined by test and analysis or estimated in some way from the machine design and the losses corresponding to each harmonic calculated as if the others did not exist. The sum is the total eddy loss. In the case of the induction motor, it is generally satisfactory to consider only the pulsating frequency corresponding to the number of stator teeth, without considering harmonics.

When it was attempted to apply formula (2) to actual machines it was found that in many cases the experimental and calculated results did not correspond as closely as was expected. In order to determine whether the discrepancies were due to inaccuracies in the formula or to the neglect of certain factors having to do with the conditions in the actual machines, the fundamental tests which are about to be described were made.

2. Iron Losses in Direct Current Machines. Electrical Engineering Papers by B. G. Lamme, p. 499.

3. Notes on Losses in Sheet Steel at Radio Frequencies; Marius Latour. Inst. of Radio Engineers *Journal*, February 1919, p. 61.

Test Methods and Apparatus

The method of test was suggested by a similar method devised by Churcher.[4] As shown by Fig. 5, a laminated yoke was constructed having pole pieces which were adjustable to the right and left in order that the air-gap could be varied. This air-gap was about 6 inches by 2 inches and its width between pole pieces could be adjusted from 7/8 inch to 0. The yoke was provided with windings as shown. High-frequency current up to 1000 cycles was obtained from a generator through an ammeter A. In general, the samples consisted of two copper bars as indicated. Two small holes were drilled near the center of one of the bars about 1/8 inch apart and thermocouple wires of copper and advance

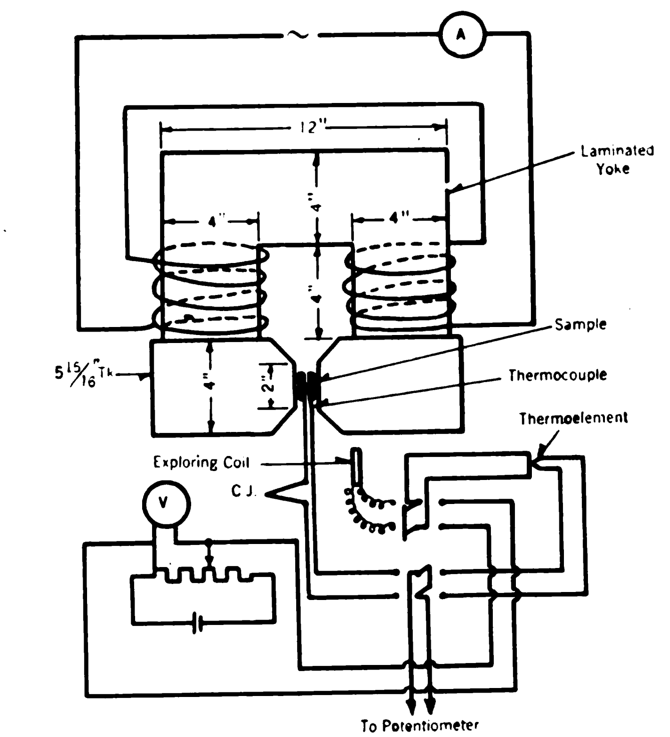

Fig. 5—Copper Eddy-Current Losses—Diagram of Connections

soldered into the holes. The bars were separated from each other by a small distance and the couple wires were insulated from the bars except at the junction. The wires were brought out from between the bars at one end, thus keeping a considerable length adjacent to the copper in order to prevent loss of heat at the junction. An exploring coil wound on a rectangular bakelite form was provided for determining the flux density in the air-gap. The coil was approximately 6 inches by 1/2 inch and had 21 turns.

The method of test was as follows: The air-gap was adjusted to the desired width and alternating-current of the desired frequency applied to the field winding. Assuming a sine wave of flux in the air-gap, the voltage which would be induced in the exploring coil for the desired induction was calculated. The voltmeter V was then adjusted to this value, the current element of a sensitive vacuum thermo couple was connected to the terminals of the voltmeter by a suitable manipulation of the switches and the terminals of the thermo-element connected to a Wolff potentiometer. The e. m. f. of the thermo-element was then read. Next the exploring coil was placed in the air-gap, the switches manipulated, and the magnetizing current adjusted by control of the high-frequency generator field until the thermo-element produced the same reading on the potentiometer as was obtained from the d-c. voltage. This gave the required induction in the air-gap. The thermo couple attached to the sample was then connected to the potentiometer. The cold junction of this couple was placed in a thermos bottle which was at any convenient temperature, preferably near room temperature. A copper sample which should be at or below the temperature in the air-gap was then placed in the gap, the high-frequency current switched on, and the ammeter adjusted to its original value without the sample. The potentiometer was set to some convenient reading corresponding to a value slightly above room temperature. Due to the eddy losses in the sample the temperature immediately began to rise. When this temperature corresponded to the setting on the potentiometer, the potentiometer galvanometer went through O and a stop-watch was started. The potentiometer was then set to a higher reading. When the galvanometer went through O again the watch was stopped and another started by means of a simple arrangement of levers. This was repeated five or six times in order to obtain sufficient data for plotting a curve between millivolts and time interval. By extrapolating back to the millivolts corresponding to the temperature at the air-gap (with corrections for cold junction temperature) the rate of temperature rise in seconds (ΔT_i) for a given change in millivolts could be obtained. Knowing the millivolts per degree for the thermo couple at this temperature, the rate of temperature rise per degree could be calculated.

The eddy losses were calculated as follows, assuming a temperature of 25 deg. cent.,

$$W = Q \frac{d\,t\,e}{d\,t} \text{ watts}$$

$$Q = 4.186 \times .0917 \times G$$

where

Q is the thermal capacity of the conductor in watt-sec. per deg. cent.,

G is the weight of conductor in grams

$\frac{d\,t\,e}{d\,t}$ is the rate of temperature rise, namely the deg. cent. rise per sec. on the assumption that there is no heat lost or gained from the outside. Since the rate

4. The Measurement of Temperature in a Rotating Armature by Means of Thermocouples, B. G. Churcher. *Journal of Sci. Inst. V. I.*, July, 1924, p. 310

was determined corresponding to the temperature of the surroundings, there was no correction for dissipated heat; 4.186 is the thermal capacity of water in joules per gram calorie; 0.0917 is the specific heat of copper with reference to water at 25 deg. cent.

Test Results

In order to keep the rate of temperature rise down to a reasonable value, very low air-gap inductions were used; namely, of the order of a few hundred gausses. Under these conditions there was no appreciable heating of the yoke material and the reluctance of the iron path was practically negligible. Therefore, for a given air-gap the induction was practically constant for a definite exciting current for a wide range of frequencies as shown by test results not given here.

If the sample had appreciable skin effect, the counter magnetomotive force of the eddy currents in the copper had the effect of increasing the reluctance of the air-gap. Therefore, when the copper was introduced into the gap

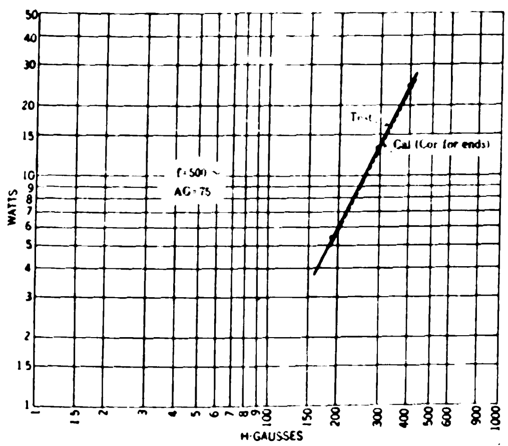

Fig. 6—Copper Eddy-Current Losses, Two Bars ¾-in. x ¼-in. x 10-in.

the exciting current increased. It was found that if the exploring coil was placed in the air-gap just above the copper, the magnetizing current had to be brought back to its original value in order to bring the air flux in the gap above the copper back to its original value. Provided the current was so adjusted, it was immaterial whether the m. m. f. was measured with or without the sample in position.

In order to obtain data for the purpose of determining the validity of our method of calculating eddy losses, a number of copper samples were tested under various conditions. Fig. 6 shows the results of the first set of tests. Two bars ¼ by ¾ by 10 inches long were placed in the air-gap (0.75 inches) with the shortest dimension parallel to the flux. Losses were determined at 500 cycles for three values of m. m. f., namely, 190, 291 and 395 gausses, and the results plotted on double log paper. The m. m. f. and flux density, namely, gilberts per centimeter and gausses are used interchangeably since in the c. g. s. system they are identical. For comparison, values as calculated by formula 2 are shown. The test and calculated values check very well with respect to magnitude and slope. As indicated by theory, the losses increased as H^2.

The next set of tests are shown by Fig. 7. The results are for the same set of bars but in this case H was held

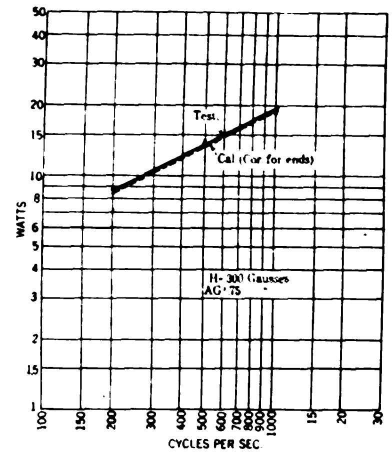

Fig. 7—Copper Eddy-Current Losses, Two Bars ¾-in. x ¼-In. x 10-In.

at 300 gausses and the frequency changed from 200 to 1000 cycles. Under the particular conditions of frequency and copper dimensions there was large skin effect. According to theory, the losses should, in this

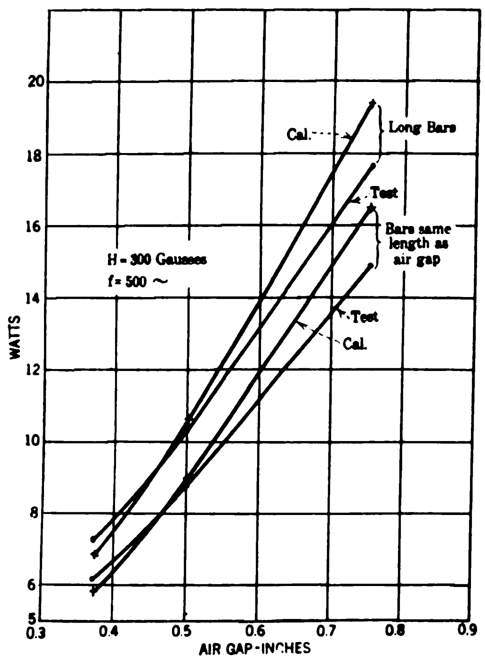

Fig. 8—Copper Eddy-Current Losses, Two Bars 1/8-In. x 1.0-In. x 10-In., Two Bars 1/8-In. x 1.0-In. x 5 15/16-In.

case, increase as the square root of the frequency. It will be seen that within the experimental errors this was the case.

It will be noted that in the case of Figs. 6 and 7 the copper bars were considerably longer than the length of the air-gap. This is, of course, the condition in rotating

machines. In several cases tests were made with long bars and then the bars were cut off to the length of the air-gap and again tested in order to determine the amount of the end effect. It was found in all cases tried that if the effective length of the bar for the long bars was taken as equal to the air-gap length plus a length equal to the vertical dimension of each bar (see Fig. 5) the end effects would be very closely compensated for. This explains the notation in Figs. 6 and 7 ("corrected for ends").

Fig. 8 shows the relation between air-gap and loss for an H of 300 gausses and a frequency of 500 cycles. In this case there were two bars, $\frac{1}{8}$ by 1 by 10 inches. The results are also given for the same bars cut to the length of the air-gap. The test results follow the theoretical values within reasonable limits, the test values being a little less for the large air-gaps and a little

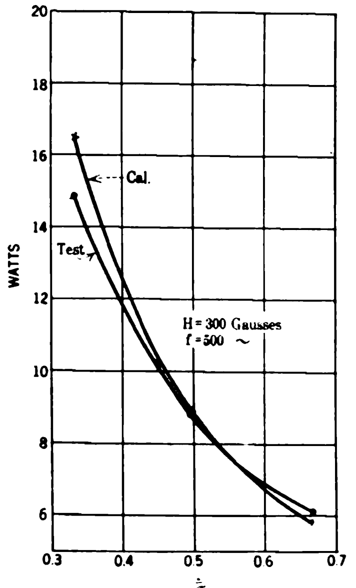

FIG. 9—COPPER EDDY-CURRENT LOSSES, TWO BARS 1/8-IN. X 1/10-IN. X 5 15/16-IN.

greater for the small air-gaps. Obviously for solid copper in the gap (100 per cent space factor) the gap would be 0.25 inch.

Fig. 9 shows the same data for the short bars only plotted against t/σ (ratio of copper thickness to gap width or the space factor of the copper).

Table I gives some further comparisons between test and calculated results and includes the data of the previously mentioned curves. In most cases the average test values have been converted to a standard m. m. f. of $H = 300$ according to the square law, although the tests were made at other m. m. fs. The dimensions in the table for the copper are approximate values. The actual values were used for the calculations.

Discussion of Results

Except in two or three cases the test and calculated results are as close as could be reasonably expected. When the space factor is low and the bars are wide, there is a tendency for the calculated results to be high. In the case of the four bars side by side with the larger cross sectional dimension vertical there is a tendency for the calculated values to be low. We may say that for all practical purposes and under the conditions of these experiments the calculated values are sufficiently

TABLE I

H gausses	f	A G	Watts Test	Watts Cal.	t/σ	Remarks
2 Bars ¼ in. by ¾ in. by 10 in. (Approximate Dimensions).						Flux
395	500	0.75	23.8	23.0		
291	500	0.75	12.9	12.5		
190	500	0.75	5.31	5.35		
300	200	0.75	8.5	8.4		
300	500	0.75	13.7	13.3		
300	1000	0.75	18.3	18.8		
2 Bars ¼ in. by ¾ in. by 5-15/16 in.						
300	500	0.75	11.9			
2 Bars 1/8 in. by 1 in. by 10 in.						
300	500	0.75	17.6	19.4	0.333	
300		0.50	10.33	10.6	0.497	
300		.375	07.33	6.88	0.665	
2 Bars 1/8 in. by 1 in. by 5-15/16 in.						
300	500	0.75	14.82	16.5	0.333	
300		0.50	8.77	9.00	0.497	
300		0.375	6.09	5.85	0.665	
2 Bars 0.299 in. by 0.484 in. by 9.281 in.						
300	500	0.75	10.95	11.75		
300	200	0.75	7.35	7.45		
300	200	.75	4.54	5.10		
4 Bars 1/8 in. by ½ in. by 8 in.						
300	500	0.75	30.1	36.4		
300	500	0.50	20.1	19.8		
300	500	0.75	14.9	12.8		
300	500	0.75	5.26	5.11*		
300	1000	0.75	20.2	18.1		
300	1000	0.75	20.5	19.3		

*5.25 by formula (1)

reliable. All ranges have been covered from the simple case of no skin effect (formula **1**) to the case of large skin effect. Moreover multiple bars have been used and the results check practically as well as for a single pair of bars.

Unfortunately, in the case of rotating machines, the conditions are not as simple as in the ideal case. In

the present tests the effective width of air-gap is the actual width of gap. In the case of rotating machines the corresponding actual width of slot is not the effective width which has to be used in the formula. By eferring to Fig. 8 or 9, for instance, it will be seen that the larger the width of the gap the greater the copper loss for a given air-leakage flux, (assuming the conductors have large skin effect). For no skin effect the losses are independent of the gap width. Now in the case of rotating machine teeth the teeth themselves are saturated to some extent, at least, or there would be no appreciable slot leakage fluxes. This means that their permeability is low and that an appreciable m. m. f. is required to force the flux through them. Again the applied m. m. f. which causes the leakage flux to pass across the slot may partly, at least, traverse a second slot and the machine air-gap. This means that due to the higher actual m. m. f. applied over that necessary to cause flux to cross the particular slot in question, the eddy currents in the copper would not be as effective in damping out the flux as would otherwise be the case, and therefore the losses are higher. This means that the value of σ in formula (**2**) should be increased by some more or less uncertain amount.

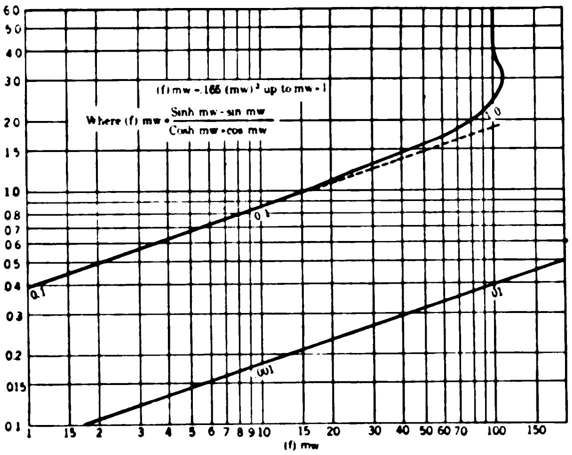

FIG. 10—COPPER EDDY-CURRENT LOSSES, SHOWING HYPERBOLIC FUNCTION IN EXPONENTIAL FORM

In the majority of machines which we have tested, σ should be multiplied by 1.5 on the average, but in some cases it has to be much higher than this and in a few cases lower. Before it would be possible to accurately predict the necessary corrections for all types of machines, much more experimental data must be obtained.

CHARACTERISTICS AND CALCULATION OF EDDY LOSSES

An analysis of the test results and of formulas (**1**) and (**2**) reveal some interesting relations. If the function

$$\frac{\sinh m\,W - \sin m\,W}{\cosh m\,W + \cos m\,W}$$

is plotted against $m\,W$ on double log paper, there is obtained the relation shown by Fig. 10. It will be seen that for any value of $m\,W$ up to 1, the function increases approximately as the cube of $m\,W$. Above 2 the function is nearly equal to 1. The reason that the function reduces to 1 is that for large values the sinh and cosh terms are practically equal and increase very rapidly in magnitude, thus making the sine and cosine values negligible. When this function reduces to 1, the losses are obtained from the first part of formula (**2**), namely

$$W_e = \frac{\pi^2 f^2 H^2}{m^3 \rho\, W\, 10^7} \qquad (3)$$

In order to further simplify this expression, assume that $\rho = 1.8$ by 10^3 (1.8 microhm centimeters corresponds to 31 deg. cent).

$$W_e = 1.688 \times 10^{-7} \frac{f^{1/2} H^2}{\left(\frac{t}{\sigma}\right)^{\frac{3}{2}} W} \qquad (4)$$

(when $\rho = 1.8$ by 10^3)

The variations of the watts per cu. cm. with frequency, air-gap, space factor and radial width of copper are now evident. It has been shown experimentally that these relations are approximately correct. They apply only when the product $m\,W$ exceeds 2 (large skin effect). Using this relation, care must be taken to note the causes of the changes in $\frac{t}{\rho}$ and W and the fact that this formula gives the watts per cu. cm. and not the total watts. If t/σ is changed by increasing the width of gap (or slot for the machine), but with the copper the same, the total eddy losses will vary as $(t/\sigma)^{-3/2}$ for a given H as shown by the formula or as $\sigma^{3/2}$ (slot width). Now if t/σ is altered by changing the total thickness of copper the weight is also changed and therefore the total loss varies at $(t/\sigma)^{-1/2}$, namely, for a given slot the total loss varies inversely as the square root of the tangential copper thickness per slot.

Again suppose the width of the copper (W) is changed by increasing the width of the individual bars then, since an increase in width means an increased total volume of copper, the losses are independent of the copper width W (for large skin effect). This is obvious from the fact that there are no eddy currents near the middle of the bars (see Fig. 4). If, however, W is changed by laminating but keeping the total weight of copper the same, the total losses are, as shown by the formula, inversely proportional to W; but as the laminating is continued the skin effect is reduced and soon the losses begin to decrease as the square of W or according to formula (**1**). Fig. 11 illustrates such a condition. It will be seen that for the particular conditions the losses increase rapidly with increasing lamination and then decrease. These are calculated values but test results would show the same thing. The main point is that laminating may increase or

diminish copper eddy losses depending upon the conditions.

Now in using this formula, m should first be calculated as shown above, namely $m = 2\pi\sqrt{\frac{f\,t}{\sigma\,\rho}}$ or $m = 0.148\sqrt{f \times \frac{t}{\sigma}}$ for $\rho = 1.8 \times 10^3$. Then if the product $m\,W$ is less than I, formula (**1**) or some modification may be used, or if desired formula (**2**) may be used. If $m\,W$ is over 2, or for accurate work over 4, formulas (**3**) or (**4**) may be used. For intermediate values use formula (**2**) or use formulas (**3**) or (**4**) and multiply by $(f)\ m\,W$ as obtained from Fig. 10. Assuming

$\rho = 1.8 \times 10^3$ formula (**1**) becomes

$$W_e = 0.915 \times 10^{-10} f^2 W^2 H^2 \quad (\text{when } \rho = 1.8 \times 10^3) \qquad (5)$$

and may be used for approximate results up to values of $m\,W$ of 1.5.

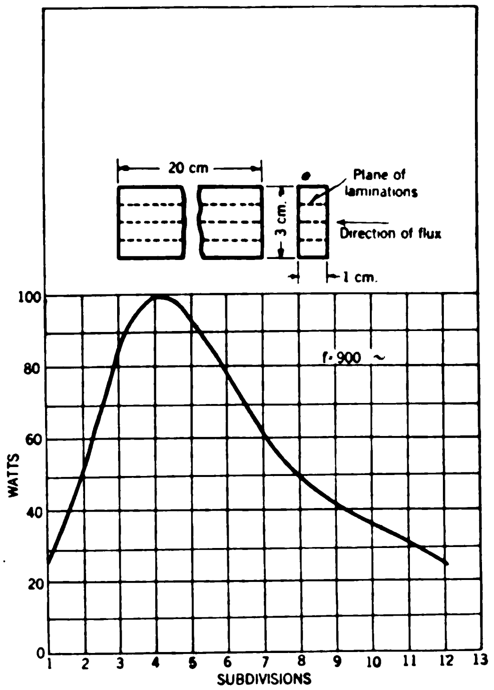

Fig. 11—Copper Eddy-Current Losses—Variation of Loss due to Laminating

Application of Formulas

As pointed out above, formula (**2**) or its modifications will, in general, give results which are of the right order of magnitude if σ the slot width is increased by 50 per cent before using in the formula. This method of calculation may be used for salient pole machines. In this case the tangential slot-leakage curves must be analyzed into their harmonics and the copper losses calculated for each harmonic. For low frequencies, formula (**1**) will usually apply, but for the higher harmonics some form of formula (**2**) must be used. In the case of wound-rotor induction motors the no-load copper eddy losses may be calculated by assuming a single frequency corresponding to the tooth-pulsation frequency. The radial as well as the tangential slot-leakage fluxes may be of importance in this case.

As a first approximation if test data are not available the radial slot-leakage flux may be assumed to be equal to the m. m. f. necessary to magnetize the teeth adjacent to the slot and the tangential slot-leakage flux to the difference in m. m. f. between the two adjacent teeth. Of course, tooth taper introduces complications but this can readily be taken care of approximately. As pointed out, the chief difficulty is in determining the total effective m. m. f. where skin effect is large. In calculating the total loss the volume of copper is that in the slot plus an amount corresponding to an added length of copper equal to W.

Summary of Formulas

For $m\,W$ less than 1 (approximately correct to 1.5).

$$W_e = \frac{\pi^2}{6} \times \frac{W^2}{\rho} f^2 H^2 10^{-7} \qquad (1)$$

$$W_e = 0.915 \times 10^{-10} f^2 W^2 H^2 \quad (\text{when } \rho = 1.8 \times 10^3) \qquad (5)$$

For $m\,W$ between 1 and 4.

$$W_e = \frac{\pi^2 f^2 H^2}{m^3\,\rho\,W\,10^7}\ \frac{\sinh m\,W - \sin m\,W}{\cosh m\,W + \cos m\,W} \qquad (2)$$

For $m\,W$ greater than 4 (Approximately correct for $m\,W$ above 2).

$$W_e = \frac{\pi^2 f^2 H^2}{m^3\,\rho\,W\,10^7} \qquad (3)$$

$$W_e = 1.688 \times 10^{-7} \frac{f^{1/2} H^2}{\left(\frac{t}{\sigma}\right)^{\frac{3}{2}} W} \quad (\text{when } \rho = 1.8 \times 10^3) \qquad (4)$$

The above formulas, when ρ is included in the constant, are based on copper at 31 deg. cent. For copper at 65 deg. cent. ρ should be taken as 2.0×10^3 instead of 1.8×10^3. For copper or aluminum alloys, use the formulas with ρ.

For cool machines on no-load test, formulas (**4**) or (**5**) will, in general, be satisfactory. For hot machines they may be modified, as indicated above but this refinement will usually be found unnecessary due to other much larger uncertainties. Formula (**4**) is to be used when $m\,W$ is greater than 2 and formula (**5**) when $m\,W$ is less than 1.5. For intermediate values of $m\,W$ corrections according to Fig. 10 may be applied or Fig. 10 may serve merely to indicate the possible errors which will result by neglecting this correction.

The above assumes that the effective slot-leakage flux is the tangential component. For the radial component, copper dimensions at right angles must be used.

Symbols

$$m = 2\pi\sqrt{\frac{ft}{\rho}}$$

$$= 0.148 f \times \frac{t}{\sigma} \quad (\text{when } \rho = 1.8 \times 10^3)$$

W_ϵ = eddy loss in watts per cu. cm. of bar material.
f = cycles per second.
t = thickness of copper bar (tangential) multiplied by the number of bars side by side in a slot.
σ = slot width
ρ = resistivity of bar material in abohms (equals microhm – cm. by 10^3).
W = radial width of individual bars in cm.
H = slot leakage m. m. f. in gilberts per cm. or slot leakage flux in gausses (no bars).

Conclusions

The above-described experiments indicate that the formulas for no-load copper eddy-current losses due to the slot-leakage fluxes are correct to within 10 or 15 per cent for all of the conditions tried which cover a wide range. In the case of rotating machines, however, we have the saturation of the teeth, other gap reluctances and other factors which make it very difficult sometimes to estimate accurately the total m. m. f. applied to the slot-leakage magnetic circuit. In general, fairly reliable corrections may be made by adding 50 per cent to the slot width. When skin effect is small no appreciable errors will result since the loss is independent of the gap reluctance, assuming a given leakage flux. This analysis gives the following interesting relations.

For small skin effect, $m\,W$ less than 1, (low frequency or narrow bars) the eddy losses for a unit volume of copper vary as $f^2\,W^2$. For large skin effect, $m\,W$ greater than 2, (high frequency or wide bars) the eddy losses for a unit volume of copper vary as $f^{1/2}$, $(t/\sigma)^{-3/2}$, W^{-1} and H^2. For variations in total copper eddy current losses consideration must be given, as previously mentioned, to the way in which t/σ and W are varied.

In the case of salient pole machines the wave shape of the slot leakage fluxes must be analyzed or the components estimated and the losses calculated for each component frequency. In the case of induction motors the tooth-pulsation frequency is to be used.

Even though these formulas often can not be used directly without considerable labor, they should serve a very useful purpose in indicating quickly the result of changing the laminating of the copper and changing the slots. The interesting fact has been pointed out that in some cases increased laminating of the copper may increase the losses, while in others it decreases them.

Summary

Check tests are presented, showing that our theoretical formulas for calculating no-load copper eddy-current losses are reliable provided all of the conditions are known. The actual application to rotating machines may yield erroneous results due to difficulties in estimating the total reluctance of the flux-leakage paths. These formulas in their present form should be useful for calculating roughly the amount of no-load copper eddy losses in salient pole machines and induction motors. They should also be useful for determining the effect of changes in the section of the individual copper bars in the slot with reference to eddy losses. Later it is hoped that more reliable and simpler methods for using these formulas will be devised.

AUTOMOBILE HEADLIGHTING

For several years the bureau has been working with technical societies, State officials, and others in the attempt to improve the headlighting of automobiles. This question has been revived more actively than ever during the past year as the result of discussions following the National Conference on Street and Highway Safety called by Secretary Hoover in December, 1924. In order to obtain more complete and reliable information regarding the actual status of headlighting and the possibility of its improvement, a joint committee representing the Society of Automotive Engineers and the Illuminating Engineering Society has recently been formed and is attempting to lay out a program of research on this subject. Members of the bureau's staff have been appointed as representatives of both societies on this committee. The bureau has also been called on for technical advice in connection with the requirements of the proposed uniform vehicle code which is to be considered at the next meeting of the national conference. In this connection the bureau has advocated the general plan of making laws and regulations as simple as possible and depending upon education of motor-car manufacturers and users for the betterment of actual road conditions. With this in view, Circular No. 276, Motor Vehicle Lighting, was issued some time ago and has found extensive circulation. This circular is not available for free distribution, but can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 20 cents per copy.

Electrification of Paper-Making Machines

BY STEPHEN A. STAEGE[1]

Fellow, A. I. E. E.

***Synopsis.**—The ever increasing speeds of paper making machines has made necessary the replacement of the inadequate mechanical drive with electrical sectional drive, and the perfection acquired in modern electrical sectional paper machine drive has made possible unlimited paper speed in so far as the drive and control is concerned.*

Not only is electrical sectional drive necessary for high speed machines but it is highly economical for even the slowest speed machines on account of the saving in power over mechanical drive, the great saving in maintenance, and the greater precision with which the section speeds can be maintained thereby greatly reducing the number of paper breaks and increasing production.

This paper outlines the several trends of development in an historical sketch of progress in the art up to the present time, devoting special attention to a unique system of direct current drive in which the section driving motors through a differential electrical field control means, cause the several section driving motors to operate in synchronous relation at any desired relative speed values, which speed relations are at the same time adjustable at the will of the operator.

INTRODUCTION

THE production of a continuous sheet of paper, 12 to 18 ft. wide and 250 to 1000 mi. long without a break on the machine—a paper speed of 1000 ft. per min. or more—has been made possible by electrical sectional paper-machine drive and control.

The frail web of paper, about three mils thick, passes without support from section to section of the machine, passing between heavy press rolls, tons in weight; threading around 30 or 40 steam-heated dryer rolls; through the eight or ten-roll calender stack weighing a hundred tons or more, and onto the reel.

In the travel of the sheet through the paper machine from the "wire" where it is formed to the calender where it is finished, the sheet usually increases in length from five to ten per cent. Therefore, the sheet is actually traveling faster when it leaves the machine than at the beginning of its travel. In fact, there is usually a progressive increase in the speed of travel of the sheet as it goes from section to section, on account of its stretch.

There are two principal types of paper-making machines, known as cylinder machines and Fourdrinier Machines. The fundamental differences are in the wet or forming-end of the machine.

The Fourdrinier Machine is the type always used for high speed, in making newsprint and kraft paper and in the manufacture of book, writing and the higher grade papers.

The Cylinder machine is inherently a slower speed type and is used chiefly in the manufacture of box and container board, roofing felt, and the heavier sheets.

The paper-making machine in its usual form consists of a number of sections independently driven but which must be maintained in operation at the proper speed relations to each other. Not only must the proper speed relation be maintained between sections, but these speed relations must be adjustable at the will of the operator so that they can be adapted to the requirements of the sheet of paper. These may change slightly in elongation or shrinkage on account of variations in the condition of the stock, temperature, atmospheric conditions and a number of other factors; the stretch or shrinkage of the sheet depending largely upon the thickness, quality, condition of stock and amount of pressure used in removing the water.

In addition to the requirement of adjustability of speed between sections to take care of variations in elongation and shrinkage, it is essential that the entire machine be adjustable in speed over a wide range, without disturbing the speed relation of the several sections.

The speed range of a newsprint machine may be 600 to 1200 ft. per min.; a kraft machine, 200 to 800 ft; a book machine, 100 to 600 ft.; a specialty Fourdrinier Machine, perhaps 100 to 800 ft.: While a cylinder machine sometimes has a speed range as great as 35 to 350 ft.; although a more common range for this type of machine is 50 to 200 ft. of paper per min.

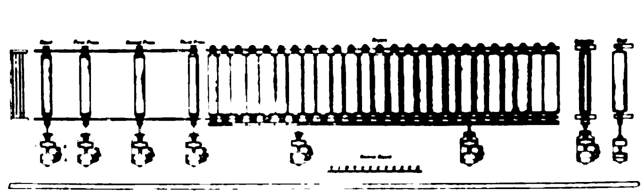

FIG. 1—TYPICAL SECTIONAL PAPER-MACHINE DRIVE

A typical high-speed Fourdrinier Machine (Fig. 1) usually consists of eight sections; a "wire" or couch section, three press sections, two dryer sections, one calender section and a reel section. Fig. 2 shows schematically a side elevation of such a machine.

The first section of the Fourdrinier Machine, known as the "Fourdrinier," "wire" or "couch" section, has a revolving wire screen of fine mesh. This Fourdrinier wire, in the form of a wide belt the width of the machine, operates around two rolls, the one at the extreme end of the machine called the breast roll and the one at the other end of the "wire," the "couch" roll. This is the driven member of the section, the breast roll being rotated as a pulley by the wire. The wire may be from

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50 ft. to more than 100 ft. long, depending upon the size and speed of the machine; and the span of the wire is kept from sagging by a large number of small "table" rolls located close together under the top pass of the wire, which carries the stock.

The press sections consist of pairs of heavy rolls, weighted with compounding levers, and between the upper and lower rolls of which the sheet, on its felt conveyor, passes. The lower roll is driven and the upper roll rotates by contact traction with the lower roll.

In the dryer sections some 15 or 20 dryer rolls or drums, four, five or six feet in diameter are nested in a group and geared together by intermeshing spur gears. There are usually two dryer sections which may be independently driven and regulated or may be geared together.

The calender stack consists usually of eight or ten chilled-steel rolls accurately ground and polished and driven by the bottom roll, all of the upper rolls being rotated by surface contact friction.

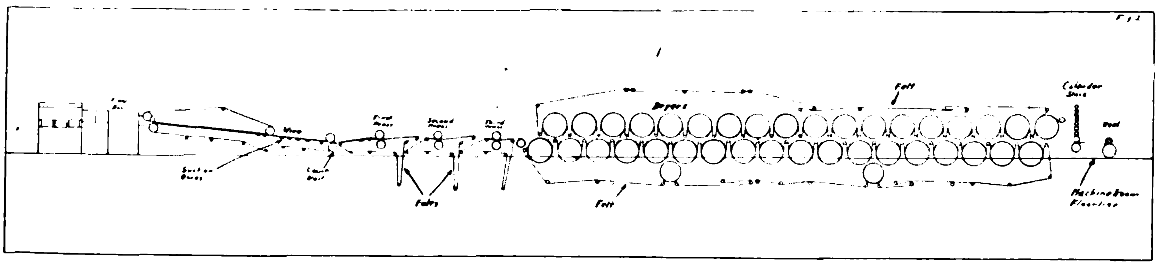
A "uniform speed" reel is commonly used, the spool and roll of paper being rotated by the traction of surface contact with the reel drum.

From the "couch" the sheet, though very wet and frail, spans a distance of a foot or more until it reaches a felt conveyor by means of which it is carried through the first press, then to the second and third presses, on independent felts and across another unsupported span to the dryer sections. Dryer felts hold the sheet in contact with the hot dryer drums as it is threaded through the nest of dryers. From the dryers, the sheet passes across a span of more than five ft. to the calender stack and thence to the reel.

Passing from the "wire" at the "couch," additional water is removed by pressure in going through the presses, and most of the remaining water is removed by heat in the steam-heated dryer sections.

The function of the paper machine is to reduce the stock mixture, evenly distributing the fibers in proper relation, fabricating them into a continuous web, removing the excess water by filtration, pressure and heat and giving the final sheet of paper the required finish, and to wind it into rolls of convenient size.

In putting the sheet on the machine, it is put over at the full normal operating speed by means of air jets, in the case of high speed machines at least, by



SIDE ELEVATION OF FOURDRINIER PAPER MACHINE SHOWING THE COURSE OF THE SHEET FROM THE WIRE TO THE REEL.

FIG. 2—SIDE ELEVATION OF FOURDRINIER PAPER MACHINE SHOWING THE COURSE OF THE SHEET FROM THE WIRE TO THE REEL

A very large percentage of the paper of today is made from wood pulp, the individual fibers having been reduced or separated by mechanical or chemical processes and mixed in a suitable proportion of water.

In the manufacture of paper, the raw material passes through several processes and refinements before it goes to the paper-making machine in a fluid mass consisting of approximately $\frac{1}{2}$ of 1 per cent stock and $99\frac{1}{2}$ per cent water.

The Fourdrinier section of the machine receives the stock from a flow box, located above the breast roll, from which it flows by gravity onto the revolving fine wire screen from a thin submerged orifice extending the width of the machine and located just above the "wire."

When the stock flows onto the "wire," much of the water immediately passes through by gravity, and further along its travel a considerable part of the remaining water is drawn through the wire from the stock film on its surface by a number of flat suction boxes located below it in which 10 to 15 inches of vacuum is maintained.

means of which a leader strip is detached from the "wire" at the couch and blown across the gap to the felt conveyor of the first press. At each section the air jet is used to transfer the narrow leader strip to the succeeding section. As soon as the leader strip has been started the sheet is widened by tapering out at the "wire" until it is the full width of the machine.

In cylinder machines, the design and functioning of the various parts is much the same as that of the Fourdrinier machine, except that the forming of the sheet is done on cylinder moulds instead of on a Fourdrinier wire. A machine may have several cylinder moulds consisting of skeleton drums covered with fine wire screen. These revolve slowly in vats containing paper stock and each cylinder mould contributes a thin layer of stock to the final heavy sheet. A revolving felt conveyor picks up the stock from the cylinder mould drums, carries the laminated stock film between small presses where it is pressed into a homogeneous fabric and part of the water is removed, and thence carries it through the first press from which the operation is similar to that of a Fourdrinier machine.

Early Methods of Drive

For many years, the paper-making machines were mechanically driven by variable speed engines or motors or other variable speed means to take care of the speed range required, and the individual sections were driven from a line shaft through gears and belt or rope drive with cone pulleys, so that by shifting the belt on the cone pulleys, the required relative speed between sections could be obtained. Such systems were unusually subject to belt slippage on account of the poor belt contact on the cone pulley surfaces and on account of the vertical-belt drives which were usually necessary; they required mechanical clutches or belt slackening and tightening devices so that any section could be stopped and started independently of the rest of the machine; and they suffered from more than the usual troubles and limitations to which mechanical drives are subject.

As early as 1905 to 1910 several installations of electrical sectional paper machine drives, but without automatic speed regulation, were made in an effort to overcome the serious shortcomings of mechanical drive, but most of these early installations because of poor speed regulation were unsuccessful—only two of these early sectional drives remaining in service. It was only through infinite care in the design and in field adjusting of the equipment that operation was made possible, and that only by frequent hand adjustments of rheostats by the operators.

The search for a more satisfactory type of drive was a difficult one. For obvious reasons, synchronous motors could not meet the various requirements of paper-machine drives and the best inherent characteristics of d-c. motors did not provide speed regulation of sufficient precision over the speed range required, and were furthermore subject to the effects of changes in resistance due to temperature changes resulting in variations in speed. An automatic speed regulator was, therefore, sought to control the speed of the d-c. driving motors for each of the sections. It was immediately apparent that none of the usual types of speed governors or regulators would suffice, inasmuch as speed control within limits of the order of $^1/_{10}$ of 1 per cent or closer was necessary for satisfactory performance. The differential principle was, therefore, finally made use of as this offered possibilities of practically infinite precision of speed control of integrated values. To correct for a tendency of the motor to change in speed, a small change in angular displacement of the motor armature with respect to a time cycle is necessary, but the motor can be made to operate for an indefinite period without gaining or losing in rev. per min.

Paper machines sectionally driven by d-c. motors and controlled by regulators of the electrical differential type have now been in operation in this country and Canada for some six years. The details of the mechanism by means of which differential speed regulation with field control is obtained, has gone through a process of evolution whereby the apparatus required has been greatly reduced and simplified and improved in quickness of response.

First Automatically Regulated Electrical Sectional Drive

In the first electrical sectionally-driven paper machine in this country to be automatically controlled by the electrical differential regulator principle, a master unit was provided to which the speed of the sections was referred (Fig. 3). The master consisted of a motor-driven a-c. generator, and from each section of the paper machine there was also driven, through a control speed changer, a small a-c. generator. Connected electrically between the master generator and the section generator was a wound rotor induction motor, the stator being connected to the master generator and the rotor to the section a-c. generator. When connected in the proper phase relation so that the magnetic field in the rotor would rotate in the same direction as the magnetic field in the stator and at the same speed, no rotational

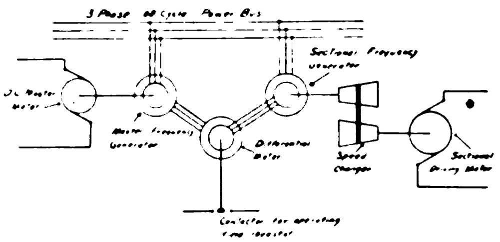


Fig. 3—Schematic Diagram of First Electrical Differential Speed Control System

movement of the rotor would take place. If, however, the d-c. section driving motor for any reason should slow down or speed up, this would, of course, cause a corresponding change in the frequency of the generator driven from the section motor, from that of the master, and the rotor of the induction motor would then rotate in the one direction or the other, depending upon the higher frequency and at a rate of speed corresponding to the difference in frequency of the two generators between which it was connected. This constituted an electrical differential.

A motor-operated field rheostat was provided in the shunt-field circuit of each of the section driving motors (Fig. 4) and through movement of the differential element, the wound rotor induction motor, contact means were provided so that a rotational movement of a very small fraction of a revolution in either direction would serve to make a contact thereby operating the rheostat in one direction or the other as required to correct the speed of the section-driving motor. This relay method of operating the field rheostat was used instead of coupling the rheostat directly to the shaft of the differential motor so as to relieve the differential control system

of the necessity of developing sufficient torque to turn the rheostat which would detract from its sensitivity; and also to obtain characteristics whereby the travel of the rheostat arm was not a direct function of the movement of the rotor of the differentially connected induction motor. Reaction magnets were provided to prevent overtravel of the rheostat and hunting.

This system was quite effective but had its limitations particularly in range of control, speed of regulation and tendency to oscillate on account of the definite step characteristic of the rheostat which obviously could not be made to meet the exact requirements of the speed necessary for the section motor.

The master and section a-c. generators used were of the induction frequency changer type which appeared to be the most desirable for this service. Standard wound rotor induction motors were used and were driven at a speed usually about 50 per cent below synchronous speed so that when excited from a 60-cycle source, the output frequency of these frequency changer generators would be about 30 cycles at the maximum paper speed and this frequency would increase as the paper speed decreased. The use of this type of generator avoided the necessity of d-c. excitation and provided all of the characteristics required and any variations in the frequency of the exciting source would have no affect upon the regulation as they would take place equally on both sides of the differential.

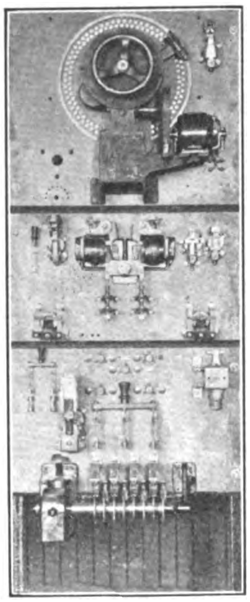


FIG. 4—DIFFERENTIAL RELAY AND MOTOR-OPERATED FIELD RHEOSTAT OF FIRST ELECTRICAL DIFFERENTIAL SPEED CONTROL SYSTEM OF SECTIONAL DRIVE

With this arrangement it will be seen that when the speed of the section motor is correct, the secondary frequency of the master and section frequency changer or generator is the same and no rotation of the induction motor connected between the two frequency changers takes place. If, however, a change in angular displacement of the section frequency changer takes place with respect to the master, a similar movement takes place in the rotor of the wound rotor motor and through the rheostat indirectly actuated by this movement, resistance is cut in or out of the shunt-field circuit of the section driving motor, thereby tending to maintain its speed at the required value.

Following shortly after the installation in 1919 of the first control system of the type described, two other systems of sectional paper-machine drive and control also came into use; one known as a "synchronous motor tie-in" system, and the other as an "interlock" system.

SYNCHRONOUS MOTOR TIE-IN SYSTEM

The "synchronous motor tie-in" system (Fig. 5), instead of automatically regulating the d-c. section motor field strength to maintain the proper speed relation between sections, employed a synchronous motor for each paper-machine section, of about one-fifth the capacity of the main d-c. section driving motor. The synchronous motors were driven from the main d-c. section driving motors through a spur-gear reduction and a pair of cone pulleys with belt drive. The synchronous motors were d-c. excited and had their three-phase armature circuits connected to a common or "dead" bus, as it was called. This "dead" bus was not connected to any other source of power.

The object of the synchronous motors was to hold the speeds of the d-c. section driving motors at their proper speed relation, as determined by the position of the belts on the cone pulleys.

In the event of a tendency of the d-c. section driving motor to change in speed, due to a load change or temperature change, the synchronous motor was called upon to carry the increase or decrease in the load of the section, or the load thrown off or taken on by the d-c. section motor due to a temperature change and corresponding change in field resistance. This was necessary in order that the synchronous motor might remain in synchronism with the "dead" bus and the other synchronous motors.

It will be observed that with this arrangement, any load taken by the section synchronous motor as a motor must be furnished by the other synchronous motors connected to the "dead" bus, as generators; and any load furnished by the section synchronous motor in question, as a generator, must be absorbed by the other synchronous motors. Since any change in load, or tendency to change in speed, on the part of a d-c. section driving motor creates a call indirectly upon each of the other section motors to carry or absorb the change in the section in question, the entire paper machine would tend to change in speed, to a degree depending upon the droop of the load speed characteristic curves of the d-c. section driving motors and in an amount, compared to the section tending to change, approximately inversely proportional to the number of sections.

It will, also, be observed that the d-c. section driving motor in question could only change in speed with respect to the frequency of the "dead" bus, or the equivalent approximate mean paper speed, an amount permitted by the change in belt stretch, creep and slip on the cone pulleys, resulting from the change in load being transmitted, with the exception of the transient speed change coincident with the angular displacement and change in phase position of the synchronous motor accompanying its change in load. The changes in load being transmitted by the belt drive on the cone pulleys being subject to any amount within the capacity of the synchronous machine and possibly passing transmission of power from the synchronous motors was eliminated and the synchronous motor rotor was geared direct to the d-c. section driving motor and the synchronous motor stator was made to rotate at a slow speed by a small variable speed d-c. motor which was geared to the stator member of the synchronous motor. Additional bearings and slip rings were provided to permit of the rotation of the stator.

In order to adjust "draw" of the sheet, or the relative speeds of the d-c. section driving motors, it was now only necessary to adjust the speed of the small d-c. motor driving the stator of the synchronous motor, by means of a hand rheostat in its field circuit; and then to

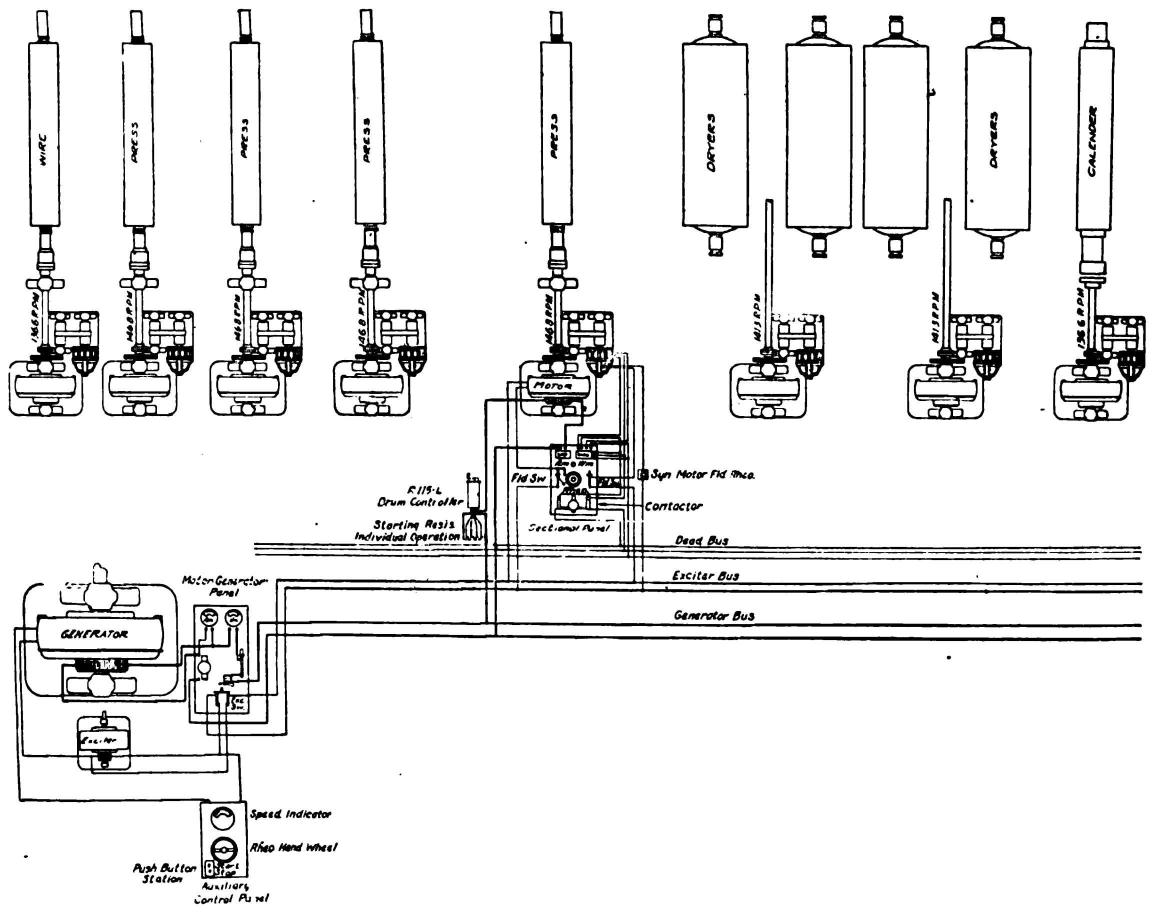


FIG. 5—SCHEMATIC DIAGRAM OF SYNCHRONOUS MOTOR TIE-IN SYSTEM OF SECTIONAL DRIVE WITH BELTS AND CONE PULLEYS

through zero torque on the synchronous machine in going from motor to generator or generator to motor (Fig. 6).

In order to maintain the synchronous motor at approximately no load, so as to be in a position to compensate for any change in either direction, it was, of course, necessary to readjust the shunt-field strength of the d-c. section driving motors at intervals, by suitable hand rheostats; a double indicating instrument being provided for each synchronous motor to indicate the approximate load as motor or generator.

This system of speed control was soon superseded by a modification wherein the belt and cone pulleys for the balance the load by adjusting the rheostat in the field of the d-c. section driving motors.

This arrangement eliminated the belt slippage factor incident to the cone-pulley belt drive, and except for variations in speed of the small d-c. motors, which were under no automatic control, the major possibilities of speed variation of the d-c. section driving motors had been eliminated. In this connection it will be seen that, while the small d-c. motors driving the stators of the synchronous motors were subject to load changes from zero to maximum and possibly even from motor to generator, if the worm gear efficiencies were high enough, considering the ratios used, the effect of the

resulting speed variations of these small motors on the speed of the d-c. section driving motors was only approximately inversely proportional to the ratio of the worm gear used in driving the stators of the synchronous motors.

"Interlock" System

The other or "interlock" system of electrical sectional paper-machine drive referred to, employed a

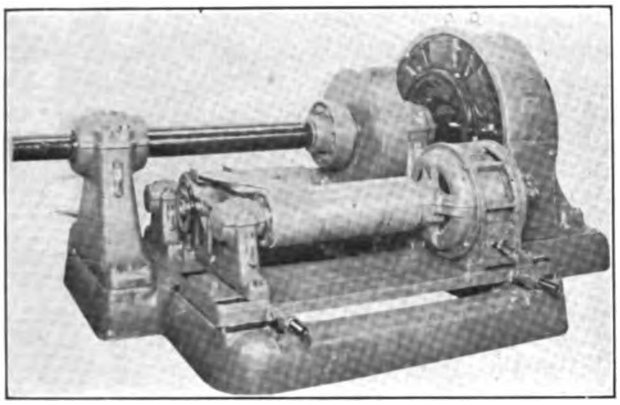


Fig. 6—Sectional Drive of Synchronous Motor Tie-In System

mechanical differential gear system for the operation of face-plate rheostats in the shunt-field circuits of the several d-c. section driving motors (Fig. 7).

A master shaft ran the entire length of the paper machine and adjacent to each of the paper machine sections, a shaft at right angles was taken off from the master shaft by means of a bevel gear. One end of the right angle shaft engaged with one member of a differential gear and the other end member of the differential gear engaged with a shaft driven by the d-c. section driving motor, through a small speed changer,

Fig. 7—"Interlock" Speed Control System of Sectional Drive

consisting of belt and cone pulleys or expanding V pulleys. The middle element of the differential gear was geared to the face-plate rheostat in the shunt-field circuit of the d-c. section driving motor. The master shaft was driven by the dryer section of the paper machine, which, therefore, became the master speed reference, and was not under regulator control.

Speed regulation of the individual d-c. section motors by this system is a function of the speed of the differential gear members, the ratio of the middle member to the rheostat arm shaft, the total resistance in the rheostat and the number of resistance steps; as well as the inherent regulation of the motors themselves and the electrical and mechanical inertia of the system. The regulation is also adversely affected by any back-lash or lost motion in the bevel, differential and rheostat gears and by the torsional elasticity of the master shaft; in fact, by any deformation or departure from synchronism or exact phase position of one part of the speed regulating system to another.

To overcome the disadvantages of the speed regulating rheostat with a rather limited number of resistance steps and of fairly high total resistance, no individual step of which is likely to give exactly the right speed, an arrangement was employed wherein the rheostat contact shoe overlaps one resistance step or button so that a very small movement of the rheostat arm will serve to transfer contact to any one of three resistance steps of the rheostat. To maintain a correct mean resistance value, it is necessary that the rheostat arm oscillate back and forth from one contact point to another, remaining in contact with either at each oscillation such a percentage of time that the mean resistance is of the required value to maintain the d-c. section driving motor at the correct average speed. Ostensibly, the only force available to cause oscillation of the rheostat arm is the d-c. section driving motor which must oscillate at the same frequency as the rheostat arm. The frequency of the oscillation is, of course, determined by the reactance of the electrical system involved, the motor field flux changes, the corresponding changes in motor torque, the inertia of the mechanical parts involved and the lost motion and torsional deformation of the gear train and shafts in the control system.

In each of the systems of electrical sectional paper-machine drive and control described, the usual method of obtaining desired changes in paper speed is by adjustment of the voltage of the d-c. generator supplying current to the armatures of each of the d-c. section driving motors.

Electrical Differential Regulator

The second step in the development of the electrical differential type of field control speed regulator system was the elimination of the a-c. system entirely and the substitution of master and section rotary contactors. These consisted of commutators or ring segments, the master and section rotary contactor being in series and serving to periodically short-circuit resistors in the shunt-field circuit of the section motor under control as illustrated schematically in Fig. 8. Both master and section rotary contactor drums or commutators operate normally at the same speed and the angular displacement of the one to the other determines the percentage of time the resistance is cut in or out of the field circuit.

The operation as will be seen, is somewhat similar to that of a Tirrill regulator, but does not have vibrating contacts.

Differing from the Tirrill regulator, there are a multiple of resistors in series which instead of being short-circuited at the same time, are short-circuited alternately in such a way as to tend to produce the least change in voltage periodically across the motor field. To handle four resistors in series, six rings on the section rotary contactor and four rings on the master rotary contactor are required.

With this arrangement, when the section rotary contactor is exactly in phase with the master rotary contactor and running at the same speed, the regulating resistance in the shunt field circuit of the d-c. section motor is short-circuited and, therefore, cut out 100 per cent of the time. When the section rotary contactor is 180 deg. out of phase, lagging behind the master, then the regulating resistance is all cut in all of the time.

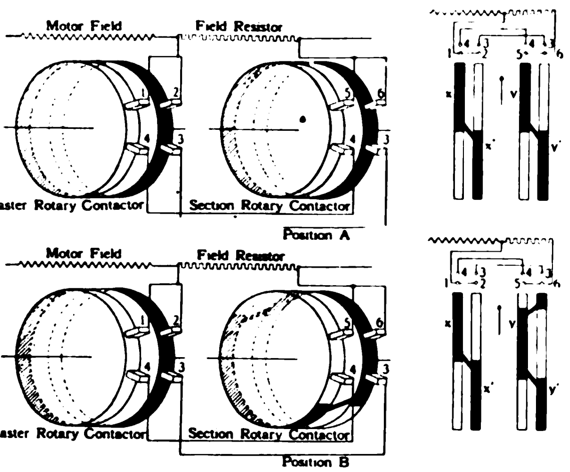


FIG. 8—SCHEMATIC DIAGRAM AND DEVELOPMENT OF MASTER AND SECTION ROTARY CONTACTORS OF ELECTRICAL DIFFERENTIAL SYSTEM

If the section rotary contactor is lagging 90 deg. behind the master, then the resistance of each resistor step is being cut in and cut out just 50 per cent of the time of each revolution of the rotary contactor drum. For any phase position of the section rotary contactor with respect to the master rotary contactor, the mean effective regulating resistance in the shunt-field circuit of the d-c. section driving motor is a direct function of the angular displacement of the section rotary contactor with respect to the master. With more than four resistance steps and a corresponding increase in the number of commutator rings, the wiring becomes very complex and difficult to trace and offers various objections for this reason.

LATEST TYPE ROTARY CONTACTOR ELECTRICAL DIFFERENTIAL SPEED REGULATOR

The third and latest development in improving and simplifying the electrical type of differential speed regulator by field control is a change in the rotary contactor design whereby it becomes in effect a continuous rheostat automatically controlled. The rotary contactor drum consists of an annular ring segment tapered at one end, forming a conducting segment and a complementary insulating segment, the two constituting the entire surface of the drum or cylinder, (see Fig. 9).

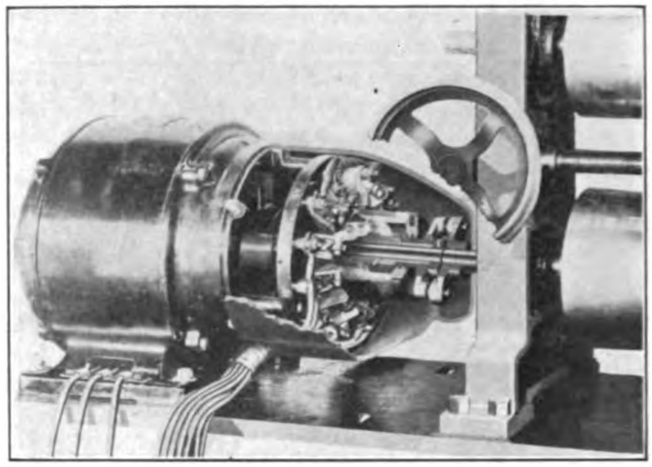


FIG. 9—LATEST SECTION ROTARY CONTACTOR UNIT OF ELECTRICAL TYPE DIFFERENTIAL SPEED REGULATOR SYSTEMS

Twelve brushes disposed radially around the periphery of the drum form a single spiral helix. Resistance units are connected between the brushes from one end of the spiral to the other in series with the shunt-field circuit of the motor. The conducting segment of the drum serves to short-circuit as many steps of resistance as there are brushes in engagement with the conducting segment at any time.

The drum is assembled on a sleeve which is mounted on the shaft of the section master synchronous motor, and is movable longitudinally on the sleeve but prevented from rotating thereon by a spline key, and the sleeve on which the drum is assembled is pinned to the shaft. The brushes are stationary and the full length of the taper of the conducting segment of the drum is equal to the "pitch" from one brush to the next in a direction parallel to the axis of the drum, plus a small overlapping allowance.

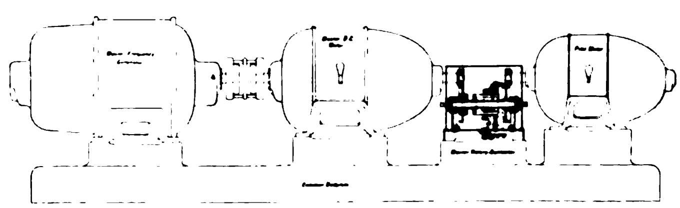


FIG. 10—MASTER SET OF LATEST ELECTRICAL TYPE DIFFERENTIAL SPEED REGULATOR SYSTEM

The speed reference in this arrangement is a master set (Fig. 10) consisting of a master frequency generator driven by a d-c. master motor and controlled with

great precision in speed by a d-c. pilot motor and master rotary contactor. It is from this master frequency generator that each of the section master synchronous motors of the section rotary contactor units operate. Both the d-c. master motor and the pilot motor of the master set operate in parallel with the d-c. section driving motors and the master rotary contactor resistors are in the shunt field circuit of the d-c. master motor. The pilot motor is the final speed reference and as it operates with substantially no-load changes and is usually located where there is little temperature change, its speed is very constant for any desired paper speed; voltage regulators being used to maintain the exciter voltage uniform and the main d-c. generator voltage constant at any desired voltage within the speed range of the paper machine.

A control speed changer, consisting of a pair of cone pulleys and belt, is provided for each section of the machine, one cone pulley being driven from the d-c. section motor to be controlled, by a chain drive; and the other cone pulley shaft coupled to the screw member of the section rotary contactor; a nut member being fixed in the outer end of the rotary contactor drum with which the screw engages. This screw member is assembled on the same sleeve with the drum to assure perfect alinement and is rotatable thereon but is restrained from moving endwise by a shoulder in the sleeve at one end of the screw and a collar at the other end on the end of the master synchronous-motor shaft. From this definite longitudinal location of the screw on the sleeve of the section rotary contactor; the spline key in the sleeve and drum, preventing rotational movement of the drum on the sleeve; and considering the engagement of the screw within the nut member of the drum; it is apparent that any difference in speed between the screw and the nut will cause a longitudinal movement of the drum beneath the brushes.

In normal operation, the screw member driven by the d-c. section driving motor through the control speed changer operates at the same speed as the nut member, drum and master; and certain resistance steps are continuously short-circuited corresponding to the brushes engaging with the continuous portion of the conducting segment of the drum. One step is being cut out periodically once every revolution, the percentage of time it is cut out corresponding with the percentage of time the brush of this step is in engagement with the tapered portion of the conducting segment which depends upon the longitudinal position of the drum beneath the brushes. The remaining resistance steps are cut in continuously, as the brushes are only in engagement with the non-conducting segment of the drum. As a result, the motor operates at a speed resulting from the mean effective resistance valve of the rotary contactor resistor—an automatic rheostat—with an infinite number of steps of infinitely small increments of effective resistance.

The extreme sensitivity of this regulating system will be appreciated by the fact that any change in angular position or phase relation of the lower cone pulley shaft of the control speed changer with respect to the master section synchronous motor, through the screw action, causes a longitudinal movement of the drum beneath the brushes and a longitudinal movement of only a few thousandths of an inch is sufficient to correct for most of the tendencies on the part of the d-c. section driving motor to change in speed. A travel of the drum of approximately three-fourths of an inch suffices to cover the range from resistance all-out to resistance all-in; and sufficient resistance is frequently used to produce a speed increase of as much as 50 per cent or more when all cut in to the shunt field circuit of the motor.

Another very important characteristic of such a differential type of regulator is the fact that any variation in speed, no matter how small, produces a positive corrective effect; and the corrective effect is cumulative and continually increases in value until the correct speed has been restored. A change in angular or phase

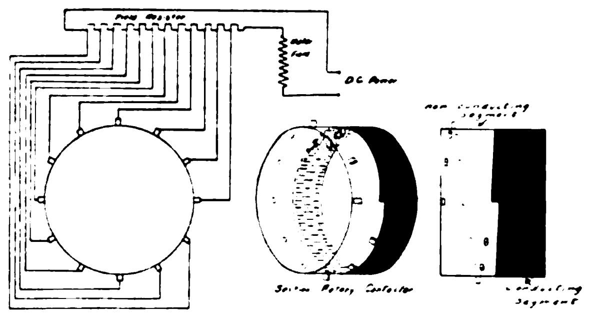


Fig. 11—Schematic Diagram and Development of Sectional Rotary Contactor Drum, Brushes and Wiring Connections of Latest Type Electrical Differential Speed Regulator Systems

position only, of the section with respect to the master serves to cut-in or cut-out sufficient resistance in the shunt field circuit of the d-c. section driving motor to maintain its speed at the same rate as before although the load may have changed.

In this respect it is interesting to observe that the d-c. motor is made to function much like a synchronous motor in so far as maintenance of speed is concerned. With the synchronous motor when a load is thrown on, the rotor falls back in phase position with respect to the generator or the frequency source and the new load is carried without more than a transient change in speed and at the same rev. per min. as before; sufficient torque having been developed in the phase displacement to carry its load. In the case of the d-c. motor with electrical speed differential field control, when a load is thrown on, the rotor falls back in phase position with respect to the master and the new load is carried without more than a transient change in speed, at the same rev. per min. as before; sufficient torque having been developed in the phase displacement and corresponding longitudinal movement of the rotary contactor drum

beneath the brushes, thereby changing the motor field resistance, so as to carry the new load without change in rev. per min. When the load is thrown off, the rotor will move forward again in a manner similar to that of the synchronous motor. The number of mechanical degrees through which the d-c. motor must fall back in phase displacement in order to carry a load of given value, at the same speed as before, depends upon the droop of the load speed characteristic curve of the motor, the resistance in the rotary contactor regulating circuit, and the ratio of longitudinal drum movement to the differential angular displacement of the rotor of the motor.

This electrical speed differential field regulator in its simplest form is not fundamentally an especially high speed regulator, nor is it especially adapted to correct with exceptional quickness for extremely heavy load changes and corresponding tendencies to speed change, although with suitable auxiliary reaction features, not necessary in paper machine drive, such conditions can be taken care of. The upper limit of speed of regulation of this system without auxiliary reaction features, is determined by the reactance of the electrical system and the inertia of the mechanical system; in other words, the speed with which the motor torque can be changed to meet the requirements of constant relative speeds, the maintenance of stability of speed and the capacity to pull into synchronism with the master promptly on starting up.

In sectional paper-machine drive all of the requirements are well within the capacity of this type of electrical speed differential regulator system and the relative speeds of the section driving motors are held constant with such precision that no variation in the "draws" of the sheet can be observed even though the paper may be traveling through the machine at the rate of 1000 ft. per min. or more which speeds are now common in modern high speed paper-making machines.

The purpose of the control speed changer between the d-c. section driving motor and the screw member of the section rotary contactor is to make possible adjustments of the speed of the d-c. section driving motors and at the same time maintaining the speed of the screw member of the rotary contactor at the same speed as the section master synchronous motor. Coincident with any shifting of the belt on the control speed changer an angular displacement of the screw with respect to the nut takes place, moving the drum longitudinally, changing the regulating resistance so as to give the d-c. section motor its new speed corresponding with the new belt position on the cone pulleys.

The coning of the pulleys of the speed changer is so small that even though a change in section "draw," or relative speeds of 25 per cent to 30 per cent can be obtained, good belt contact is always secured; and as no load is transmitted by the belt no slippage or creep that can in any way be detected takes place.

Of much value in sectional paper-machine drive and fundamental in this electrical speed differential field regulator system, is the fact that the section motors do not have to oscillate in speed to maintain the proper mean regulating resistance values; nor does any other part of this control system oscillate. The motors operate at a constant uniform speed and the exact mean effective regulating resistance values required for uniform motor speeds at any desired value are obtained by the constantly rotating tapered conducting segment of the drum of the section rotary contactor.

With the twelve steps of regulating resistance normally employed in the design of the rotary contactor, resistance values sufficiently high to meet every requirement of electrical sectional paper-machine drive can be used with practically no visible sparking at the brushes and with negligible wear of brushes or drum. The mechanical movement between the screw and nut of the rotary contactor is so small that there is practically no wear of those parts.

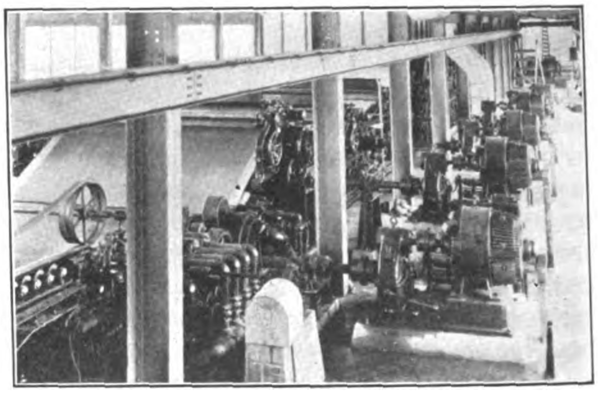


Fig. 12—Sectional Paper Machine Drive Installation of Electrical Differential Type, Field Control, Speed Regulator Systems

In order that the screw member may readily reengage with the nut member of the section rotary contactor, should it run out of engagement in shutting down or starting up, small helical springs are so disposed within the drum that they come into engagement and begin to compress just before the screw leaves the nut so that there is a sufficient force to cause the reengagement of the screw and nut as soon as the speeds of the respective members are such as to permit.

Full automatic push-button control of starting and stopping operation, "inching" and changing of "draw," as well as the adjustments of the speed of the machine as a whole for any paper speed within its range, adds greatly to the flexibility and makes the equipment practically fool-proof.

Rumors have been heard of the development in Europe of an a-c. type of electrical sectional paper machine drive wherein commutator-type variable speed a-c. motors are understood to be used for driving the paper-machine sections; with a differential mechanism for automatically shifting the motor brushes to control

the relative speeds of the section driving motors; and by changing the master speed to effect speed adjustment over the entire range of the paper machine. Information is not at hand to confirm the successful installation and performance of this type of drive and control.

The use of electrical sectional paper machine drive has made possible the operation of paper-making machines economically at higher speeds than was possible with existing mechanical systems of drive. This was largely due to the rather limited amount of power that can be transmitted by means of cone pulleys and belt drive. With electrical sectional paper-machine drive a very considerable saving in power is accomplished and maintenance is reduced to a minimum as compared to mechanical drive. On account of the elimination of belt slippage and sectional speed variations incident thereto, breaks in the paper are greatly reduced and the operating efficiency materially increased. More exact speed regulation throughout is made possible and many other distinct advantages in specific cases and kinds of paper machines and types of product have added greatly to the general efficiency, flexibility and operating technique in the modern paper-making machines.

The object of this paper has been to chronicle the advance in the art of electrical sectional paper-machine drive and control, to indicate the several more or less distinct lines of development; to outline the outstanding characteristics of each of the several types and to point out novel and rather unique methods, so far as the author knew, for obtaining speed regulation of great precision and for the making of d-c. motors to operate at synchronous relative speeds.

The author wishes to express his appreciation of the privilege of using in this paper illustrations kindly furnished by the following: Vocational & Educational Committee of the Paper Industry and McGraw-Hill Book Company, Publishers of "Manufacture of Pulp and Paper." The Paper Mill and Wood Pulp News. The General Electric Company. Westinghouse Electric & Manufacturing Company.

Discussion at New York Section Meeting

HYDROGEN AS A COOLING MEDIUM FOR ELECTRICAL MACHINERY[1]

(KNOWLTON, RICE & FREIBURGHOUSE)

NEW YORK, N. Y., OCTOBER 23, 1925.

G. E. Luke: In determining the probable temperature rise of any electric machine, we may first start with the calculation of the volume of fluid necessary to be circulated through the machine in a given time.

Thus, comparing air and hydrogen as possible fluids, the volume of hydrogen required will be only 2 or 3 per cent more for hydrogen than for air, on the basis of the same temperature rise of the gas due to the same loss absorbed. This temperature rise in the gas used should not be over one-half of the maximum temperature rise of the ventilating surfaces.

The ventilating-surface temperature can be calculated, when the surface-heat-transfer coefficient (K) is known. Considerable data regarding this constant (K) are available for air[2]. However, little experimental data are published for hydrogen. Some experimental tests by Rice[3] on a small cylinder (axial flow) gave a heat transfer for hydrogen 137 per cent of that for air at an average velocity of 5000 ft. per min. On the other hand Rice[4] gives for large plane surfaces this heat transfer (K) as proportional to $\frac{\rho\, k}{\mu}$, where ρ, k, and μ are the density, thermal conductivity, and viscosity of the gas, respectively. On this basis, the unit heat transfer from the surface will be about the same for hydrogen as for air.

Pohl[5] has calculated from Nusselt's[6] work this coefficient (K) to be about 50 per cent greater for hydrogen than for air. The equation given by Nusselt can be reduced to the form[7] of

$$K \,\alpha\, k^{n-1} \quad (\rho\, C_p\, V)^n$$

where

K = unit surface heat transfer
k = thermal conductivity of the gas
ρ = density of gas
C_p = specific heat of gas
V = velocity of gas.

This equation is also practically the same as that given by Pohl. Thus, the ratio of the heat transfer with hydrogen to that obtained with air will depend upon the exponent (n) of the velocity factor. Thus, with (n) = 1, the ratio is about 98 per cent and with n = 0.786 as given by Nusselt the ratio becomes about 150 per cent. The writer has found that for turbulent gas flow where the gas path is straight and uniform, the heat loss varies as $V^{0.85}$ to $V^{0.95}$; and where the air path is irregular the unit heat loss varies as $V^{0.75}$ to $V^{0.85}$. Hence, it is estimated that in an average generator the unit heat dissipated with hydrogen will be about 25 per cent greater than with air, which is not far from the figure given in the paper.

The paper states that the rate of heat transfer in the coolers should be about three times greater for hydrogen than for air. This figure seems too high; it might be correct for the tubular surface but is probably too high for the fin surface, and this later surface is usually several times greater than the tubular surface. The writer estimates the heat transfer in the usual type of cooler to be 50 to 100 per cent greater for hydrogen than for air. This, of course, is a big factor since the cost and size of the present cooler can be reduced.

The majority of the iron and copper losses in the core have to flow an appreciable distance through the iron to the ventilating surface. This necessarily requires a temperature drop. Where radial ventilation is used, the heat flow is mainly across the lami-

1. A. I. E. E. JOURNAL, July, 1925, p. 724.

2. See *Cooling of Electric Machines*, by G. E. Luke, TRANS. A. I. E. E., 1923, p. 635-636.

3. See *Free and Forced Convection of Heat in Gases and Liquids*, TRANS. A. I. E. E., 1923, p. 653.

4. Forced Convection of Heat in Gases and Liquids, Eng. & Ind. Chem., May, 1924.

5. "Fundamentals of Heating Calc.," by R. Pohl. *Arch. f. Electro.* June 30, 1923.

6. "Heat Transmission in Conduits," by W. Nusselt, Z. V. d. I., October 23, 1909.

7. This was done on the basis of (K) being independent of the temperature of the gas and surface, which is practically true of the range in which we are interested.

nations, in which direction the heat flow has a high-resistance path due to the varnish and gas film between the laminations.

With one-watt flow across a 1-sq. in. section of the usual 0.017-in. varnished iron laminations, the temperature drops are approximately:

Deg. cent. drop through

Iron	Varnish	Gas	Total
1.0	11.0	(Air) 21.0	33 deg. cent.
1.0	11.0	(Hydrogen) 3.0	15 deg. cent.

Hence the rate of heat flow across the laminations should be at least doubled by using hydrogen as the cooling medium.

One of the most important portions of the heat-flow path is from the copper through the insulation. This part has more influence in limiting the rating than any other since the thermal conductivity of insulating materials is so low. The thermal resistance through ordinary insulation in air is about 3000 times greater than that through copper. All insulation in the built-up wrapper will necessarily contain some small gas spaces; hence these gas spaces, if they are air, will offer considerable resistance to the heat flow, since the thermal resistance of air is about ten times that of the insulation itself.

To check the above, the Westinghouse Research Laboratory has made tests on the thermal conductivity of the insulation on turbo armature coils. The results show that the thermal conductivity of these mica insulations as used is from 150 per cent to 250 per cent as great with the coils in hydrogen as obtained on the same coils in air. The particular ratio depends upon the compactness of the insulation; that is, the percentage gas space in the wrapper. This increase in heat flow with the hydrogen cooling system will result in a considerable reduction of the conventional "hot spot."

The temperature of the rotor copper is usually the limiting temperature, with air as the cooling fluid. It will also tend to be the limiting factor when hydrogen is used, due to space limitations and to appreciable temperature drops through the solid iron core which will be unaffected by the gas used for cooling.

In the tests given by the writers, the apparatus simulated conditions found in a solid rotor, where there would be a considerable temperature drop through the iron. However, in a ventilated rotor, even better results could be expected, since this drop through the iron would be reduced.

Comparative Corona Effects Under 15,000 Volts for 19 Days.

As to the insulation, the writer also agrees with the authors, that its life would be materially increased in a hydrogen atmosphere. Oxygen in the air is the main factor which causes mechanical deterioration. Dr. C. F. Hill made tests regarding the corona action upon insulation in air and in hydrogen. The results were even better than those quoted in the paper in favor of hydrogen. Two kinds of insulation were tested; one varnished cambric, the other a mica wrapper. Both were wound on a glass tube and 15,000 volts a-c., 60 cycles, was applied for 19 days. Most of the stress was through the glass tube but a heavy corona could be seen covering the insulation. At the end of the test, the sample in hydrogen was unchanged, while the one in air was radically altered. The varnished cambric was bleached and was very brittle, the paper in the mica wrapper was completely destroyed. The hydrogen prevented the chemical action found on the sample in air.

As to the possibility of explosive mixtures with hydrogen, the average of nine investigations[8] gives the explosion limits as 7.9 to 69.4 per cent hydrogen in a hydrogen and air mixture.

An indicating or recording instrument for giving the purity of the mixture can be easily obtained by using the conductivity-cell bridge method[9]. This is exceedingly accurate and is well suited for such purposes.

Gases other than hydrogen can be used for a cooling medium. Thus helium, (if made available in the future) is an inert gas with a density about 1/7 of that of air. Its specific thermal capacity is about 73 per cent of that of air and its thermal conductivity is almost as high as that of hydrogen. Such a gas would be preferable to the operating men.

L. B. Bonnett: From the user's point of view, there are some very striking things in this Table II, showing the results of the tests on the small 3000-kv-a. machine. If we can expect to get a one-third increase in capacity out of the same material, presumably at approximately the same price, we are getting something that is very interesting indeed. At that increased rating the total loss is practically the same, in fact, it has slightly decreased.

Looking at it from a little different point of view, many of us use stand-by machines that are in operation ready to take load and the no-load losses are a very important factor. If the use of hydrogen can reduce those losses by say 50 per cent, that indeed is a very great advantage for this particular duty.

This light-load loss too, has another rather interesting application. Turbo-generators are commonly equipped with closed ventilation and air coolers and very frequently condensate is used for cooling. Since the light-load losses are usually more than half the full-load losses, the condensate at light loads has to be recirculated in a more or less complicated fashion or some other means of cooling supplied. This very great reduction in the fixed losses would mean that the losses would decrease more nearly in proportion to the load and the condensate itself might be perfectly adequate for cooling the machine all the way down.

With all the advantages mentioned in this paper,—a real astonishing catalog of advantages,—it behooves us, the users, not to be too sure that the one disadvantage, the possibility of an explosion, is an insurmountable defect. I believe our serious consideration is well worth while.

W. B. Kirke: It is hoped that further investigation on the life of insulating material when operated in hydrogen as compared to operation in air can be made. It might be found quite practical to operate at higher temperature limits in hydrogen than have been standardized for operation in air. It is also to be hoped that this paper will be supplemented by others which will indicate the installation cost of such a ventilating system, and some idea of the equipment necessary for its operation.

C. J. Fechheimer: A few years ago the only media for cooling considered were air, oil and water. The use of oil or water has never met with favor in this country, even though certain important advantages could be secured by their adoption. It seems that electrical engineers were not aware until a few years ago that the gains to be obtained by means of some other gas were sufficient to warrant employing it instead of air. Even after the suggestion of the use of a lighter gas was offered to the designing engineers, they did not immediately consider its adoption. The gas proposed in the Schüler patent is hydrogen, and the first thought that entered the mind of the engineer was the danger of explosion. It was not until he learned that

8. See article by C. J. Rodman, *Elec. World*, 6-24-22.

9. Thermal Conductivity for Analysis of Gases. Technical Paper, Bureau of Standards, No. 249

detonation will not occur if hydrogen constitutes more than about 70 per cent of a mixture with air, that he felt that possible gains were great enough to warrant investigation. We now have records in this paper of the studies and researches given by three engineers of one of the leading electrical manufacturing companies on this subject. It is the first public presentation to a group of engineers of a systematic study of this advance which it is believed will considerably modify the design and construction of large electrical machines in the future.

Of the various gains to be obtained by means of hydrogen, there are two of prime importance. The first is the enormous reduction in windage loss due to the low density; and the other is the decrease in thermal drop through the insulation. In the large high-speed steam turbo alternator the windage is the greatest loss and may be as high as 50 per cent of the total. By substituting hydrogen for air this loss becomes almost negligible. In addition to the gain in efficiency, the temperature rise due to the windage becomes insignificant, whereas in the present day machine it is from 5 to 10 deg. cent.

It has been recognized for a number of years that the tiny voids in insulation reduce the net thermal conductivity of the wrapper to about 50 to 75 per cent of that which would obtain if the wrapper were solid throughout. Now we find that, because hydrogen diffuses so readily, hydrogen will supplant the air and the resistance to heat flow in the voids will be decreased to about one-seventh, and the net conductivity will be greatly improved. The authors find 30 to 58 per cent improvement in net conductivity for the field core, and they estimate about 42 per cent gain for the armature coil. Also, because the thermal conductivity is high, the transverse drop through a package of laminations is reduced and the drop from the surface is decreased. So the authors find that as a result of all the gains, a certain turbo-alternator can be rated about 30 per cent higher by substituting hydrogen for air. But that is not the final word; to take full advantage of the properties of hydrogen, the machine should be proportioned differently. For example, the velocities of the gas in the vent ducts can be increased, and the lamination-package thickness can be enlarged. Owing to the reduction in total losses, the volume per unit time of the gas may be lowered.

Also, as the authors state, there is a likelihood of reducing thickness of insulation wall in the stators, when mechanical considerations do not enter. At present it is difficult to state how much the weight, cost and size of the generator may be decreased, if full advantage of all gains is taken in the design. But certainly the cost will be reduced considerably.

There are a few points which are not covered in the paper. Two will be mentioned. In very large machines as designed at present, it is not feasible to evacuate in order to replace the air by hydrogen or vice versa, as the stresses arising from atmospheric pressure are prohibitive. While it is possible so to proportion those parts as to prevent collapse while evacuating, it is believed that an alternative plan which will maintain all parts at or near atmospheric pressure should be entirely satisfactory. The plan is to replace the air by an inert gas, such as nitrogen, and then to replace this inert gas by hydrogen. Tests are now being conducted for determining how satisfactorily this can be done.

Another feature is that to minimize leakage, suitable stuffing boxes should be provided where the shaft passes through the openings in the end bells. It seems at present that this is the most difficult part of the problem. Experimental work is now under way on a water-gland seal; and with this device it is believed that the leakage will be negligible. Ample precautions are being taken to avoid the escapement of water into the generator.

The authors have used the thermal-conductivity method for determining the extent to which the hydrogen is contaminated. Another method consists of a small fan driven at constant speed, the inlet and outlet of which join into the system. The pressure which the fan generates is directly proportional to the density of the gas, and the pressure difference between the inlet and outlet can readily be indicated on an ordinary manometer. The relation between the percentage of hydrogen and the reading on the manometer is linear, assuming that air is the contaminating gas. The authors state that with the thermal conductivity method, 1 per cent impurity will change the potential drop from 11.5 to 12.5 volts or 8.7 per cent. With the density method, the same change in constituency will alter the manometer reading 13.3 per cent. Thus, there is greater sensitivity, and it is believed that the device is more direct and simpler than the thermal method. The density method can be used to operate a signal, or possibly to operate switches automatically.

While further experimental work must be done prior to the building of machines for service, the outlook is very bright, and it is believed that the time is not far distant when machines using hydrogen will be in operation.

J. Rosen (communicated after adjournment): The authors' investigations into the difficulties of ventilation of electrical machinery will be welcome as being of theoretical interest, more particularly as they have some bearing upon the conditions for generating at higher voltages than have been customary in the past. I do not think, however, that the use of hydrogen can be considered practicable at the present moment. It has the drawback of increased cost and complication in design. Further, I do not think that the danger of forming an explosive mixture can be altogether avoided. The closed-circuit system of ventilation has now been generally adopted for large alternators. The advantage with the use of hydrogen in avoiding the danger of fire also applies to the closed-circuit system using air, as, with the limited amount of air in the latter, the damage that can be done by fire is limited. I illustrate this by the following example:

The volume of air in the alternator and ducts of the closed-circuit system of a 25,000-kv-a. alternator at 3000 rev. per min. is approximately 2000 cu. ft. containing 40 lb. of oxygen. This quantity of oxygen could consume 15 lb. of carbon or 40 lb. of wood, but as the principal product of combustion is carbonic acid gas, and a flame is extinguished when only 4 per cent of carbonic-acid gas is present, the amount of wood consumed would only be about 2 lb. The total weight of combustible material in the alternator, including wood packing and insulation exceeds 1000 lb. It is obvious therefore that the fraction of material that would be damaged, or consumed by fire would be negligible.

To reduce the losses in the fans attached to the rotor body, I prefer to use separately driven fans, and to adopt a suitable system of ventilation to reduce the pressure drop through the alternator to a minimum. By this means, an improvement in efficiency of one per cent can be obtained. In the ventilation scheme described in the paper[10] "Some Problems in High-Speed Alternators and their Solution," the air-pressure drop through the alternator is reduced to approximately 3-in. water gage.

Robert Pohl: The valuable research which Messrs. Knowlton, Rice and Freiburghouse publish on this subject might, with advantage be extended to the use of methane. In a paper published in 1923 (*Archiv. F. Elect.*, June 30, 1923, p. 361) I defined what one might term the cooling constant of various gases and showed that this constant is even higher for methane than for hydrogen. Since methane is also cheaply obtained as a by-product, its use may well be considered. Although the risk of explosion is not serious in any case the much smaller area of "exploibility" would be a practical advantage.

E. H. Freiburghouse: From the discussions it is evident that other engineers have also been giving active consideration to the subject and almost all of them seem very optimistic for the future use of hydrogen as a cooling medium for electrical machinery.

Opinions and data which have geen given seem, in the main, to agree quite well with those given in the paper. Although the

10. *Journal I. E. E.*, Vol. 61, No. 317, p. 447-8.

points raised by Mr. Fechheimer were not covered in the paper they have been carried out or considered during the investigation by the authors.

Mr. Fechheimer mentions the use of an inert gas, such as nitrogen, for replacing the air and hydrogen in the generator before and after the installation of the hydrogen. Nitrogen was used for this purpose during the heat tests which were made upon the 3380-kv-a. generator.

It was realized from the beginning that to prevent the leakage of hydrogen between the rotating and stationary parts of the generator was the most difficult and expensive problem to solve. Two different types of seals have been developed each of which reduces the leakage to a negligible value. In the liquid seal it is thought that oil is preferable to water.

A small fan driven at constant speed was used in some of our earlier investigations to determine the density of the gas mixture and, as Mr. Fechheimer states, it has several attractive features.

If hydrogen is used as a cooling medium, the authors believe that Mr. Rosen will agree that fans upon the rotor of the generator are preferable to separately driven fans. We believe that the pressure drop of the air through the generator should greatly exceed the 3 in. of water which Mr. Rosen mentions, if the necessary velocity of the air is obtained for a high value of unit-surface heat transfer.

THREE-PHASE, 60,000-KV-A. TURBO ALTERNATORS FOR GENNEVILLIERS

(Edouard Roth)

New York, N. Y., October 23, 1925.

W. F. Dawson: The author is to be particularly congratulated on the production of a very fine machine. It has shown low heating, many novel and ingenious ideas, good mechanical engineering, and, I should say, very good efficiency. But there is one feature of the design that is quite startling to us in the United States. I know I speak for myself and for my immediate colleagues although I do not know that I speak for other manufacturers in this country.

Mr. Roth has laid particular stress on the fact that, by means of his leakage slot, he has achieved very low short-circuit current, current as a result of sudden short circuit. He has also pointed out that he has done this in preference to using very high armature reaction and a correspondingly low flux. Nevertheless, his armature reactions are proportionately higher than we would feel safe in using.

If we go back to the *Electrical Review* of London, April, 1923, we find there the saturation and impedance curves (page 646, issue of April 27th, 1923). The "saturation," 6000 volts is, expressed in field amperes, about 136 amperes. The short-circuit impedance at 4200 amperes is approximately 270 amperes. We feel that in designing alternators, particularly those to carry inductive load, the excitation required for normal ampere short-circuit impedance should not be much in excess of the excitation required at normal open-circuit voltage.

I understand that it is the practise of many European designers to allow a high short-circuit impedance, making a machine in which the full-load field excitation is three times the open-circuit excitation.

I also understand that somehow in general they are successful with it, probably because the increment of the load is small compared with the total load and perhaps, too, because of the more general use of automatic voltage regulators. I have had at least two or three glaring cases in my own practise, in which, before I realized the importance of designing for "voltage stability," the voltage would break down at or about full load. One case was in a cotton mill where one turbo alternator was carrying the entire load of the mill and, according to the calculations which I learned later how to make, the machine should have had a voltage breakdown at about 2300 kw.; it was rated at 2500 kw. I furnished a new armature which had lower armature reaction and, of course, higher flux, and the trouble disappeared.

I have had other cases into which it is not necessary to go; we have also noticed it particularly in the case of ship propulsion machines where one turbo alternator is to take care of the induction-motor load. That machine, or a group of machines, will be running along satisfactorily, but rough sea will increase the load on the motors and the voltage falls faster than the amperes increase, hence the kv-a. is reduced and the motors break down.

I should like the author to tell whether he has had any such experience?

Philip Torchio: Mr. Roth's paper gives an excellent illustration of the progress in large turbo alternator design. Some of the special features of his machines will undoubtedly be commented upon by expert designing engineers. From an operator's standpoint, I wish to express my sincere appreciation of the remarkably low temperature rises of the copper in the stator and the rotor. The long narrow slots with an abundance of radiating area, the winding bars of the armature, with their careful assembling to eliminate eddy-current losses and a combination of axial and radial ventilation, have been used to secure results which are superior to any with which I am acquainted. In making this statement I wish to add that I have not had the time to analyze closely how much the results are influenced by the differences in number of poles and the relative capacities of the machines compared. Mr. Roth has already mentioned how the difference in number of poles for machines of same capacities affects the total weights of such machines. Undoubtedly to some extent the number of poles imposes limitations upon the temperature rises. The employment of leakage slots may, however, be of a decided advantage in giving remarkably low temperature rises.

As to the advantage of reducing the short-circuit current, I shall be very much interested to learn of the comments of designing engineers. In our practise we have, for more than 13 years, considered it essential to the safe operation of a large system to install reactors between generators and buses so as to protect the main bus against sort-circuit failures in generator windings. In such installations, therefore, the reduction of short-circuit current on sound generators is limited by the external reactors, and designers may not find it necessary or desirable to employ leakage slots. This is a problem that should receive consideration in the discussion.

C. M. Laffoon: These generators are unique, in that certain design features are carried to rather extreme limits. The author states that the 45,000-kv-a. turbo generators, which were installed in the Gennevilliers station in 1922, were the largest four-pole turbo generators built, up to that time. This statement is somewhat liable to misinterpretation because these are 50-cycle machines and the design and construction of a given size, four-pole generator, operating at 1500 rev. per min. are not so difficult as the design and construction of a four-pole, 60-cycle generator which operates at 1800 rev. per min. At the time these Gennevilliers generators were installed, they were rated at 40,000 kv-a. At the same time the Westinghouse Company was installing the first of the Hellgate generators, which were rated at 43,750 kv-a., but were six-pole, 1200-rev. per min. The Westinghouse Company has since built generators of this same kv-a. rating but of four poles, 1800-rev. per min. Recent tests on these generators show that they will carry 50,000 kv-a. at 80 per cent power factor and do not exceed the standard guarantee of 60 deg. cent. temperature rise on the armature winding and 90 deg. on the field winding. The Westinghouse Company has also built 62,500-kv-a. generators for the Brooklyn Edison Company, but these were of six poles and 1200-rev. per min. At the present time a four-pole, 1800-rev. per min. 62,500-kv-a. 80 per cent power factor turbo generator is being developed by the Westinghouse Company and 1800-rev. per.

min. generators with ratings as high as 75,000 kw. and 90 per cent power factor appear feasible to build and operate.

It is to be noted that this generator is being wound for 6000 volts, which is a relatively low voltage for 60,000-kv-a. rating. In the United States the majority of central stations generate at voltages varying from 11,000 to 13,800 and with some companies there is a decided tendency to specify a final insulation test voltage of three times normal plus 1000 instead of the standard insulation test of twice normal plus 1000. However, some utility companies are considering the advisability of having generators wound for lower voltages and solidly connecting the generators to step-up transformers without any intermediate circuit breakers. In this case the final insulation test voltage would be on the order of four times normal plus 1000. On the other hand, other companies in the far west are considering 16,500-volt generators. At the present time there does not appear to be sufficient data available to determine the maximum voltage stresses due to switching, short circuits, and lightning to which the generator windings may be subjected during actual service conditions. Until these data are available, it will be difficult to determine the voltage and insulation strength which will give the greatest protection against over-voltages and still not seriously affect the cost and the reliability of operation from the standpoint of temperature.

In going over this paper the following outstanding features are of paramount importance.

1. Small physical dimensions.
2. Low short-circuit ratio, i.e., a low ratio of no-load field ampere-turns to the field ampere-turns which are required to maintain full-load sustained armature current.
3. High leakage reactance.

In comparing the physical dimensions of this 50-cycle generator with those of a four-pole, 60-cycle, 1800-rev. per. min. generator of the same kv-a. rating, it is noted that the overall length of the active iron including the ventilating ducts is considerably less than that required for the 60-cycle generator. This is partly due to the fact, as previously indicated, that, for a given rotor diameter the design and construction of a 50-cycle generator are less difficult than they are for a 60-cycle generator of the same rating and number of poles. Since the mechanical stresses in the rotor body and retaining rings are proportional to the square of the peripheral speed, approximately 20 per cent more ampere-wires per inch of wound periphery can be obtained for a given rotor diameter for the 50-cycle generator than for the 60-cycle generator on the basis of the same number of poles. In either case for a given short-circuit ratio, the kv-a. output is proportional to the product of the total flux, rotor ampere-turns, and rev. per min. Hence, the length of the active iron of the 50-cycle generator would be appreciably less than that of the 60-cycle generator and would be equal to that of the 60-cycle generator multiplied by the inverse ratio of the total flux in the machine. Since the iron loss varies approximately as the second power of the flux density and about as 1.2 power of the frequency, the relative total flux for the two cases will depend on the effectiveness of ventilation for each generator. An examination of the temperature data of Table I shows rather high stator-iron temperatures as compared to the temperatures on the bare copper. This indicates that the stator iron is worked at rather high magnetic induction and consequently this feature also tends toward a short machine.

From Fig. 13, the short-circuit ratio of this 60,000-kv-a. generator is approximately 0.475. This same value was obtained from the specified dimensions and design data which were given for the armature and field windings. The short-circuit ratio of a Westinghouse generator of the same rating would be on the order of 1. Similarly, the full-load field ampere-turns are approximately 3.1 times the no-load field ampere-turns, whereas, in the case of the Westinghouse generator, the ratio is about 2 to 1. This means that the armature ampere-turns are high as compared to the no-load field ampere-turns and a small change in the armature load current produces a large change in generated voltage and kw. output. Fig. 2 herewith shows the relation between armature current and voltage, armature current and kw. output, and kw. output and voltage for the 60,000-kv-a. Gennevilliers generators and for a 62,500-kv-a., 60-cycle, 1800-rev. per min. generator with the field excitation corresponding to full rated kv-a. at 80 per cent power factor. The curves for the 60,000-kv-a. Gennevilliers generators were determined from the specified design data and physical

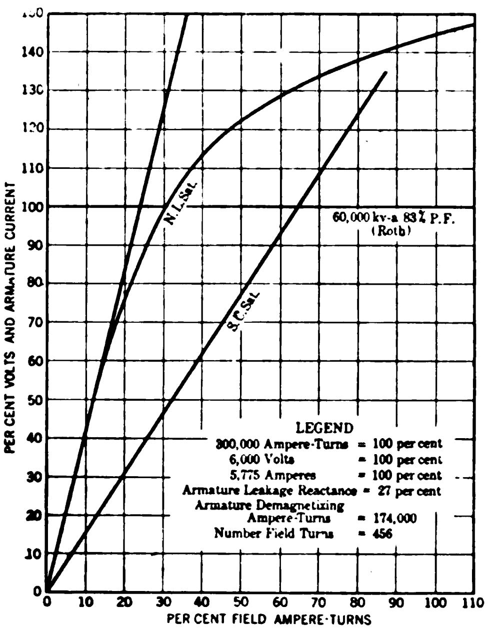


Fig. 1—No Load and Short Circuit Saturation Curves 60,000-Kv-a., 50,000 Kw., 83 Percent Power Factor 6000 Volt, 50-Cycle, 1500-Rev. Per Min., 5775-Ampere Gennevilliers Generators

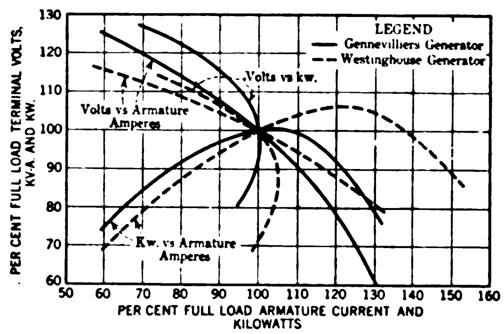


Fig. 2—Load Characteristics for 50,000-Kw. Turbo Generators 80 Percent Power Factor and Constant Field Excitation

dimensions of these machines, and the no-load and short-circuit saturation curves of Fig. 1 herewith. The curves in Fig. 1. are the same as given in Fig. 7 of the paper for the 45,000-kv-a. generators but modified to suit the design constants of the 60,000 kv-a. generators. An analysis of the load curves in Fig. 2 shows the following comparison of the stability characteristics of the two generators when operating at 7 per cent power factor loads, and with a field excitation corresponding to full-load 80 per cent power factor conditions:

1. The maximum kilowatt output of the Westinghouse generator is 106 per cent whereas that of the Gennevilliers generator is only 100 5 per cent.

2. The Westinghouse generator will deliver 100 per cent kilowatt output with an armature-current range of 100 to 138 per cent, whereas the Gennevilliers generators will deliver full kilowatt output over an armature-current range of 100 to 108 per cent only.

3. The rate of change of terminal voltage with respect to kilowatt output, at the point of 100 kw. output, is approximately five times as great for the Gennevilliers generator as for the Westinghouse generator.

This comparison shows that the Gennevilliers generators, which are designed with a low short-circuit ratio and much more sensitive to sudden changes in load than the Westinghouse generators which have a short-circuit ratio which is more than twice as large. Hence, when operating alone or in parallel with other generators which have the same characteristics, it would be necessary to provide voltage regulators in order to maintain reasonably constant voltage for rapidly changing loads on the system. The application of quick-acting voltage regulators to these machines is difficult because of the extremely wide range in field current required in going from no-load to full-load operating conditions.

If these generators were operated in parallel with other generators which have greater stability under changing load conditions, that is short-circuit ratios of 1 or more, it would be necessary not only to provide high-speed voltage regulators but the characteristics of the voltage regulators and of the governors on the driving turbines would have to be carefully designed to meet the particular conditions. But even then, there is always the possibility that hunting action may take place between the generators with poor and good regulating characteristics and reach such magnitudes as to cause the machines to pull out of step.

In the case of high-voltage transmission system the design of the generators should be such that the armature ampere-turns are small as compared to the no-load field ampere-turns; that is, the short-circuit ratios should be high.

A generator designed with a low short-circuit ratio has considerably smaller dimensions than one designed for a high short-circuit ratio on account of the fact that the portion of the field ampere-turns which is used to give stability in the high short-circuit ratio machine is used to give kv-a. output in the case of the generator with the low short-circuit ratio. There is no doubt but that generators with short-circuit ratios as low as 0.475 can be operated satisfactorily with hand regulation on systems which have reasonably smooth load curves, as well as with automatic voltage regulators on systems with varying loads, provided the voltage regulators and turbine governors are designed with the necessary characteristics. However, there is no doubt that such generators require careful attention and are likely to give trouble during transient disturbances or sudden load changes. The extent to which it is desirable to reduce the short-circuit ratio, and hence increase the output for given physical dimensions depends, to a large extent, on the load characteristics of the system on which the generator is to operate, the characteristics of the generators which operate in parallel, the characteristics of the voltage regulators and turbine governors, and the amount of attention the operators give to the machine. Our own experience and observation indicate that turbo generators which have short-circuit ratios of approximately unity give satisfactory operation on the average central-station system in this country. However, this value of short-circuit ratio can and must be widely departed from in the case of generators which operate on systems or central stations in which greater or less generator stability is necessary.

The leakage reactance of the armature winding of the Gennevilliers generators is unusually high for turbo generators. A large portion of this reactance is obtained by providing leakage slots immediately above the slots for the main winding. If it is necessary to limit the initial values of short-circuit current to values comparable with those delivered by slow-speed waterwheel-type generators and the reactance must be within the generator, this is an attractive method of obtaining a high reactance. The mechanical forces on the end turns are reduced and the increase in reactance due to the air slots does not materially increase the iron loss in going from no-load to full-load conditions. However, it must be remembered that the use of these slots increases the over-all diameter of the machine, the cost, and the value of the iron losses. The increase in diameter and cost are partially offset by the fact that more room is obtained for the armature copper. An increase in diameter not only adds to the weight but also the shipping difficulties. The iron loss in the stator teeth is usually about one-half of the value of the loss in the core. The additional tooth projections increases the iron loss in the stator teeth about 60 per cent and this corresponds to an increase in the total iron loss of approximately 20 per cent. In the case of particular generator, the additional 20 per cent increase in iron loss corresponds to 0.15 to 0.20 per cent reduction in the generator efficiency.

The leakage reactance of a 60-cycle, 1800-rev. per min. Westinghouse turbo generator of the same rating would be from 15 to 18 per cent, and the end turns of the armature winding are sufficiently well braced to withstand a three-phase short circuit at the generator terminals under no-load initial conditions and 110 per cent of normal rated voltage, as required by the 1925 A. I. E. E. Standards. So far as the initial values of the short-circuit currents are concerned, this condition corresponds very favorably with the actual conditions under full-load operation. In machines of this class the percentage of winding failures due to short circuits has been very small. In general we feel that the end turns can be sufficiently well braced to withstand short circuits that occur under usual operating conditions when the leakage reactance of the generator is 10 per cent and above. If still greater protection is desired it can be obtained by making further improvements in the bracing instead of increasing the leakage reactance by a method which involves an increase in cost and overall diameter, and a decrease in the generator efficiency of 0.15 to 0.12 per cent.

A comparison of the temperature rises obtained by detectors C, 10, and 12 show that when carrying 50,200 kv-a., the temperature rise on the bare copper at the midway axial position is only 37.5 deg. cent or 10 deg. higher than the temperature rise of detector placed between the conductor sections. Using this same temperature difference, the temperature rise of the bare copper near the ends of the machine would be 50 to 56 deg. cent. The iron temperatures vary over quite a wide range, being particularly high in the teeth at the ends of the machine and in the core at the middle of the machine. The temperature rises of the armature and field windings compare very favorably with corresponding temperatures obtained on Westinghouse generators which have a similar system of ventilation. This particular form of the multiple-path radial system of ventilation is exceptionally well worked out from the standpoint of utilizing the frame space behind the stator punchings, and gives excellent results in stator and rotor ventilation. The air requirements for the generator are approximately 105,000 cu. ft. per min. and the author states that approximately 26.5 per cent of the air passes through the rotor body. This is an unusually large percentage for the rotor and no doubt is responsible for the low temperature of the field winding.

In order to determine the losses of turbo generators when operating under normal load conditions, it is necessary to know the volume of cooling air and its temperature rise for any particular load condition. Various methods have been suggested and used for measuring the amount of air passing through the machine. When the air discharges to the atmosphere the air volume can be determined with a good degree of accuracy by

measuring the velocity head at the discharge from a specially designed stack or nozzle. The discharge velocity can be made practically uniform over the entire discharge section by properly designing the stack and passing the air through fine-mesh screens as it leaves the generator. However, the most promising method is the one suggested by the author, in which the generator is operated as a synchronous motor under no-load conditions and the electrical input and final temperature rise of the cooling air are measured for two widely different values of voltage. If temperature detectors of the thermocouple or resistance type are properly placed in the inlet and outlet air ducts and due care exercised in making the measurements, the air volume can be determinded with a satisfactory degree of accuracy. Since most large turbo generators cannot be tested at the manufacture works under normal load conditions, it seems very essential that all such generator units should be so arranged that the steam end can be disconnected and the generator operated as a synchronous motor. The operating companies should have sufficient interest in the performance of the machines to be willing to cooperate with the manufacturers in making the tests.

Briefly summarizing, the 60,000-kv-a. turbo generators as described by Mr. Roth are exceedingly interesting on account of:

(1) The small physical dimensions which result from the following:

a. The generators are designed for 50 cycles at 1500 rev. per min., and consequently the stator iron can be worked at a higher magnetic induction than in a 60-cycle generator;

b. The short-circuit ratio is unusually low; that is, the portion of the field ampere-turns which is used to give stability in the case of a Westinghouse generator is used to give kv-a. output in the Gennevilliers generators; and

c. The ventilating system provides excellent cooling for both stator and rotor.

(2) Low short-circuit ratio, which results in a machine that is sensitive to load changes and is likely to be very unstable when operated on a system with rapidly changing load. The application of voltage regulators is more difficult on account of the wide range of exciting current which is required for a given load change.

(3) The high armature leakage reactance, which is obtained from the additional slots, provides short-circuit protection and the additional reactance which is secured does not materially increase the core loss under stable load conditions. However, this method of obtaining high reactance involves an increase in cost and overall diameter, and 0.15 to 0.20 per cent reduction in generator efficiency.

C. J. Fechheimer: A few points of interest in this paper will be pointed out in this discussion.

1. The scheme of stator ventilation is unique, as the circumferential system is combined with the axial system. The air which flows circumferentially does not pass through the stator teeth and into the air gap, but the air that flows axially first flows radially inward and then axially through the leakage slots.

Referring to Fig. 2 you will notice that at the back of the core through which the air passes first axially to get into the radial slots, there are eight openings distributed about. The air passes down, radially, in the vent ducts and then, in the same vent ducts, some passes around circumferentially and goes out. Some of the air goes farther radially between the coils and gets into the leakage slots and then moves axially. You see that on one side are shown one kind of guide for the air and on the other side of the line, the guides are arranged differently. Now on the right side of the line, the guides are for the air coming in, and to the left they are for the air going out; that is, the air moves axially and then out, radially, in the next vent duct; and that is the one at 45 deg. to the left of the division line. It moves axially through the leakage slot.

It would seem that the objections which were raised to the circumferential system of ventilation are believed not to apply to Mr. Roth's machine.[1] In the tests on the model for circumferential flow described in my A. I. E. E. paper in 1924, the air flowed radially through the vents and then circumferentially through the air gap. Although an analytical study of Mr. Roth's system of ventilation has not been made, the low temperatures obtained and the comparatively small dimensions, indicate that the system is excellent. It would seem that the supply of air to the leakage slots is sufficient to maintain comparatively low temperatures in the tooth belt where the material is worked the hardest.

2. The method which Mr. Roth uses for measuring the losses and air volumes at full load is novel. Mr. Roth assures us that he can obtain accuracy by calibrating the system, operating idle as a synchronous motor with known total losses at two different voltages. In the equation on page 10, what is the order of magnitude of $\Delta t_2 - \Delta t^1$? I presume it is about 10 deg. cent. and to obtain accuracy these temperature rises must be measured with extreme care.

The measurement of the temperature rises of the air by means of resistance coils connected in a Wheatstone-bridge network is one that is frequently used, and if proper precautions are taken, it should lead to accurate measurements. With small temperature rises, it is necessary to measure resistances with extreme accuracy, as a one degree change in temperature corresponds approximately to only 0.4 per cent change in resistance; or, if the temperature rise is 10 deg., it is necessary to read to 0.04 per cent if the error is to be not over 1 per cent. In some of our work, temperature rises of the order of only two degree are obtained, and then it is necessary to read to 0.008 per cent. While, with extreme care, such measurements of resistance can be made, there are possible sources of error, such as those due to contact resistance or those which might arise from the stretching of some of the wires, and this introduction of considerable errors.

In the early work on air-volume measurements by the thermal method at the Westinghouse Company, resistance measurements were made, but they were abandoned partly because of the necessity for great precision in measurement and partly because a few of the wires stretched and the resistance was consequently changed. We have since been using large numbers of thermocouples connected in series, and, for the most part, have been able to secure very reliable results. We can read our volumes within about 1 per cent. Of course, if only a few thermocouples are used, this method is not recommended, as a reliable average is not then obtainable.

3. The volume of air through the rotor seems to be very high. In conversation Mr. Roth explained to me the method which he used for measuring it. I think that the method is of sufficient interest to warrant him telling the members of the Institute what it is.

4. The device shown in Fig. 14, for measuring the pressure of the cooling air, is a model of part of the machine in which the flows are imitated as accurately as possible. I should inquire of Mr. Roth how close the agreement was between the pressure measured in the model and the pressure measured in the machine. I am a great believer in imitating in a model, conditions in the actual structure; but in this, care must be exercised, as sometimes the conditions are extremely difficult to imitate with sufficient accuracy.

5. Mr. Roth states that with a salient-pole alternator, the self-excitation is synchronous. It may be of interest to those who have not noted it before that it is possible to increase the

1. *An Experimental Study of Ventilation of Turbo Alternators.* TRANS A. I. E. E., 1924, pp. 486-488.

load on a salient-pole alternator gradually when it is being excited by condensive reactance until, at a certain load, the alternator pulls out of step and runs at a speed slightly above the frequency of the line. In other words, in a salient-pole machine just as in a turbo alternator it is possible to have self-excitation and operate as an asynchronous generator. One of the oscillograms in the discussion referred to by Mr. Roth shows this very clearly.[2]

E. H. Freiburghouse: I agree in general with what Mr. Laffoon has said as to the principles governing the limit of electrical stability of alternators and I too question whether these generators which have been described by Mr. Roth possess the necessary margin of stability.

Nevertheless, Mr. Roth has informed me that generators having these characteristics do operate successfully and that the power-station people do not find it necessary to employ voltage regulators. He states that voltage regulators have been installed but their use has not been found necessary.

Some years ago, the General Electric Company rebuilt a large foreign-made, turbine-alternator in which they even increased the originally high synchronous impedance. There have always been doubts about the stability of that generator; however, it has now been operating satisfactorily for seven years although the excitation for synchronous impedance is 2.04 times that for normal voltage at no load. The above is an abnormal ratio which we do not advocate. Instead, we usually make the ratio less than unity.

The deep, partially closed, leakage slots which Mr. Roth has employed to increase the reactance, also inherently make it necessary to assemble the stator bars axially from the end of the core. Obviously, the fit of the coil cannot be so close in the slot as if it were inserted radially under pressure from the air gap or open end of a slot. However, his machine is much shorter than we are building for that output.

We do not believe that 27 per cent reactance is necessary to insure the safety of the turbine-type alternator which has its stator winding laced at the ends to supporting rings. This machine as built in America is apparently flexible and strong enough to withstand many thousand dead short circuits without permanent distortion of the end structure. I recently witnessed a number of dead short circuits upon generators rated 35,300 kv-a. upon which there was no permanent distortion whatsoever.

Referring to the heating of these generators as given by Mr. Roth in Table I, we find that the temperatures obtained during the open-circuit run No. III were fairly uniform throughout the core; however, this was not the case during the sort circuit test No. I. On tooth G, Fig. 15, the rise was 70 deg. cent.; on tooth F, 27 deg.; and on tooth E, 26 deg. G was in the second package of iron from the end of the core whereas the others were in the middle of the core. I venture to say that the extra heating of tooth G was caused by flux from the magneto-motive-forces of the stator winding outside of the core. We are interested to know what temperatures were obtained at the other end of the core by couples 1, 2 and 3.

W. B. Kirke: This paper brings out new methods of incorporating characteristics of high reactance without obtaining excessive armature reaction. At the same time the use of leakage slots provides an effective method to keep the temperature rise within low limits.

The first characteristic of high reactance is provided for in a great many systems in this country by the use of external reactors in the circuit connecting the generator to the bus. Such reactors not only aid in keeping the voltage near normal with a generator short circuit but they also reduce the interrupting duty on the generator circuit breakers. On the other hand, if the reactance is built into the machine by the use of leakage slots or other means, a generator short circuit means dropping the voltage of the bus section fed by that unit.

Increasing the stability of the machine is a very desirable feature. As systems are more extended and more power plants interconnected, one wonders if ever a condition will exist when the extreme ends of an interconnected system will start rocking, due to lack of stability of the interconnected system. Any measure tending to increase the stability of a single unit will aid in stabilizing a large system consisting of many such units.

The use of leakage slots would seem to indicate a considerable advantage in ventilating the unit. With the maximum size of turbo generators steadily increasing as the size of systems and interconnection facilities develop, capacities of 100,000 kv-a. will soon be required. Any method which indicates an improved means of ventilation should be given thorough analysis by designing engineers.

Robert Pohl: "The most interesting part of Mr. Roth's paper is his advocacy of leakage slots below the main stator slots. This design is for obvious reasons superior to the deep slot bridges advocated by Miles Walker many years ago, but somewhat similar in principle to the practise of some makers to use much deeper open slots than necessary for the winding. The author has convincingly demonstrated the advantages of his design. I should like to say, however, that the properties of such leakage slots do not appear to me generally advantageous but only in special cases. In the first place why employ so high a reactance as 27 per cent? If Mr. Roth's 60,000-kv-a. alternator had been made without leakage slots its reactance of 18 per cent would have been fully high enough for all ordinary requirements and perhaps already too high for stations with feeder reactances and a poor power factor. In Europe we have often to deal with station power factors much below 0.8 down to 0.6. In such cases the increase of reactance makes itself seriously felt in the size and to some extent in the efficiency of the alternator.

As to the author's comparison of the two methods of obtaining high reactance, leakage slots or increased electric loading, one misses the third alternative, i.e., a separate reactor. It is obvious that an alternator with separate reactor will as regards stability, auto-excitation and stresses on end connections, behave exactly as a corresponding alternator with leakage slots and equal total reactance. A short circuit on the alternator terminals need hardly be feared. It seems to me that the leakage-slot design with its appreciable increase in the stator dimensions is the more expensive way of creating the desired additional reactance. If so, it can only be justified by the remaining advantage, i.e., the improvement in ventilation. This seems to me the decisive point. Here one has to distinguish between bipolar and multipolar designs. In bipolar turbo alternators the output is mostly limited by the temperature rise of the rotor. The stator winding is generally cool enough when placed in the ordinary way in close proximity to the rotor. Hence there appears to be no cause for changing this practise. The same applies to smaller four-pole machines with solid rotors. In the larger four-pole and even more so in the six-pole designs with built-up rotors the ventilation of the latter is more effective and the limiting temperature may be found in the stator winding. Here it may well be advantageous to employ an otherwise unnecessary depth of slot or leakage slots after Mr. Roth's proposal if there is no other way of improving the ventilation.

Another way of improving the cooling of altenators is the use of hydrogen or other gases superior to air as cooling media.

Franklin Punga: I congratulate Mr. Roth on his contributions to developments in the design and construction of large turbo generators, and in particular on the means by which he was able to increase to 60,000 kv-a. the rating of the 45,000-kv-a. generator, without altering the external dimensions.

2. Trans. A. I. E. E., 1920, Vol. XXXIX, p. 1637.

Regarding certain features I should like to make the following observations:

I thoroughly endorse the employment of a stator slot provided with a large open portion at the end opposite the air gap. This is very useful for ventilation purposes. In the design which I some time ago proposed to the Thyssen firm, and contrary to the design of Mr. Roth, the lower third of the slot was widened as shown in the accompanying illustration of the slot, Fig 3. The principal reason for this relates to winding construction technicalities. In the normal partly or entirely closed slot, the conductor has to be inserted axially. This makes it necessary to make a relatively great allowance for clearance between the side of the slot and the insulated conductor, otherwise the insulation on the conductor is liable to be harmed in the process of being inserted into place in the slot. Should any repair of the winding ever be necessary it is exceedingly difficult to remove such a conductor from the slot. In designs in which the conductor is inserted radially into an open slot, it is practicable to allow less clearance between the insulated conductor and the sides of the slot. This is desirable for several reasons, such as (1) obtaining a better space factor, and (2) decreasing the liability to corona phenomena. When employing my design of slot the insulated conductor is first introduced axially into the space in the lower third and is then pressed radially

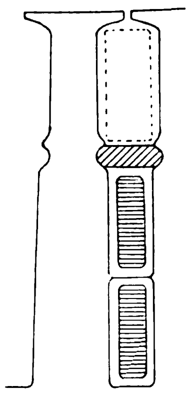


Fig. 3

upward into place, the space available in the ventilating ducts being convenient for the application of the necessary radial pressure.

But this design of slot fulfils a second important purpose. It is well known that if the tooth saturation is too great, the flux passing parallel to the sides of the slot occasions a considerable copper loss. For this reason it is customary to employ a relatively low no-load tooth saturation (some 16,000 lines per sq. cm.), so that at full load the value of 20,000 lines per sq. cm. shall not be exceeded. Now the difference between the tooth saturation at full load and that at no load is chiefly dependent upon the distorting ampere-turns. The decreased tooth section in the lower third of the slot consequently serves as insurance against too great saturation in the portions where the copper is located and will be found especially valuable in turbo generators with a cos near ϕ unity.

Furthermore the slot leakage is of course also decidedly increased, although not so much as in the case of the turbo generator designed by Mr. Roth. The advantages which Mr. Roth mentions, relating to relatively great slot leakage are all of them correct, but a disadvantage of the great slot leakage ought not to be overlooked, namely, the radial saturation of teeth at particular parts of the circumference on the occurrence of sudden short circuits. For instance if we represent the leakage of one slot by a vector, this will be of uniform magnitude and direction until we come to a place on the circumference where one phase winding is completed and the next phase winding begins. In a four-pole machine with two conductors per slot, and 100 per cent winding pitch, there are on the circumference twelve such places. The slot leakage vector moves through 60 electrical degrees and the consequence is that at these points a flux represented by a vector of equal magnitude passes through the tooth and into the laminations behind the slots. Consequently in such a machine at short circuit there would be complete saturation of twelve teeth equally distributed around the circumference. This would decrease the effectiveness of the great slot leakage. In this respect the use of fractional-pitch windings is of advantage since the number of these teeth is then increased from twelve to twenty-four so that the flux set up in each tooth is appreciably smaller.

Mr. Roth's observations about self-excitation have interested me very much. In German power houses it is now required that large polyphase generators shall be able to carry as leading load 80 per cent of their rating. This requirement has a close relation to the problem of self-excitation discussed by Mr. Roth. This problem will be of even more importance in the future if the lengths and voltages of transmission lines are increased.

In conclusion I should like to briefly mention that the principal progress which has been made in the development of large turbo-generators has been due to the avoidance of stray losses. These stray losses were due to (1) current distortion in the slot copper; (2) flux passing parallel to the slot sides and of too high tooth saturation; (3) flux passing from the field into the open slot; (4) variations in flux density around the circumference of the field, due to the slot openings; (5) the leakage flux from the end windings, (a) in the copper of the end windings, (b) in the end clamping parts (6) iron short circuits due to bad workmanship in slotting and assembling the cores.

From this paper of Mr. Roth's and from his previous publications it is very evident that the author has dedicated much study and research to the problem of decreasing the stray losses and of their exact measurement.

J. Rosen (communicated after adjourment): I would refer only to one section of Mr. Roth's paper in which he deals with the difficulty of alternator instability. It is sometimes forgotten that many of the difficulties lie in the excitation circuit. Some ten years' ago, instability was experienced on an 18,000 kv-a. alternator, operating at unity power factor and sometimes with a leading power factor. The alternator air-gap was increased, with entirely satisfactory results.

Later experience and tests on other plants showed that attention should also have been directed to the design of the exciter. One of the improvements adopted was the addition of a few series turns to the exciters, which overcame entirely the alternator instability difficulties which had up to that time, been experienced. The tests have proved that sudden changes. in load, faulty synchronising, and faults in the transmission line are reflected in the alternator rotor by momentary increases in the value of the rotor current. I would refer to the papers, and the discussions upon them, on "Exciter Instability" by R. E. Doherty[3] and "Some Problems In High-Speed Alternators and their Solution"[4] by the writer, in, which the whole problem is discussed in full.

Calculated figures are given by Mr. Roth of the total inherent reactance of the plant. It would be of interest to learn if they are confirmed by actual sudden-short-circuit tests at the normal operating voltage.

E. Roth: The most important observation presented in this discussion has been expressed by Messrs. W. F. Dawson, Philip Torchio, C. M. Laffoon, E. H. Freiburghouse and W. B. Kirke

3. Journal A. I. E. E., Vol. XLI, No. 10, p. 731.
4. *Journal* I. E. E., Vol. 61, No. 317, p. 452-3.

and regards the armature reaction to which American practise gives lower values than that which exists in our alternators.

Mr. Laffoon has given a very complete statement of this point and I am in general in agreement with him. His comments apply more particularly to the conditions of stability.

These machines were designed to run first at $41\frac{2}{3}$ cycles in parallel with the distributing system of Paris, and later at 50 cycles. In fact the machines have never been operated at $41\frac{2}{3}$ cycles. Moreover the customer wanted a very low value of instantaneous short-circuit current, of about four times the normal current, which condition had never been required before from large turbo alternators. It was therefore necessary to design a machine in accordance with these requirements without neglecting, of course, the condition of stability.

Four years' experience have shown that these machines have been giving entire satisfaction to the users. Had difficulties arisen with regard to stability, it would have been easy to enlarge the air-gap of these machines sufficiently, without exceeding the standard American temperature rise of 90 deg. cent., which up to the present has never been attained in our machines.

These machines have been designed for 35,000 kw. at 80 per cent power-factor, that is 43,750 kv-a.; in fact, they are operated at 40,000 kw. and 50,000 to 55,000 kv-a.

Based upon this experience the 60,000-kv-a. machines have been built on the same principles but the flux has been increased slightly and the air-gap enlarged to maintain the same conditions of stability. Considering the operating conditions we are confident that they will run as satisfactorily as the former, and should difficulties arise these could be easily remedied.

As pointed out by Messrs. Torchio, Kirke and Pohl, the low value of the instantaneous short-circuit current could have been obtained by reactance coils. This solution was examined very seriously but had to be rejected. Indeed, these reactance coils are very cumbersome and the price of the alternator together with reactance coils, has been found higher than that of the alternator with leakage slots alone. The efficiency using reactance coils is less than with the solution adopted; first it is not possible to build reactance coils with a loss smaller than 0.15 to 0.20 per cent and further when external reactance coils are used the alternator has to be operated at a higher terminal voltage, which creates core losses which do not exist in the case of leakage slots.

With regard to operation the use of reactance coils or of leakage slots leads exactly to the same result. Whenever it is desired that the voltage drop at the busses on short-circuit be not too high, individual reactance coils should be installed on every feeder.

I wish to emphasize what I have already stated in my paper, that using leakage slots in a given machine does not practically alter the conditions of stability; thus should a customer require from American manufacturers as small an instantaneous short-circuit current as in the Gennevillier's machines, they could obtain it, without changing any of the properties of their machines, by simply adding leakage slots.

I greatly appreciate the technical progress which the American manufacturers have obtained by designing their 62,500-kv-a. turbo-alternator for 1800 r. p. m. I know very well the difficulties which they may have encountered and I think that this is still a more marked progress than that which the Socéité Alsacienne has made when they built their 45,000-kv-a. alternators for 1500 rev. per min., which capacity was at that time only realised at 1200 and 1000 rev. per min. I have learned with great interest that Mr. Laffoon sees the possibility of constructing 75,000-kw. machines at 90 per cent power-factor and 1800 rev. per min. In Europe we think that it is possible to build 50-cycle turbo alternators for over 100,000 kv-a. at 1500 rev. per min. and for 40,000 kv-a. at 3000 rev. per min.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

NEW CORRUGATED BULB AIDS IN THE PREVENTION OF AUTOMOBILE HEADLIGHT GLARE

The introduction of the corrugated automobile headlight bulb is an important step in the more exact and complete control of the beams from headlights toward which various refinements in the manufacture of the several elements of the equipment are contributing.

Glaring headlights which so greatly detract from both the pleasure and safety of night driving, result for the most part, first, from failure to properly focus and aim the headlamps, and second, from the limitations of a fixed-beam system on any except smooth, level roads. Considerable effort is being put forth to bring about better headlight adjustment and depressible-beam equipment, using the new two-filament headlight lamp, overcomes the limitations which are inherent in a fixed-beam system.

There is a third though lesser source of glare which

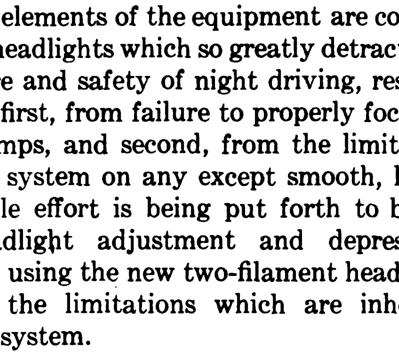
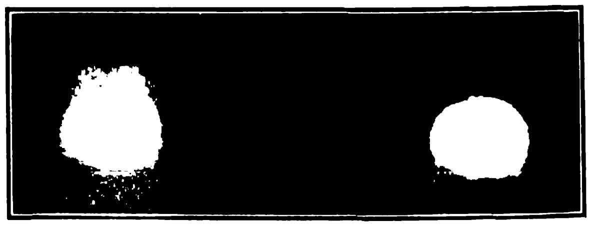
A  B

Fig. 1—(a) Light Reflected from the Inner Surface of the Spherical Part of a Bulb with a Light Source Near Its Center, Forms an Image Removed from the Filament by an Amount Varying with the Displacement of the Light Source from the Center

(b) The Corrugation on the Spherical Part of the Bulb Disperse the Light and Prevent Formation of Images



A B

Fig. 2—(a) Cross Section of a Beam of Light from a Parabolic Reflector with a Lamp having a Smooth Bulb from which an Image or Secondary Light Source is formed as in Fig. 1 a.

(b) Cross Section of the Beam of Light when the Image or Secondary Light is Eliminated

is found even with properly focused and aimed good equipment. It is the secondary source or filament image which is formed in a headlight by the rays reflected from the inner surface of the spherical part of the bulb. The filament is at the center of this hemisphere and hence, when it is exactly placed, the image is superimposed on the filament. Actually, there is frequently a slight displacement from this exact position, in which case the image is off-set as illustrated in Fig. 1a. The brightness of this image, or secondary source, may be as much as five per cent of that of the

filament. The equipment, adjusted for the main source, will then direct the secondary beam from the image at a different angle, as indicated in Fig. 2A, and often this will be toward the approaching driver's eyes, causing him annoyance. When the spherical surface is broken up with corrugations, the reflected rays are dispersed sufficiently to avoid the formation of a definite image, as in Fig. 1B, and the resulting secondary beam.

The corrugations on headlight bulbs were not placed there to add a novelty feature, but represent the result of a long and successful search for the best means of avoiding glare from source images in the bulb.

COST AND STANDARD OF LIGHTING

Assuming no decrease in the purchasing power of money, as much light can be purchased today for one or two cents as could be bought a century ago for one dollar. But unfortunately our dollar has had many shrinking moods during this period, and this must be taken into account in any comparison of lighting standards with those of a century ago. For the sake of comparison let it be assumed that the purchasing power of gold is only one-third as great today as it was one hundred years ago. If the use of light were keeping pace with the efficiency of light production, the workman would be supplied with three hundred times more light than he then had. But the standard of working conditions has also greatly altered. If it be assumed that this has increased about five times, the workman today should be supplied with about fifteen hundred times more light than he had a hundred years ago.

If the workman in that age of candles had an intensity of illumination of two-thirds of a foot-candle, he should have a thousand foot-candles today, if the use of light is to keep its proper pace. Of course, light is more generally distributed now in a well-lighted factory than was the case in those earlier years. The workman benefits by this better condition, but the fact remains that the actual artificial illumination under which he works is only a few times that enjoyed by his predecessor of a century ago. It is known that the best intensity of illumination for general work is of the order of magnitude of a thousand foot-candles, and on the basis of the foregoing assumptions the workman is entitled to it. If not satisfied with the assumptions, anybody may reduce them as he sees fit. Even the most radical scaling down would leave us with a hundred foot-candles or more. Then why is the workman not supplied with this amount at least? Here is a question that the reader may find it interesting to attempt to answer.—*Electrical World.*

THE SOLUTION OF A RESIDENCE STREET LIGHTING PROBLEM

Engineering, perhaps more than any other profession, has many precepts and fundamental principles upon which there can be no differences in opinion among the members of the profession. Nevertheless, there are certain phases of this field of science in which the opinions and specifications sponsored by different engineers, may be as widely diversified as the diagnoses of a particular medical case by several physicians. It is only natural to expect that such a condition may frequently be encountered in any line of endeavor inasmuch as the realm of man's absolute knowledge is limited, consequently a thorough interchange of ideas on any problem upon which there is likely to be a diversity of opinion is nearly always advantageous to those concerned with its solution. As elsewhere, this is quite true in illuminating engineering as has been shown by the advances which have been made in this field during recent years.

Among the commercial applications of artificial lighting there have been few upon which there has been such a diversity of opinions as on the requirements and specifications of proper street lighting. In view of this fact the Illuminating Engineering Society has, at some of its past meetings, chosen the symposium* form of discussion for this subject. Sometime in advance of the actual meeting a typical street lighting problem was selected and a blueprint layout and photograph of a definite residential street were sent, together with a questionaire, to a number of illuminating engineers who were more or less concerned with the design of street lighting installations. A summary of the solutions for lighting this section of a residence street, obtained from these engineers is given in the accompanying table in a manner which shows very readily the similarities and differences in the different designs.

The consensus of opinion seems to favor a series, underground distribution system, operating at 6.6 amperes with a staggered arrangement of units, for a residential street in a city of 100,000 such as the one under discussion in this particular case. There is, of course, a variance in the recommended costs per mile for the different solutions but even such differences in cost estimates are not as great as they probably would have been ten years ago, because engineers are now more fully agreed as to what constitutes reasonably adequate street lighting. With one exception, the recommended mounting heights are included in the comparatively small range of 11 to 16 ft. and an ornamental unit is specified.

At present, there seems to be no thoroughly satisfactory method of comparing illumination values on city streets. However, by measuring these values in terms of lumens per foot there is at least some indication as to the total amount of light which is available. Using this method of measurement we find that these different solutions vary from 13 to 50 lumens per foot in their recommendations.

This general method of treating the street lighting problem seems likely to crystallize our ideas regarding practise and so not only advance the art but also tend toward the establishment of definite styles. The great value comes from the opportunity of summing up and comparing the ideas of various engineers.

*Discussion before the Annual Convention of the A. I. E. E. at Detroit, September, 1925.

THE SOLUTION OF A RESIDENCE STREET LIGHTING PROBLEM

Solution No.	Cost per Mile per cent of Average	Illumination values	Size of Incandescent Lamps Lumens	Amp.	Arrangement of Lamps	Spacing Ft.	Fixture	Standard	Bracket	Mounting Height Ft.	Distribution System
1	158	30-40 Lumens per foot	4000	15	Staggered	120	Rippled alabaster globe and canopy. Dome refractor	Ornamental		11½	Series, underground. Insulating transformers
2	49	13 Lumens per foot	2500	6.6	One side	196	Ornamental. Post-top, refractor type	Reinforced concrete		11	Series, underground. Film cut-outs
3		19.3 Lumens per foot	200 watt 110 volt		Staggered	124	Copper casing, porcelain reflector, diffusing globe	Ornamental	9 ft. ornamental	16	Multiple underground. Clock or remote control
4	154	25 Lumens per foot	2500	6.6	Staggered	100	Rippled alabaster globe and canopy	Ornamental iron, steel or concrete		12	Series underground. Insulating transformers
5	74	20-25 Lumens per foot	3250 lumens 200 watt, 115 volt		Staggered	155	Rippled alabaster globe. Dome refractor	Steel or concrete	4½ ft. ornamental	16	Multiple underground. pilot wire control
6	68	Ft.-c Max. 0.07; Min. 0.03; Av. .05	2500	6.6	Staggered	150	Ornamental lantern, asymmetric refractor	Concrete post		15	Series, underground. Film cut-outs
7	65	16.6 Lumens per foot Ft.-c Max. 0.292; Min. 0.026; Av. 159	2500	6.6	Staggered	150	Ornamental pendant. Dome refractor	Ornamental tubular steel	6 ft. pipe	16	Series, underground. Insulating transformer
8	87	22 Lumens per foot 55 Lumens at street crossings	2500	6.6	Staggered	130	Pendant, diffusing	Ornamental iron	Gooseneck	14	Series, underground. Film cut-outs
9	38	Ft.-c Max. 0.20; Min. 0.03; Av. 10	4000	6.6	Center span	273	Non-ornamental. 4-Way, 2-Way refractor	Wooden pole	Mast arm or span wire	25	Series, overhead. Film cut-outs
10	97	20-Lumens per foot	2500	6.6	Staggered	115	Ornamental lantern, Dome refractor	Ornamental iron		11	Series, underground. Film cut-outs
11	222	50 Lumens per foot Ft.-c Max. 0.35; Min. 0.20; Av. 0.25	4000	15	Staggered	80	Ornamental lantern, refractor	Reinforced concrete		13	Series, underground. Film cut-outs
12	89	25 Lumens per foot	2000	7.5	Staggered	100	Ornamental reflector without globe; frosted lamp	Ornamental concrete		12½	Series, underground. Film cut-outs

SUMMARY OF ESSENTIAL FEATURES OF ALL SOLUTIONS

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The 1926 Midwinter Convention

A LARGE PROGRAM OF IMPORTANT TECHNICAL PAPERS WAS DISCUSSED AT WELL-ATTENDED SESSIONS

The fourteenth Midwinter Convention of the American Institute of Electrical Engineers, held February 8-11, 1926, maintained the tradition of its predecessors in their constantly growing importance, in the increasing number of members and guests in attendance, and in the character of the papers presented and discussed. Of all the Institute meetings, the Midwinter Convention is preeminently the working convention of the year, at which entertainment is largely subordinated to the consideration of the most technical professional problems, and the attendance this year of over 1500 members attests the worth of these conventions to the electrical profession. The entertainment features, consisting of a Smoker Tuesday evening, a Dinner-Dance Wednesday evening and two instructive popular lectures Thursday evening were well patronized and greatly enjoyed. The heaviest snowfall in several years occurred at the time of the convention and for several days almost paralyzed vehicular traffic, but despite this handicap the visits of inspection to numerous engineering establishments in and about the city of New York with few exceptions were carried out according to schedule. Monday morning was devoted to registrations of members and guests and to several committee meetings. At such intervals as occurred between the technical sessions, other committee meetings were held from time to time during the convention week.

MONDAY AFTERNOON

Technical Session

The opening session of the convention convened at 2.30 p. m. in the Engineering Auditorium and was called to order by President Pupin, who extended heartiest greetings to the members assembled. He then introduced Percy H. Thomas, Chairman of the Transmission Committee, who conducted the Transmission Session which followed.

The general subject of the first session was Stability on Transmission Lines and for the benefit of those who were not entirely familiar with the subject of stability on transmission lines, Mr. Thomas gave a brief general explanation of the subject.

The first four papers of this session were presented and discussed together as their subject matter was closely related. The first paper, *Investigation of Transmission-System Power Limits*, by C. L. Nickle and F. L. Lawton was presented by Mr. Nickle. Chairman Thomas then called for the second paper, *Calculation of Steady-State Stability in Transmission Lines*, by Edith Clarke, Miss. Clarke abstracted her paper. The third paper entitled, *Practical Aspects of System Stability*, by Roy Wilkins was abstracted by Mr. Wilkins and the fourth paper, *Further Studies of Transmission Stability*, by R. D. Evans and C. F. Wagner was abstracted by Mr. Evans.

In the extended discussion which followed on this group of papers, remarks were made by R. D. Evans, H. W. Smith, H. H. Dewey, H. H. Spencer, H. K. Sels, R. E. Doherty, C. L. Fortescue, H. B. Dwight, J. W. Legg, Svend Barfoed and Mr. F. L. Lawton read a written communication by L. F. Woodruff. The discussion was closed by C. A. Nickle, Edith Clarke, Roy Wilkins and C. F. Wagner.

Chairman Thomas next called for the presentation of the last paper *Transmission Stability with Over-Compounded Voltages*, by H. B. Dwight, this was abstracted by the author. The paper was then discussed by C. B. Christie and a written discussion from L. F. Woodruff was read.

MONDAY EVENING

Technical Session

The next session of the convention convened at 8.15 p. m. and was called to order by E. B. Meyer, Chairman of the Meetings and Papers Committee. Mr. Meyer announced the subject of the evening was dielectrics and insulation. Three papers were scheduled for this session under the auspices of the Committee on Electrophysics and J. H. Morecroft, Chairman of that committee presided at the meeting.

Chairman Morecroft announced that each author would be allowed fifteen minutes to abstract his paper and that the three papers would be read in succession and then discussed together. The first author called upon by Chairman Morecroft was J. B. Whitehead, who abstracted his paper on *Dielectric Absorption and Theories of Dielectric Behavior*. The next paper, *The Theory of Absorption in Solid Dielectrics*, by V. Karapetoff was also summarized by the author. The next paper of the evening by C. L. Dawes was *Ionization Standards in Paper-Insulated Cables*. This too was abstracted by the author.

Extended discussion participated in by A. E. Kennelly, H. B. Smith, E. W. Davis, W. A. Del Mar, R. E. Marbury, R. W. Atkinson, E. S. Lee, E. W. Roper, W. B. Kouwenhoven, J. Slepian, W. F. Davison, George B. Shanklin, S. L. Gokhale and C. A. Adams followed the presentation of these three papers. Closures were made by Messrs. Whitehead, Dawes and Hoover.

TUESDAY MORNING

Technical Session

The Tuesday morning session on Protection, Control and Bus Construction was under the auspices of the Committee on Protective Devices with F. L. Hunt presiding. The following

papers were presented in abstract by their authors: *Operating Performance of a Petersen Earth Coil*, by J. M. Oliver and W. W. Eberhardt, (presented by Mr. Oliver); *Theory of Auto-Valve Lightning Arresters*, by Joseph Slepian; *Current Limiting Reactors with Fire-Proof Insulation on the Conductor*, by F. H. Kierstead; *Temperature Rise and Losses in Structural-Steel Members Exposed to the Fields from A-C Conductors*, by O. R. Schurig and H. P. Kuehni, presented by Mr. Schurig; *Carrying Capacity of Sixty-Cycle Busses for Heavy Currents*, by Titus G. Le Clair and *Supervisory Systems for Electrical Power Apparatus*, by Chester Lichtenberg.

The following members took part in the discussion: K. B. McEachron, H. B. Dwight, V. M. Montsinger, S. I. Oesterreicher, C. E. Stewart, C. F. Wagner, R. G. Weiser, H. C. Forbes, A. E. Kennelly, L. P. Ferris, H. L. Wallau, W. W. Eberhardt and Joseph Slepian.

Tuesday Afternoon

Technical Sessions

Parallel sessions were held on Tuesday afternoon; Session A, on Electrical Machinery, convened in the Engineering Auditorium and Session B, on Communication and Sound Reproduction, in the fifth floor assembly room.

Session A was under the auspices of the Electrical Machinery Committee and was called to order by E. B. Meyer, who requested H. M. Hobart, Chairman of the Electrical Machinery Committee, to take charge of the meeting. Chairman Hobart called on the authors of the following papers to abstract their articles, which were subsequently discussed. The papers presented were: *Experimental Determination of Losses in Alternators*, by Edouard Roth (presented by E. H. Freiburghouse); *No-Load Copper Eddy-Current Losses*, by Thomas Spooner; *Mechanical Forces Between Electric Circuits*, by R. E. Doherty and R. H. Park; *Ventilation of Turbo-Alternators*, by C. J. Fechheimer and G. W. Penney.

The discussion which followed was by Messrs. W. F. Dawson, B. L. Barns, S. L. Henderson, Joseph Slepian, W. J. Foster, C. J. Fechheimer, E. H. Freiburghouse, with closures by R. E. Doherty and E. H. Freiburghouse.

Session B was called to order by H. P. Charlesworth, Chairman of the Committee on Communication, under whose auspices the session was held. Chairman Charlesworth announced that as the program of papers was diversified in character, the session would take up each subject, followed directly by its discussion.

The first paper on the program was *The Development and Application of Loading for Telephone Circuits*, by Thomas Shaw and William Fondiller and was presented by Mr. Shaw. The paper was discussed by F. B. Jewett, W. L. Smith, M. I. Pupin, with closure by William Fondiller.

The next paper on the program called for by the Chairman was entitled *Cipher Printing Telegraph Systems*, by G. S. Vernam, and was discussed by L. F. Morehouse and Paul W. Evans. This paper was followed by one on. *Refraction of Short Radio Waves in the Upper Atmosphere*, by W. G. Baker and C. W. Rice, presentation being made by Mr. Rice. The discussion which followed was by A. E. Kennelly and W. B. Kouwenhoven with closure by W. G. Baker.

The final paper in the session was presented by its author, J. B. Maxfield and was entitled *High-Quality Recording and Reproducing of Music and Speech*. At the close of the presentation a demonstration of the audiophone was given and a comparison between this and the older style of phonograph was shown. The paper was discussed by C. R. Hanna, H. B. Marvin, E. W. Kellogg, A. E. Kennelly and closure was by J. P. Maxfield.

Tuesday Evening

Smoker

Tuesday evening was devoted to a Smoker at the Hotel Astor at which about one thousand men were present, filling the Belvedere Room to capacity. The entertainment which was furnished by the New York Section consisted of moving pictures, an excellent male quartet, an interesting slight of hand performance, including an explanation of some tricks frequently employed at spiritualistic seances, together with popular music by an excellent band. A buffet supper was served toward the close of the evening and the informal but thoroughly enjoyable performance was fully appreciated by all who were present.

Wednesday Morning

Technical Session

The session on Wednesday morning was under the auspices of the Electrical Machinery Committee and Mr. H. M. Hobart, Chairman of that Committee presided.

The first paper was presented by Professor Karapetoff on the subject of *Parameters of Heating Curves of Electrical Machinery*. This paper was discussed by G. E. Luke, F. H. Kierstead, W. F. Dawson, C. J. Fechheimer and the discussion was closed by Professor Karapetoff.

The next paper was on the *Rating of Electrical Machinery as Affected by Altitude*, by C. J. Fechheimer and was abstracted by the author. This was discussed by R. E. Doherty, P. L. Alger, Earl B. Paxton, E. B. Dawson and W. F. Dawson, with closing remarks by Mr. Fechheimer.

The next paper, on the subject of *Motor Band Losses*, by Thomas Spooner, was presented in abstract by the author. It was discussed by G. E. Luke and J. F. Lincoln.

The final paper of the session, *Starting Characteristics of Polyphase Squirrel-Cage Induction Motors and Their Control*, was presented by its author, H. M. Norman, and was discussed by Professor B. B. Bailey, with closure by Mr. Norman.

Wednesday Afternoon

Inspection Trips

Wednesday afternoon was set aside for numerous inspection trips to the prominent engineering works in New York and vicinity, all being generously thrown open to the inspection of members of this Convention. The bus service, which had been provided to carry many of the visitors to the points of inspection, was necessarily cancelled on account of the snowbound condition of the streets, but many parties were organized, making the trips by either public or private conveyances.

Wednesday Evening

Dinner-Dance

The annual Dinner-Dance at the Hotel Astor which has become an invariable feature of the Midwinter Convention was held on Wednesday Evening, and as usual proved to be a most pleasing and enjoyable function. The dinner was attended by between six and seven hundred people and the music during the dinner and for the dancing was furnished by Paul Whiteman's Picadilly Players.

The evening was a thoroughly enjoyable one and the dancing continued until an early hour.

Thursday Morning

Technical Session

The session on Thursday morning was devoted to subjects of Electromagnetism and Physics and was held under the auspices of the Electrophysics Committee, J. H. Morecroft, Chairman, presiding.

The first paper announced by the chairman was *Calculation of Magnetic Attraction*, by Th. Lehmann. This paper, which had been translated by C. O. Mailloux was also abstracted by him. The next paper presented was by Hans Lippelt on the subject of *The Magnetic Hysteresis Curve* and was presented by the author. The third paper of the session by Carl Hering, entitled, *Properties of the Single Conductor* was next presented by Dr. Hering. The final paper, *Heaviside's Proof of His Expansion Theorem* was then presented by its author, M. S. Vallarta.

At the close of the presentations Chairman Morecroft called

for the discussion of the papers in their regular order. The discussion which followed was by Joseph Slepian, S. L. Gokhale, S. L. Quimby, M. F. Skinker, R. H. Park and J. J. Smith. Closures were made by Dr. Mailloux, Mr. Lippelt and Dr. Hering.

THURSDAY AFTERNOON

Technical Session

The final technical session of the Convention was held Thursday afternoon under the auspices of the Committee on Instruments and Measurements, with William A. Del Mar presiding.

Five papers were presented at this session, the first three presented and discussed being as follows:

A New Wave-Shape Factor and Meter, by L. A. Doggett, J. W. Heim and M. W. White; presented by Mr. White. *Practical Application of Vibration Instruments to Rotating Electrical Machines*, by J. Ormondroyd and *A High-Frequency Voltage Test for Insulation of Rotating Electrical Machinery*, by J. L. Rylander.

After these papers had been presented in abstract, a discussion followed by Messrs. J. J. Smith, C. T. Weller, V. M. Montsinger, C. E. Lee, W. B. Craigmile, F. K. Brainard, C. W. Bates, and G. E. Luke, followed by closures by Messrs. Doggett, Ormondroyd and Rylander.

The second group of papers at this session was presented as follows:

The Cross-Field Theory of Alternating-Current Machines, by H. R. West and *Rating of Heating Elements for Electric Furnaces*, by A. D. Keene and G. E. Luke. These were discussed by P. L. Alger, K. L. Hansen, and Joseph Slepian. The closures were by Mr. West and Mr. Luke.

This completed the technical program of the Convention.

THURSDAY EVENING

Illustrated Lectures

The Convention convened Thursday Evening at 8.15 p. m. in the Engineering Auditorium to hear two illustrated lectures by Dr. Alexis Carrel, and Major Allen Carpe.

Dr. Carrel, who is a member of the Rockefeller Institute for Medical Research, gave a lecture illustrated with motion pictures showing the life of tissues outside of organisms. The pictures showed the actual growth of living cells under artificial conditions, some strains of which in Dr. Carrel's laboratory have been living and growing since 1912.

Major Allen Carpe, a Fellow of the Royal Geographical Society, described and showed motion pictures of the Ascent of Mount Logan, the highest peak in Canada which is 19,850 feet in height. Some remarkable motion pictures were shown, covering the actual climb, hand sledding over the lower glaciers, the higher levels of the mountains and pictures of the party on the summit.

Both of these lectures were highly entertaining as well as instructive and were received with hearty applause.

ACKNOWLEDGMENTS

Credit for this most successful Convention is due to the excellent work of the committees in charge of the various features of the meetings. The Meetings and Papers Committee is to be congratulated upon providing the valuable program of technical papers. The entertainment features which were provided by the New York Section were of very high class and most appropriate. The excellent general arrangements and conduct of the entire Convention was due to the efficient work of the various Convention Committees, the personnel of which was as follows:

General Committee: H. A. Kidder, Chairman: H. H. Barnes, G. L. Knight, E. B. Meyer and L. F. Morehouse.

Entertainment Committee: H. H. Barnes, Chairman: G. W. Alder, J. B. Bassett, H. Y. Hall and H. S. Sheppard.

Dinner-Dance Committee: J. B. Bassett, Chairman: A. F. Dixon, E. E. Dorting, C. R. Jones, J. F. Kelly, F. A. Muschenheim and R. A. Paine, Jr.

Smoker Committee: G. W. Alder, Chairman: H. B. Coxhead, R. R. Kime, E. C. Soares, S. B. Williams, Jr. and C. V. Woolsey.

Inspection Trips Committee: H. Y. Hall, Chairman: C. M. Gilt, I. W. Green, G. C. Hall, R. R. Kime, J. T. Lawson and G. H. Stickney.

Special Meeting Committee: H. S. Sheppard, Chairman: L. W. W. Morrow and J. W. Walters.

Finance Committee: G. L. Knight, Chairman.

Regional Meeting at Cleveland March 18-19

The Cleveland Regional Meeting arranged by the Middle Eastern District of the Institute will be held on March 18 and 19 with headquarters at the Hotel Cleveland. An attractive program will be presented including papers on sectionalized electrical drive, domestic refrigeration, engineering and humanity, and lighting. On Thursday, March 18, a dinner will be given at which the Honorable Newton D. Baker will make an address. Another feature will be a visit to Nela Park. Details of the program are given below.

SECTIONAL ELECTRIC DRIVE

Thursday morning and afternoon will be devoted to papers and discussion on sectional electric drive. Engineers in a number of industries will be interested in this subject, for although this synchronized group type of drive was developed primarily for application to paper machines, it may now be applied to any driven apparatus where the conditions require a fixed angular relation between the different sections of the machine and where the advantages to be gained warrant the investment. It may well be considered in such applications as are found in the steel mill, the baking plant, the textile finishing plant, or in the rubber mill.

The regional dinner will be held Thursday evening and Friday evening will be spent at Nela Park of the National Lamp Works of the General Electric Company. An unusual program has been arranged, during which the magic of light will be portrayed by striking demonstrations.

Opportunity will be afforded also to make inspection trips to other Cleveland industries at the pleasure of the members.

A luncheon meeting for Counselors of Student Branches of the District has been scheduled for Friday noon.

A very enthusiastic group of committee members has made arrangements for this meeting; lack of space prohibits the publishing names other than the various chairmen who are as follows: A. G. Pierce, Vice-President of Middle Eastern District; A. M. MacCutcheon, General Chairman; G. A. Kositzky, Finance; H. B. Dates, Program; L. D. Bale, Transportation; I. H. Van Horn, Trips; A. M. Lloyd, Registration; C. N. Rakestraw, Dinner; H. L. Grant, Publicity; C. L. Dows, Reception, and E. H. Martindale, Attendance.

PROGRAM OF CLEVELAND MEETING

THURSDAY MORNING

Registration

9:45 A. M. Welcome, A. G. Pierce, Vice-President, A. I. E. E.

10:00 A. M. Technical Session: A. M. MacCutcheon, Chairman

Electrification of Paper-Making Machines, S. A. Staege, Westinghouse Electric & Mfg. Co.

This paper outlines the several trends of development in a historical sketch. It devotes special attention to a unique system of direct-current drive in which the section driving motors through a differential electrical field-control means, are caused to operate in synchronous relation at any desired relative speed values, which speed relations are at the same time adjustable at the will of the operator.

The Development of the Sectional Paper-Machine Drive, H. W. Rogers, General Electric Company.

In this paper the author deals with the history and development of the sectional drive as furnished by the company with which he is connected, and the relative merits of each particular type. The operation of sectional drives is explained.

THURSDAY AFTERNOON

2:00 P. M. Technical Session: A. M. MacCutcheon, Chairman.

Sectional Paper-Machine Drive, R. N. Norris, Harland Engineering Co.

This paper describes the type of control for sectionalized electric drive which has most generally been used in Europe and in Canada, and which has recently been successfully introduced into the United States. It tells of results secured particularly on very high-speed paper machines. The speed of each section motor, is referred to a master control speed through a simple mechanical differential.

THURSDAY EVENING

7:00 P. M. Regional Dinner, Hotel Cleveland.
Address by Honorable Newton D. Baker.

FRIDAY MORNING

9:45 A. M. Technical Session: Chester L. Dows, Chairman.

Some Scientific Phases of Refrigeration, Charles F. Kettering, President, General Motors Research Corporation.

(1) A comparison of the problems of the household and small commercial refrigeration with those of the large commercial type; (2) a description of the various types of refrigerating mechanisms; (3) the analyzing of many possible refrigerants; (4) an explanation of the reason for the development of special electric motors for this small refrigeration work; (5) the unusual requirements of producing, selling and servicing large quantities of these smaller refrigerators.

FRIDAY NOON

12:30 P. M. Luncheon Meeting of Branch Counselors.

FRIDAY AFTERNOON

2:00 P. M.—Technical Session, Chester L. Dows, Chairman.

Domestic Refrigeration from the Central-Station Point of View, George E. Miller, Cleveland Electric Illuminating Co.

Possibilities of this device as a load builder and its effect on the earnings of central-station companies. The return per kilowatt of demand, load factor, power factor. Illustrated.

Engineering and Humanity, Farley Osgood, Consulting Engineer, Past-President, A. I. E. E.

FRIDAY EVENING

Meeting at Nela Park

8:00 P. M.—Lighting Session, at Nela Park.

Nela Park, Its Organization and Objectives, R. W. Shenton, National Lamp Works, General Electric Company.

Recent Developments in Lighting, Ward Harrison, National Lamp Works, General Electric Company; Past-President, Illuminating Engineering Society.

Inspection Trips: Through Lighting-Research Laboratories; Historical Rooms; War-Trophy Exhibit; Industrial; Automobile and other Demonstrations.

SATURDAY MORNING

Inspection Trips: Inspection trips will be arranged to places of interest at the wishes of those attending the meeting.

Regional Meeting at Madison May 6-7

A two-day Regional Meeting will be held by the Great Lakes District of the Institute in Madison, Wisc., on May 6 and 7. Some very timely topics are on the program for discussion including rural electrification, transmission and distribution, cooperation in research between colleges and industries and radio interference. A number of foremost authorities will give papers or addresses on these subjects.

The committee in charge of the meeting consists of: Chairman, Edward Bennett, Vice-President of Great Lakes District; J. B. Bailey, A. G. Dewars, H. R. Huntley, L. E. A. Kelso, Carl Lee and R. G. Walter.

PAPERS AND ADDRESSES FOR MADISON REGIONAL MEETING

Rural Electrification, by Grover C. Neff, Wisconsin River Power Co.

Important Features of a Successful Plan for Rural Electrification, by George G. Post, Milwaukee Electric Railway and Light Co.

The Quality Rating of High-Tension Cable, by D. W. Roper, Commonwealth Edison Co.

Tests on High-Tension Cable, by F. M. Farmer, Electrical Testing Laboratories.

The Effect of Internal Vacua on Cable Operation, by W. A. Del Mar, Habirshaw Electric Cable Co.

Some Interconnected-System Operating Problems, by Frank G. Boyce, Consumers Power Co.

Cooperation Between the Colleges and the Industries in Research, Papers or addresses by:

Wm. E. Wickenden, Society for the Promotion of Engineering Education.

Dean A. A. Potter, Purdue University.

Benjamin F. Bailey, University of Michigan.

Edward Bennett, University of Wisconsin.

Behavior of Radio Receiving Systems to Signals and to Interference, by L. J. Peters, University of Wisconsin.

Regional Meeting at Niagara May 26-29

A three-day Regional Meeting will be held in Niagara Falls, N. Y., on May 26-28, by the Northeastern District of the Institute. Many interesting papers are scheduled for the meeting and the recreational activities are being carefully arranged.

The technical subjects to be discussed include dielectric power-factor measurement, insulation, transmission, power-plant tests, machinery, rectifiers, speed measurements, and others.

The entertainment features have been planned as follows: On Thursday afternoon, May 26, there will be a trip down the Niagara Gorge with stops at various points of interest and inspections of the power plants on both sides of the river. On Thursday evening will be the convention dinner and a number of Institute officers will make short addresses after which will follow a lecture of general interest to ladies and men. Late in the evening if it can be arranged the Falls will be specially illuminated. On Friday evening there will be a lecture or entertainment or possibly a motion picture.

Details of the program will be published in later issues of the JOURNAL.

Future Section Meetings

Baltimore

Mechanical Power and Trend of Civilization, by C. E. Skinner, Westinghouse Electric & Mfg. Co., Engineers' Club. March 19, 8:15 P. M.

Talk by a Member of the Local Section, Engineers' Club. April 16, 8:15 P. M.

Connecticut

Power Production. Hartford. March 9.
Illumination. Norwich. March 19.
Bay of Fundy. New Haven. April 9.

Lehigh Valley

Automatic Control of Centrifugal Pumps, by Otto Haentjens, Barrett Haentjens & Co., and

Wallenpaupack Hydro-Electric Development, by N. G. Reinecker, Pennsylvania Power & Light Co. Wilkes-Barre. March 26.

Oil Switches, by George A. Burnham, Condit Electric Mfg. Co., and

Horsepower, by John J. Johnson, Westinghouse Electric & Mfg. Co. Hazelton. April 23.

Pittsfield

Round-Table Discussion. March 9.

St. Louis

Development of Electric Power Generation and Distribution, by Col. Peter Junkersfeld, President, McClellan & Junkersfeld. March 17.

Automatic Stations, by C. A. Butcher, Westinghouse Electric & Mfg. Co. April 21.

Coming Plenary Meeting of International Electrotechnical Commission

Preparations are now well advanced for the meeting of the International Electrotechnical Commission to be held in New York in April. This Commission, which is an international standardizing body in the electrical industry, was organized in 1906 following suggestions made at the Electrical Congress held in St. Louis in 1904. Despite its many years of activity it has never held a meeting in this country, the reason for this being the intervention of the war. The meeting in New York will be the first one which has been held with full representation of all the countries which were active in the Commission prior to the war.

Plans for the meeting, in so far as they have been formulated, are as follows:

European delegates will arrive on *S. S. Andania*, due in New York on April 11th. Hotel arrangements are being made through the U. S. National Committee; the hotel headquarters will be the Hotel Astor. The meetings will be held in the Engineering Societies Building, 29 West 39th Street, New York, N. Y. The greater part of the activities of the Commission will center about the meetings of the various Advisory Committees of the Commission, which Advisory Committees are organized to formulate the work in particular fields and to report their results to the Plenary Meeting of the Commission. The preliminary schedule of the meetings is given in the following table:

Particular attention should be directed to the general meeting which is to be held in the Engineering Auditorium on the evening of April 13th. It is proposed that this meeting shall be conducted under the auspices of the engineering and technical societies which support the work of the U. S. National Committee and that the membership of these Societies shall be invited to attend this meeting. The meeting will be addressed by notable engineers from foreign lands and the work and purpose of the International Electrotechnical Commission will be set forth by them. The preliminary list of delegates indicates that amongst those present will be Sir Richard Glazebrook, K. B. E., Chairman, British National Committee, Sir Archibald Denny, Bart., Chairman, British Engineering Standards Association, Prof. C. Feldmann, President, Dutch Electrotechnical Committee, Professor P. Strecker, President, German Electrotechnical Committee, Mr. E. Huber-Stockar, President, Swiss Electrotechnical Committee, together with Signor Guido Semenza, President of the International Electrotechnical Commission. The preliminary list gives the names of 55 delegates from Europe; Norwegian, Russian, Polish, Spanish, French, Belgium, German, British, and Swiss, the German, British and Swiss delegations being particularly strong numerically. It is expected that later accessions will bring the list up to about 100.

In connection with the meetings in New York, there will be a number of entertainment features offered to the visiting delegates and at the close of this meeting, a tour will be offered which will include Philadelphia, Washington, Pittsburgh, Chicago, Detroit, Niagara Falls, Ottawa, Montreal, Boston, Schenectady and New York. The Canadian National Committee, which is cooperating in this enterprise will welcome the delegates at Niagara Falls and will conduct them to Montreal, where it is expected that a public meeting will be held in their honor.

The delegates will be received in various cities by local committees who will attend to making their stay at these places both profitable and enjoyable.

It may be noted that the first President of the I. E. C. was Lord Kelvin, and that Professor Elihu Thomson was President in 1911 at the time of the meeting in Turin. Dr. C. O. Mailloux is Junior Past-President and the Honorary President of the Commission. The President of the U. S. National Committee is Dr. C. H. Sharp and the Secretary is Mr. F. V. Magalhaes. The Chairman of the Reception Committee for the foreign visit is Mr. John W. Lieb, who is associating with himself a number of those most distinguished in the electrical industry.

Arrangements for the entertainment in New York are in the hands of Mr. F. W. Smith, of the United Electric Light & Power Company, and arrangements for the tour are being perfected by Mr. C. E. Skinner of the Westinghouse Electric & Manufacturing Company.

PRELIMINARY PROGRAM
PLENARY MEETING AND ADVISORY COMMITTEES OF I. E. C.

Time	Tuesday, 13th.	Wednesday, 14th.	Thursday, 15th.	Friday, 16th.	Saturday, 17th.	Sunday, 18th.	Monday, 19th.	Tuesday, 20th.	Wednesday 21st.	Thursday, 22nd.
Morning 9.30 to 12.30	Opening Meeting	Prime Movers (Hydraulic Turbines) Rating (Electrical Machinery)	Prime Movers (Hydraulic Turbines) Rating (Electrical Machinery)	Prime Movers (Hydraulic Turbines) Transformer Oils			Rating (Electrical Machinery) Transformer Oils	Prime Movers (Steam Turbines) Traction Motors	Committee of Action	Prime Movers (Steam Turbines) Terminal Markings
Afternoon 2.30 to 6.30	Experts' Papers on Rating	Prime Movers (Hydraulic Turbines) Rating (Electrical Machinery)	Prime Movers (Hydraulic Turbines) Rating (Electrical Machinery)	Prime Movers (Hydraulic Turbines) Transformer Oils			Prime Movers (Steam Turbines) Transformer Oils	Prime Movers (Steam Turbines)	Plenary Meeting	Prime Movers (Steam Turbines) Terminal Markings
Evening	General meeting arranged by American Committee	Rules and Regulations	Symbols Standard Pressures	Vocabulary High Pressure Tests			High Pressure Tests	Lamp Holders and Caps		

A. I. E. E. Director's Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Tuesday, February 9, 1926.

There were present: President M. I. Pupin, New York; Past President Farley Osgood, New York; Vice-Presidents Harold B. Smith, Worcester, Mass.; Edward Bennett, Madison, Wis.; L. F. Morehouse, New York; A. G. Pierce, Cleveland, O.; and W. P. Dobson, Toronto, Ont.; Managers H. P. Charlesworth, New York; H. M. Hobart, Schenectady, N. Y.; Earnest Lunn, Chicago, Ill.; G. L. Knight, Brooklyn, N. Y.; W. K. Vanderpoel, New York; John B. Whitehead, Baltimore, Md.; J. M. Bryant, Austin, Tex.; E. B. Merriam, Schenectady, N. Y.; M. M. Fowler, Chicago, Ill.; and H. A. Kidder, New York; National Treasurer George A. Hamilton, Elizabeth, N. J.: National Secretary F. L. Hutchinson, New York.

The minutes of the Directors' meeting held December 11, 1925, were approved as previously circulated.

Reports were presented of meetings of the Board of Examiners held January 11 and 25 and February 5, 1926, and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken: 268 Students were ordered enrolled; 392 applicants were elected to the grade of Associate; 15 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 14 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

In accordance with a request from Vice-President Morehouse, the Board authorized the holding of a Regional Meeting of Geographical District No. 3, in New York City, in November 1926.

Complying with a request of the Lehigh Valley Section, the Board granted authority for the extension of territory of that Section to include the following additional counties in Pennsylvania: Berks, Wyoming, Wayne, Columbia, Northumberland, and Montour.

A request from the Portland, Seattle, and Spokane Sections for certain readjustments in their boundaries to take in additional territory was referred to the chairmen of the Sections and Finance Committees with power.

Upon the recommendation of the Committee on Student Branches, authority was granted for the organization of a Student Branch of the Institute at Ohio University, Athens, Ohio.

Consideration was given to the report of the Special Committee on Institute Prizes which had been appointed in August 1925 to consider and recommend to the Board of Directors policies and procedure regarding Institute prizes. The recommendations of the committee relating to the establishment and award of National and Regional Prizes were adopted as applicable to all papers presented commencing January 1, 1926. Reference to the policy and procedure regarding Institute prizes thus adopted may be found elsewhere in this issue.

A report was presented from the General Convention Committee of the 41st Annual Convention of the Institute, held at Saratoga Springs, N. Y., June 22-26, 1925, which included a summary of receipts and expenditures in connection with the convention. The report was received with an expression of appreciation and ordered filed for future reference.

With reference to the various actions that have been taken by the Board of Directors defining the Institute's policy regarding standardization matters, and in order to summarize and confirm the general policy of the Institute in such matters, the following resolution was adopted:

Whereas this Board has by various actions taken in recent years adopted a definite policy regarding the relation of the Institute to standardization activities, and

Whereas it appears desirable to restate this policy from time to time, therefore be it

Resolved that the following brief statement of this policy be and hereby is adopted for publication and for transmission to the members of the Standards Committee and to representatives of the Institute upon any other committees, or upon joint bodies, dealing with the formulation of standards:

POLICY OF A. I. E. E. REGARDING THE FORMULATION OF STANDARDS

1. To continue to develop, publish and maintain in the name of the Institute electrical standards as it has done for the past 25 years.
2. That in doing this work the Institute will continue as it has in the past to avail itself to the fullest degree of the assistance of others—both individuals and organizations—with a view to serving the interests of all who may be properly concerned in this work.
3. That standards after having been developed by the Institute in accordance with 1 and 2 and adopted by the Board of Directors as Institute Standards will be, when in the opinion of the Institute such a step is proper, presented to the American Engineering Standards Committee for approval by them as American Standards.
4. That such presentation to the American Engineering Standards Committee for their consideration for approval as American Standard will be done in full conformity with the Constitution, By-Laws and Rules of Procedure of the American Engineering Standards Committee which Committee the Institute was instrumental in initiating and has continued to and does now endorse and support.
5. That when and if standards of the A. I. E. E. have been further advanced to the stage of being designated as "Approved as American Standard by the American Engineering Standards Committee," they shall continue to be printed as standards of the A. I. E. E. with a statement of approval by the American Engineering Standards Committee added to the title page of each particular standard.

The 1925 report of the President of the United States National Committee of the International Commission on Illumination, was presented and received, and copies ordered sent to each member of the Board.

In compliance with a request from the United Engineering Society, the President was authorized to nominate three members of the Institute to serve on a committee of twelve to be appointed by the Trustees of the United Engineering Society to make continuing endeavors to increase the funds of Engineering Foundation and Engineering Societies Library.

An invitation to be represented at the Pan American Congress to be held in Panama, June 18-25, 1926, was referred to the President with power to appoint a delegate.

The President was also authorized to appoint a representative to attend the National Conference on Street and Highway Safety to be held in Washington, March 23-25, in accordance with an invitation from Secretary Hoover of the Department of Commerce.

Other matters of importance were discussed, reference to which may be found in this and future issues of the Journal.

Institute Prizes

At the meeting of the Board of Directors of the Institute held February 9, a report was presented by a special committee appointed several months ago to consider Institute prizes and to make recommendations regarding prizes which should be awarded in the future; also, to formulate the necessary regulations for the award of these prizes. The committee which prepared this report consisted of Messrs. L. W. W. Morrow, Chairman; H. P. Charlesworth; H. A. Kidder; C. E. Magnusson; M. E. Skinner; and A. C. Stevens. The Board adopted the committee's recommendations with an expression of appreciation for the valuable services rendered. The substance of the report is embodied in the following statement relating to the prizes to be awarded for papers presented at National, Regional, Section and Branch meetings during the calendar year 1926 (prizes for 1925 papers will be awarded under the previous rules).

NATIONAL PRIZES

The following National Prizes may be awarded each year.

1. Best Paper Prize.
2. First Paper Prize.
3. Best Regional Paper Prize.
4. Best Branch Paper Prize.

a. The *Best Paper Prize* shall be awarded the author or authors of the best original paper presented at any meeting of the Institute.

b. The *First Paper Prize* shall be awarded the author or authors of the most worthy paper presented at any Institute meeting, provided the author or authors have never previously presented a paper before the Institute.

c. The *Best Regional Paper Prize* shall be awarded the author or authors of the best paper presented at any Regional or Section Meeting of the Institute.

d. The *Best Branch Paper Prize* shall be awarded the enrolled student author or authors of the best paper presented at a Branch meeting.

e. All prizes shall be presented at the Annual Convention of the Institute in June.

f. Prizes will be awarded for papers presented during the calendar year preceding the year during which the Annual Convention is held.

g. A cash prize of $100 and a suitable certificate of award shall be given the author or authors of each paper receiving a prize. At the discretion of the Committee on Award of Institute Prizes, any prize award may be omitted in any year in which at least three papers are not submitted in competition for each prize. Also, at the discretion of this committee, a single paper may be awarded more than one of the prizes available, and honorable mention may be made of papers which did not receive prize awards.

h. All National prizes shall be awarded by the Committee on Award of Institute Prizes. This committee consists of the chairmen of the Meetings and Papers, Publication, and Transmission Committees, and such others as the Board of Directors may designate.

i. To be considered in the competition, all "first" papers and all papers not presented at national conventions, must be presented with a written communication to the National Secretary of the Institute on or before February 15th of the year following the calendar year in which they were presented. Papers presented at any national convention are all eligible for consideration, but "first" papers and those presented at other than national meetings, must be submitted formally. This may be done by the author or authors, by an officer of the Institute, or by the executive committees of the Institute in the Geographical District. As a normal procedure, papers presented for prize awards which were presented at Regional, Section or Branch meetings, shall be presented through the executive committees of the Geographical Districts.

j. Papers, other than those presented at national conventions, must be submitted in triplicate, to the National Secretary of the Institute.

k. Papers awarded prizes shall be published in full or in abstract, in the JOURNAL, in the TRANSACTIONS, or in pamphlet form.

l. All papers submitted for prizes (excepting for the Branch Paper Prize) must be written by members of the Institute, and when papers are written jointly at least one of the authors must be a member of the Institute, and the cash value of the prize shall be divided.

m. The fundamental consideration in the award of the National prizes, is the quality of the contribution made for the advancement of electrical engineering.

REGIONAL PRIZES

The following Regional Prizes may be awarded each year. in each Geographical District of the Institute.

1. Best Paper Prize.
2. First Paper Prize.
3. Best Branch Paper Prize.

a. The *Best Paper Prize* shall be awarded the author or authors of the best paper presented at Regional, Section or Branch Institute meeting in the District.

b. The *First Paper Prize* shall be awarded the author or authors of the best paper presented at an Institute meeting in the District, provided the author or authors have never before presented a paper before the Institute at any National, Regional or Section meeting.

c. The *Best Branch Paper Prize* shall be awarded the author or authors of the best paper presented at a Branch or Regional meeting of the Institute in the District. The authors must be enrolled Students of the Institute.

d. *Regional Prize Awards* shall be made by the District executive committees or by another committee appointed by the District executive committee.

e. Each prize shall consist of $25 from the national treasury, and a suitable certificate of award issued by the officers of the Geographical District concerned.

f. Papers must be submitted in duplicate to the District Committee on Awards, on or before January 10th of the year following the calendar year in which the papers have been presented.

g. All Regional papers submitted in competition for National prizes, which have been presented at other than national meetings, should be submitted to the National Secretary of the Institute through the District executive committee or by the authorized District Committee on Prize Awards. If in any District this procedure is inadvisable, papers may be submitted directly to the National Secretary by an officer of the Institute in the District.

Scientific Congress

BRUSSELS, BELGIUM—JUNE 1926

During June next, the Association of Engineers of Brussels will celebrate the fiftieth anniversary of its foundation.

A scientific congress will be held upon this occasion, comprising two sections, one on civil engineering and the other on mechanics, electricity, chemistry and various industries.

The Institute has been invited to be represented at this congress, and American members who contemplate being in Belgium in June are requested to advise the National Secretary promptly, at Institute Headquarters, New York, so that any additional information which may be received, including the exact dates of the congress may be sent to them.

John Fritz Medal Award

The date for the presentation of the John Fritz Medal to Edward Dean Adams has been fixed for the evening of Tuesday, March 30th, at 8:15 p. m. in the Engineering Auditorium. The Board of Award, representing the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, extends a cordial invitation to all interested friends. The award will be made by Fred J. Miller, Chairman of the Board, and the speakers of the evening will be the Honorable James Montgomery Beck, formerly Solicitor-General of the United States and Arthur Edwin Kennelly, D. Sc., Professor of Electrical Engineering, Harvard University and Massachusetts Institute of Teohnology.

Electrical Heating Conference at Purdue

Electric heat treating of metals in industry, including the use of electric furnaces and similar equipment, will be the subject for a state-wide conference of manufacturers and electric power producers to be held at Purdue University, Lafayette, Ind.,

March 16, 17 and 18. The conference which will be largely in the nature of a school with demonstrations of every description, relating to the use of electric heat treating equipment, was decided on at a recent meeting of Prof. C. F. Harding of the School of Electrical Engineering, and Prof. W. A. Knapp, in charge of the engineering extension department, with state utility men.

Among the features already arranged included a visit to the Ross Gear and Tool Works at Lafayette which has in operation two electric furnaces and plans to install more during the coming months.

Nomination of Officers of New York Section for Year 1926-27

On February 15, 1926 The Executive Committee of the New York Section of the A. I. E. E. appointed a Nominating Committee as follows: L. F. Morehouse, Chairman; H. H. Barnes, C. E. Stephens, J. C. Parker, E. E. Dorting. The committee is particularly desirous of receiving suggestions from members of the Section for officers for 1926-27. A Chairman, secretary-treasurer, and two members of the Executive Committee are to be nominated. Petitions signed by not less than ten members of the Section may be made and should be received prior to March 8, 1926. Send your suggestions or petitions to L. F. Morehouse, Chairman Nominating Committee New York Section, 33 West 39th St., New York, N. Y.

Columbia University Offers Scholarship in Electrical Engineering

The governing bodies of Columbia University have placed at the disposal of the American Institute of Electrical Engineers each year a scholarship in Electrical Engineering in the Schools of Mines, Engineering and Chemistry of Columbia University. The scholarship pays $350 toward the annual tuition fees which vary from $340 to $360, according to the details of the course selected. Reappointment of the student to the scholarship for the completion of his course is conditioned upon the maintenance of a good standing in his work.

To be eligible for the scholarship, the candidate recommended will have to meet the regular admission requirements, in regard to which full information will be sent without charge upon application to the Secretary of the University or to the National Secretary of the Institute.

In a letter addressed to the National Secretary of the Institute, an applicant for this scholarship should set forth his qualifications (age, place of birth, education, reference to any other activities, such as athletics or working way through college, references and photograph). A committee composed of Messrs. W. I. Slichter, Francis Blossom and H. C. Carpenter will consider the applications and will notify the authorities of Columbia University of their selection of a candidate The last day for filing of applications for the year 1926-27 will be June 1, 1926.

The course at the Columbia School of Mines, Engineering and Chemistry, is three years in length and is on a graduate basis. A candidate for admission must have had something of a general education, including considerable work in mathematics, physics and chemistry. Three years of preparatory work in a good college or scientific school should be sufficient, if special attention has been given to the three preparatory subjects mentioned. A college graduate, with a Bachelor of Science degree in engineering can generally qualify to advantage. The candidate is admitted on the basis of his previous collegiate record, and without undergoing special examinations.

The purpose of this advanced course is to produce a high type of engineer, trained in the humanities as well as in the fundamentals of his profession. It is hoped that enrolled students and others qualified will show a keen interest in this scholarship.

Electrical Exhibition Held By Yale Branch

On December 11-12, 1925, an electrical exhibition at which many interesting displays were made, was held by the Yale University Branch of the Institute in the Dunham Laboratory, and attended by two thousand people.

Among the exhibits were a miniature power plant, a miniature electric train and railway substation, motors and control, high-voltage equipment, household refrigerators and other appliances, an automatic telephone exchange, radio and telegraph demonstrations, and numerous interesting trick displays.

University of Illinois Offers Research Assistantships

To assist in the conduct of engineering research and to extend and strengthen the field of its graduate work in engineering, the University of Illinois maintains fourteen Research Graduate Assistantships in the Engineering Experiment Station. Two other such assistantships have been established under the patronage of the Illinois Gas Association. These assistantships, for each of which there is an annual stipend of $600 and freedom from all fees except the matriculation and diploma fees, are open to graduates of approved American and foreign universities and technical schools who are prepared to undertake graduate study in engineering, physics, or applied chemistry.

An appointment to the position of Research Graduate Assistant is made and must be accepted for two consecutive collegiate years of ten months each, at the expiration of which period, if all requirements have been met, the degree of Master of Science will be conferred. Half of the time of a Research Graduate Assistant (approximately 900 clock hours for each ten-month period) is required in connection with the work of the department to which he is assigned, the remainder being available for graduate study.

Nominations to these positions, accompanied by assignments to special departments of the Engineering Experiment Station, are made from applications received by the Director of the Station each year not later than the first day of April. The nominations are made by the Executive Staff of the Station, subject to the approval of the President of the University. Nominations are based upon the character, scholastic attainments, and promise of success in the principal line of study or research to which the candidate proposes to devote himself. Preference is given those applicants who have had some practical engineering experience following the completion of their undergraduate work. Appointments are made in the spring, and they become effective the first day of the following September. Vacancies may be filled by similar nominations and appointments at other times.

Research work and graduate study may be undertaken in architecture, architectural engineering, ceramic engineering, chemistry, civil engineering, electrical engineering, mechanical engineering, mining engineering, municipal and sanitary engineering, physics, railway engineering, and theoretical and applied mechanics.

Additional information may be obtained by addressing The Director, Engineering Experiment Station, University of Illinois, Urbana, Illinois.

Research Fellowships in Lehigh University

On or before June 1, 1926, the Institute of Research of Lehigh University will appoint three research fellows, as follows:

1. One New Jersey Zinc Company Research Fellow in Science and Technology, with endowment provided by the New Jersey Zinc Company. Appointment to this Fellowship will be for the period of two academic years beginning September 1, 1926, annual stipend $600, payable in ten monthly installments, and freedom from University fees, except the matriculation fee of $5.00 and the graduation fee of $10.00. Half of the time of the holder must be devoted to research work in the field

of science or technology to which he is assigned; the other half to graduate study leading to the degree of Master of Science at the end of the two year appointment, providing all University requirements for this degree have been satisfied.

2. TWO HENRY MARISON BYLLESBY MEMORIAL RESEARCH FELLOWS IN ENGINEERING, with endowment provided by widow of Col. Henry M. Byllesby, (M. E., Lehigh, 1875), President of the Byllesby Engineering and Management Corporation. Appointment to either of these Fellowships will be for the period of two academic years, beginning September 1, 1926, with an annual stipend of $750, payable in ten monthly installments, and freedom from University fees, except the matriculation fee of $5.00 and the graduation fee of $10.00. Half of the time of the holders must be devoted to research work on some problem in electrical, mechanical or hydraulic engineering proposed by the President of the Byllesby Engineering and Management Corporation and approved by the Institute of Research; the other half to graduate study leading to the degree of Master of Science at the end of the two year appointment, providing that all University requirements for this degree have been satisfied.

Applications for appointment may be submitted by graduates in engineering or science of colleges, universities or technical schools whose requirements for graduation are substantially the equivalent of those at Lehigh University. Applications must be submitted before May 1, 1926, and they must be accompanied by a catalog of the institution from which the applicant graduated, a certificate of his college work, a list of three or more references, a recent photograph of himself, together with a statement concerning his practical experience and any other evidence of his qualifications for the position which he may choose to submit. The applicant must also indicate the line of graduate study he desires to undertake and his special qualifications for such work.

As previously indicated, appointment to these Fellowships is for the period of two years of ten months each. The holder of each of these Fellowships is required to devote approximately ninety hours per month to research work, under the direction of the Head of the department to which he is attached, without allowances for holidays or vacations during the academic year. Each appointee must pledge himself to remain through the full term of his appointment and to refrain from accepting any kind of employment during either ten month period included therein.

Applications or requests for additional information should be addressed to: CHARLES RUSS RICHARDS, President, Lehigh University, Bethlehem, Pa.

National Museum of Engineering and Industry

In accordance with an invitation extended by the National Museum of Engineering and Industry to several Societies many of whose members had joined it individually to nominate representatives to its Board of Trustees, the National Societies of Civil, Mining, Mechanical and Electrical Engineers, the American Association for the Advancement of Science, the American Chemical Society and the Society for the Promotion of Engineering Education have responded favorably and are now represented on its Board constituted as follows:

SAMUEL INSULL
CHAIRMAN

L. P. ALFORD[3]	FREDERICK A. HALSEY
B. C. BATCHELLER	DUGALD C. JACKSON[7]
NICHOLAS F. BRADY	LUIS JACKSON
F. H. COLVIN	F. B. JEWETT[4]
NORMAN DODGE	JOHN W. LIEB
GANO DUNN[4]	FRED R. LOW[3]
A. S. DWIGHT[2]	W. W. MACON
THOMAS EWING	L. C. MARBURG
JOHN R. FREEMAN[1]	H. P. MERRIAM
MICHAEL FRIEDSAM	M. I. PUPIN[5]
H. A. GILLIS	W. L. SAUNDERS[2]
HENRY GOLDMARK	J. WALDO SMITH[1]

ELMER A. SPERRY[6]

1 Nominated by American Society of Civil Engineers.
2 " American Institute of Mining and Metallurgical Engineers
3 " American Society of Mechanical Engineers.
4 " American Institute of Electrical Engineers.
5 " American Association for the Advancement of Science.
6 " American Chemical Society.
7 " Society for the Promotion of Engineering Education.

Many of its members have donated original historical documents, old patent records, books, drawings, prints, models, photographs and descriptions of important work, etc., to the National Museum and correspondence regarding these things is solicited.

The Secretary would like to hear by letter from any one recounting items of historical value or interest or, if they should happen to be in the neighborhood, he would welcome a call during which experiences may be dictated to his amanuensis. all of these accounts will be carefully catalogued and placed in the research file for the reference of any one who can make proper use of them. They will eventually go for permanent preservation to the National Museum which is to be part of the Smithsonian Institution at Washington.

The Secretary may be addressed as follows: H. F. J. Porter, Secretary, National Museum of Engineering and Industry, 29 West 39th Street, New York City.

Ocean Magnetic and Electric Observation Carnegie Institution

A fifth volume of "Researches of the Department of Terrestrial Magnetism" has appeared from the press of the Carnegie Institution, Washington, D. C. This volume contains articles on Magnetic Results by J. P. Ault, Atmospheric-Electric Results by Messrs. J. P. Ault and S. J. Mauchly, and also further data on Ocean magnetic and electric observation and studies in atmospheric electricity based on observations made aboard the *Carnegie* during its cruises during the years 1915-21.

Midwest Power Conference Held in Chicago

To consider how the available power resources of the country, especially of the middlewest section, might best be developed for the benefit of the people and the industries, a meeting known as the Midwest Power Conference was held in Chicago in the Furniture Club of America, January 26 to 29. This conference was sponsored by the local divisions of the A. I. E. E., A. S. M. E., A. I. M. E., N. E. L. A., Western Society of Engineers and the National Safety Council.

The conference opened with an address by Samuel Insull on "Power Developments in the Mississippi Valley," followed by the presentation of seventeen papers dealing with the advantages of full development, distribution and use of power resources, fuel, boilers, turbines, diesel engines, power generation, industrial power, superpower, rural service and safety first aid. G. E. Pfisterer, 37 W. Van Buren St., Chicago, was Secretary of the General Arrangement Committee.

Library Service

As few members of the American Institute of Electrical Engineers appreciate the very convenient and practicable service offered by the Engineering Societies Library and as I have personally found it most useful, I should like to point out to readers of the JOURNAL some of the opportunities it offers through its expert staff.

The library will furnish, at short notice, photoprint copies of pages of any available book or periodical, including illustrations, at 25 cents a page. This will permit, for example, obtaining a permanent copy of any article or extract, for which only a reference is available.

In case of long articles which would be expensive to photoprint, complete, the library will sometimes make the prints and

loan them at a reasonable per diem charge with the option of subsequent purchase.

The library will translate any available article in a foreign language at about $6.00 a thousand words, so that references to foreign articles can be very readily investigated.

The library will make searches of the periodicals or technical books and list all articles bearing on any particular subject matter that may be prescribed. Where such a search is to be for general information, or to find what has been written about some particular matter or what has been done to solve a special problem, the time required is short and the charge small. In the case of patent searches or exhaustive studies, the time and charges will be such as may be appropriate.

This is an extremely convenient and valuable service when one gets in the habit of using it, especially for an engineer who has new designs to make or new problems arising from time to time.

The library will lend books where duplicates are available for a 5 cents per diem charge, delivering them by mail, and such books are available on many subjects. They may usually be subsequently purchased.

The library has a sort of clipping bureau to the extent that it will follow the technical periodical press and regularly send notices or articles or books appearing on any particular subject, an appropriate charge being made.

In general the library is ready in any practicable manner to use the books and periodicals and the services of the staff to help members of the founder societies or any other persons who may wish to take advantage of the facilities, to get any information that may be wanted, quickly, and conveniently, and without visiting the library, if desired. Engineers should make use of this service as often as possible, first because as they come to realize the convenience of it they will obtain great benefit and second because it strengthens the library and enables better service to be given.

PERCY H. THOMAS

ENGINEERING FOUNDATION

ELECTION OF OFFICERS

At the annual meeting of Engineering Foundation February 11, the following officers were elected for the ensuing year: Chairman, Lewis B. Stillwell (member, American Institute of Electrical Engineers, American Society of Civil Engineers); Vice-Chairman, Elmer A. Sperry (member, American Institute of Electrical Engineers, American Society of Mechanical Engineers). George A. Orrok (member, American Society of Mechanical Engineers, Am. Inst. of Mining and Metallurgical Engineers, American Society of Civil Engineers). Additional members of Executive Committee, J. Vipond Davies, (member Am. Inst. of Mining & Metallurgical Engineers, Am. Society of Civil Engineers). Arthur M. Greene, Jr., (member, American Society of Mechanical Engineers). Director and Secretary, Alfred D. Flinn; Treasurer, Jacob S. Langthorn; Assistant Treasurer, Henry A. Lardner.

United Engineering Society

EXTRACTS FROM PRESIDENT'S REPORT FOR YEAR 1925

Throughout 1925, as in the preceding year, the energies of the Trustees were devoted largely to improving the investment of trust funds. Especial attention was given to the Engineering Foundation endowment. A new active bank account was authorized to be established January 1, 1926 at the Fifth Avenue branch of The Farmers' Loan and Trust Company.

In June, the $50,000 legacy establishing the Henry R. Towne Engineering Fund was received in cash. It has been invested.

Assessment of Engineering Societies Building for taxation in 1925 was reduced by the Department of Taxes and Assessments, after a hearing, from $1,450,000 to $195,000, applying only to space occupied by taxable organizations.

A medallion of General Pershing was placed in the Entrance Hall as a companion to the medallion of Marshal Foch received in 1921. In December, the flags of the 24th Regiment of Engineers (Mechanical) were received and placed in the cabinet with the flags of the 27th Engineers received in 1924.

President Ralph Budd, of the Great Northern Railway, presented to United Engineering Society a bronze replica of the statue of John F. Stevens, Hon. M. Am. Soc. C. E., set up last July in Marias Pass through the Rocky Mountains, which he discovered. The statuette was placed in the Library.

A name for the Auditorium in Engineering Societies Building was adopted in December. It is "Engineering Auditorium."

By direction of the Board of Trustees, the Secretary has prepared a History of United Engineering Society and the Fifth Revision of the Charter and By-Laws.

Engineering Societies Building is in excellent condition and fully occupied, with a waiting list. Erection of new buildings and remodeling of old ones in the vicinity have improved the external fire hazard. In November, a contract was made with the New York Steam Corporation for heating service from its new main in 39th Street and at the end of the year the necessary piping was being installed.

Memberships of the Founder Societies at the end of 1925 totaled 55,695 and of the Associate Societies 52,204, an aggregate of 107,899 engineers having headquarters in our building.

All departments of United Engineering Society closed the year without deficits. The assets for which the Society is responsible (real estate at cost, trust funds at book value, and Library as appraised) total $3,145,395.44.

BALANCE SHEET

ASSETS

Real Estate:		
Land	$ 540,000.00	
Building	1,369,398.28	
Equipment	33,171.16	
Founders' Preliminary Expenses	24,000.00	$1,966,569.44
Investments and Cash Uninvested:		
Depreciation and Renewal Fund		$ 192,623.70
Engineering Foundation Fund		479,542.97
Library Endowment Fund		97,506.37
General Reserve Fund		10,000.00
Reserve for Depreciation of Library Capital		4,000.00
Henry R. Towne Engineering Fund		49,953.13
Operating Cash and Petty Cash		8,310.38
Accounts Receivable		4,389.45
		$2,812,895.44

LIABILITIES

Founders' Equity in Property	$1,966,569.44
Depreciation and Renewal Fund	192,623.70
Engineering Foundation Fund	479,542.97
Library Endowment Fund	97,506.37
General Reserve Fund	10,000.00
Reserve for Depreciation of Library Capital	4,000.00
Henry R. Towne Engineering Fund	49,953.13
Deposits on Account Hall Rentals	35.00
Credit Balance in Accounts Receivable	101.68
Deferred Credit—Miscellaneous Contributions to Library	3,065.87
Credit Balance in Activity Accounts	9,479.28
	$2,812,895.44

MEETING OF THE BOARD OF TRUSTEES

At the annual meeting of the Board of Trustees of United Engineering Society held January 28, the following officers were elected for the ensuing year: President, W. L. Saunders; 1st Vice-President, Bancroft Gherardi; 2nd Vice-President, Lewis D. Rights; Secretary, Alfred D. Flinn; Treasurer, Jacob S. Langthorn and Assistant Treasurer Henry A. Lardner.

PERSONAL MENTION

H. W. YOUNG, President of the Delta-Star Electric Co., Chicago, sailed March 6th on the Berengaria for a six weeks business trip to England, France and Italy. He is accompanied by Mrs. Young.

B. LAZICH has resigned his position in the Equipment Engineering Department of the Bell Telephone Company at Pittsburgh, to accept a position in the engineering department of the Union Switch and Signal Co. at Swissvale. Pa.

HAZAEL COLATINE PRADO, of Santander, Cauca. Columbia, S. A., an Associate of the Institute. has been laying out a new town of over 62 plazas, at the hacienda of La Libertad, Municiple de San Joaquin, Caldas. These blocks consist of sixteen lots 15 x 30 meters, given away by the owner.

WALTER P. HOLCOMBE, member of the Institute and JOHN C. PARKER, Fellow, were appointed vice-presidents of the Brooklyn Edison Company at a meeting of the board of directors yesterday. Mr. Holcombe has been purchasing agent for the company for several years, and Mr. Parker has been chief electrical engineer for the Company.

A. W. BERRESFORD, Fellow of the Institute and its President during the year 1920-21, has just been appointed executive vice-president of the Nizer Corporation, Detroit, manufacturers of the Nizer Electric Ice Cream cabinets and automatic refrigerating units. Mr. Berresford, for some twenty years, has been vice-president and general manager of the Cutler-Hammer Manufacturing Company. He was also recently elected vice-president of the American Engineering Council.

MISS EDITH CLARKE, Associate of the Institute and for the past six years, engineer of the General Electric Company at Schenectady, N. Y., is the first woman member to present a paper before the American Institute of Electrical Engineers, when her paper, *Steady-State Stability in Transmission Lines*, was delivered at the Midwinter Convention of last month. Miss Clarke is a Vassar graduate, she took her engineering degree at Massachusetts Institute of Technology and upon April 13, 1923, became one of five women members of the A. I. E. E.

FARLEY OSGOOD, Past-President of the Institute, has opened offices in the National Bank of Commerce Building, New York, for consulting engineering in the design, construction, operation and interconnection of public utilities.

After receiving his education at Massachusetts Institute of Technology, Dr. Osgood went in 1894 with the American Bell Telephone Company, Boston. In 1897-98, he affiliated himself with the New England Telephone and Telegraph Company, and finally became Division Manager of the New York and New Jersey Telephone Company. In 1904 he was appointed Chief Engineer and General Manager of the New Milford Power Company, and in 1908 he was made General Superintendent of the Public Service Electric Company of New Jersey, advancing later to the position of Vice-President and General Manager of that Company.

He has always been an active worker in the A. I. E. E., the N. E. L. A. and other representative organizations. In 1911-14, he was a Director of the Institute, Vice-President in 1914-15-16 and President in 1924-25. From 1921 to 1922 he was Chairman of the Institute's New York Section, and he has served the Institute also on the following committees: Executive, Finance, Edison Medal, Standards, Safety Codes and others.

L. C. BROOKS, who has been identified with marine electrical applications since the inception of the art on the *U. S. S. Kearsarge* and *Kentucky*, twenty-five years ago, and for the last eight years electrical engineer of the Bethlehem Shipbuilding Corporation, has resigned. Mr. Brooks has been chairman of the A. I. E. E. Committee on Applications to Marine Work for two years. He expects to take a much needed vacation, after which his plans may lead him into an entirely new field of activity.

Obituary

Edmund Hugh Pryce died at his home, 568 West 149th Street, New York City, on February 12th. Born at Llanidloes, Wales, in 1872, Mr. Pryce's early education was through the English Grammar School at the Oswestry Grammar School, South Kensington course at Oswestry. For five years he was apprenticed in technical shops and offices of the Cambrian Railway Company. This was followed by two years' training in mechanical and electrical engineering with the Central Marine Engine Company. He was also with the British India Steam Navigation Company for seven years in varying capacities and held the Chief Engineers Certificate granted by the Board of Examiners, Trinity House, London. Coming to the United States, Mr. Pryce was first engaged with the National Automatic Fire Alarm Company as constructing Electrical Engineer, but left them very shortly to enter the Wool Exchange. Mr. Pryce joined the Institute in 1904 but continued as an Associate until the time of his death.

Charles C. Clancy Grandy, Radiologist of the Lutheran Hospital, Fort Wayne, Indiana, an Associate of the Institute since 1920, and past-chairman of the Fort Wayne Section of the A. I. E. E., (1923-1924) died the morning of February 12th, 1926. Doctor Grandy was born at Wall Lake, Iowa. After finishing High School at Warsaw, Indiana, he entered the Indiana University from which he obtained his A. B. in 1908 and A. M. in 1909. He next attended the Rush Medical College, Chicago, Illinois, from which he graduated with his M. D. degree in 1911. Since then he has been doing the X-ray work at the Fort Wayne Lutheran Hospital, having charge of the laboratory there. Doctor Grandy will be much missed by his medical colleagues as well as by the members of the Institute's Fort Wayne Section. Due to his death, the meeting scheduled for February 12th was cancelled.

Robert Alexander Paine, Jr., after an illness of a month's period, died at the Methodist Episcopal Hospital, Brooklyn, February 7th. His death is keenly felt by his business associates in the Brooklyn Edison Company, for whom he has been plant engineer for some time past. He was born in Richmond, Va., August 30, 1887 and his early schooling was obtained in the Ashland Grammar School, Ashland, Va. September 1904 he entered the Randolph-Macon College, at Ashland, obtaining his A. B. degree there in 1905. He next attended the Virginia Polytechnic Institute, Blacksburg, Va., whence he graduated June 1908 with a B. S. degree in Electrical Engineering and in June 1909 with a degree in Mechanical Engineering. June 1910 he entered the Testing Department of the General Electric Company, Schenectady, but left the following year to become assistant to the Chief Engineer of the Coney Island and Brooklyn Railroad Company, Brooklyn, N. Y. Here he was promptly appointed acting electrical engineer in charge of electric operation, remaining with them until in 1914 he became general foreman, Development Research Bureau of the Edison Electric Illuminating Company of Brooklyn. Mr. Paine was elected to the grade of Associate in the Institute in 1913.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus

relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Research Div., Detroit, Mich.
2.—H. R. Bailey, Room 923, Electric Bldg., Portland, Ore.
3.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
4.—Ralph Elsman, 120 Broadway, New York, N. Y.
5.—L. W. Ferguson, Box 331, Barbourville, Ky.
6.—Chas. A. Foust, 10505 93rd St., Woodhaven, N. Y.
7.—George Frasher, 1209 So. 4th Ave., Louisville Ky.
8.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
9.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
10.—Wm. J. Hay, 320 Second St., Aspinwall, Pa.
11.—Wendell E. Haywood, 823 Boatmens Bank, St. Louis, Mo.
12.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
13.—Harry W. Kohler, 200 14th St., Milwaukee, Wis.
14.—Charles L. Leaf, 175 Dodd St., East Orange, N. J.
15.—John E. Lewis, 376 Meyran Ave., Oakland Station, Pittsburgh, Pa.
16.—Chas. W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
17.—J. A. McDermott, Y. M. C. A. Lima, Ohio.
18.—Raymond W. Noddins, 230 East Ohio St., Chicago, Ill.
19.—Lieut. A. G. Scott, 68 West 107th St., Apt. 2D, New York, N. Y.
20.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Nat'l Bank, Cincinnati, Ohio.
21.—C. D. Smith, 857 St. Charles St., New Orleans, La.
22.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
23.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.

Book Review

ANNUAL PROCEEDINGS OF THE A. S. T. M. Prices: $6.00 in paper, $6.50 in cloth and $8.00 in half-leather binding.

Part I (962 pp.) contains the annual reports of 35 of the standing committees of the Society, with the discussion thereon at the annual meeting. These include reports of Committees on Ferrous Metals, Non-Ferrous Metals, Cement, Ceramics, Concrete Gypsum, Lime, Preservative Coatings, Petroleum Products, Road Materials, Coal and Coke, Water-proofing Materials, Electrical Insulating Materials, Rubber Products, Textile Materials, Thermometers, Metallography, including a report on Metal Radiography and X-ray Crystallography. Methods of Testing and Nomenclature and Definitions: 83 tentative standards which have either been revised or are published for the first time; annual address of the President and the annual Report of the Executive Committee.

Part II (454 pp.) contains 26 technical papers with discussion, giving valuable information regarding results of investigations by experts in the field of engineering materials including the fatigue of metals, the effect of temperature on the properties of metals and investigations on the corrosion of metals. Mention should also be made of the many papers on cement and concrete and on the stability of bituminous mixtures as well as on such subjects as bituminous materials, paint, gypsum, brick, textiles, etc.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (JAN. 1-31 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ADMINISTRATION OF INDUSTRIAL ENTERPRISES.

By Edward D. Jones. New edition. N. Y., Longmans, Green & Co., 1925. 618 pp., illus., tables, 9 x 6 in., cloth. $4.75.

The purpose of this book is to present in compact outline a survey of the art of business management as it exists in the United States at this time. The treatment aims to present practise with reasonable fullness of detail but, wherever possible, to deduce and formulate the general principles, or the philosophy, controlling action.

The chief outstanding characteristic is the inclusion, for the first time in such a treatise, of a full discussion of the underlying general principles of administration which govern all efficient joint enterprises, whether of a business nature or otherwise.

This edition has been thoroughly revised, the new material exceeding the subject matter of the first edition. The numerous bibliographies have been brought up to date.

AERONAUTICAL METEOROLOGY.

By Willis Ray Gregg. N. Y., Ronald Press Co., 1925. (Ronald Aeronautic Library). 144 pp., illus., diagrs., tables, 9 x 6 in., cloth. $2.50.

Intended to give concisely the essential facts concerning the upper air and to point out their relation to the development and safety of aeronautics. The book is intended for pilots, aeronautical engineers and others requiring an intimate knowledge of the characteristics of the atmosphere.

ARCHITECTURAL IRON DESIGN AND DETAILING, as Required by the Laws of New York.

By Daniel M. Driscoll. N. Y., D. Van Nostrand Co., 1926. 349 pp., illus., plates, tables, 8 x 11 in., cloth. $4.00.

The subjects covered are the designing and detailing of stairs, elevator drip pans, door bucks, door saddles, doors, gratings, sidewalk gratings and other miscellaneous metal work, and fire-escapes; and the fabricating and setting of light structural steel. Appendices give useful tables, cuts of stock ornamental moulding and shapes, the Building Code of New York City, the Tenement House Law and Labor Law of New York State, the Code of Ordinances and the Rules of the Board of Standards and Appeals of New York City, and a glossary. The book is intended for draftsmen, not beginners. It should be particularly useful be-

cause of its careful attention to the laws governing the design of these articles.

BUREAU OF STANDARDS.

By Gustavus A. Weber. Balt., Johns Hopkins Press, 1925. (Institute for Government Research. Service monographs, no. 35). 299 pp., illus., 9 x 6 in., cloth. $2.00.

The history, activities and organization of the Bureau of Standards are presented in detail in this volume, which gives a complete account of its purpose, its achievements and their cost. The laws governing it, the character of its plant, its functions and its personnel are described, and a full bibliography of the sources of information bearing on it is given.

CONDENSED COLLECTION OF THERMODYNAMIC FORMULAS.

By P. W. Bridgman. Cambridge, Harvard University Press, 1925. 34 pp., 9 x 6 in., cloth. Price not quoted.

This collection of formulas is intended both for students of thermodynamics and for use in practice. The formulas given apply to systems for which temperature and pressure are a possible set of independent variables; and to systems for which pressure is a function of temperature, and temperature and volume are a possible set of independent variables. The latter table applies to two-phase systems such as water and steam in contact.

Illustrative examples show how the tables are used. The author also shows how to extend the tables, in a number of cases, to systems subjected to other external forces than a hydrostatic pressure.

THE DYNAMO....v. 3, Alternators.

By C. C. Hawkins. 6th edition. N. Y., Isaac Pitman & Sons, 1925. 572 pp., illus., diagrs., 9 x 6 in., cloth. $8.50.

The first two volumes of this edition appeared a few years ago. They are now supplemented by a third volume devoted to alternators. It discusses armature winding, the loop e.m. f. of the heteropolar and the toothed armature, armature reactions, the construction of armatures and field magnets, the design of the salient-pole alternator, the turbo-alternator with cylindrical rotor and the parallel working of alternators. The treatment is brief enough for the student, but is intended to provide a basis for further consideration of the various phenomena discussd, with reference to sources of more detailed information.

ELECTRICAL POWER AND NATIONAL PROGRESS.

By Hugh Quigley. Lond., George Allen & Unwin, 1925. 160 pp., graphs, 9 x 6 in., cloth. 8-6.

The volume, which is based on articles that have appeared in various British newspapers, examines the probable effects of a reorganization of power generation and distribution on the industrial life of Great Britain, and the economic consequences of the national development of electrical power.

HISTORY OF ENGINEERING.

By A. P. M. Fleming & H. J. Brocklehurst. Lond., A. & C. Black; [N. Y., Macmillan Co.], 1925. 312 pp., illus., 9x6 in., cloth. 12/6.

The title is misleading, for with the exception of a chapter on ancient engineering, the account is limited to the development of engineering in Great Britain. For that country, the authors give a concise, readable account of progress in the refinement of measurement; the construction of docks, harbors, canals, roads and bridges; the invention of the steam engine; the development of railroad, gas, oil and electric engineering; and of the influence of progress in iron making on engineering.

HUTTE, DES INGENIEURS TASCHENBUCH, v. 1.

By Akademischen Verein Hütte. Berlin, Wilhelm Ernst & Sohn, 1925. 1080 pp., diagrs., table. 8 x 5 in., cloth. 12,20 mk.

When twenty-five editions of a book have been called for in sixty-eight years, its popularity is evident. In spite of its frequent revision, the new edition shows still further important changes and novelties. An attempt has been made to collect the theoretical principles of all engineering in volume one, and this has necessitated some rearrangement. A new section, "Technical physics," has been added, and new chapters provided on nomography and the kinetics of gearing. All sections have been carefully revised and new standards have been adopted.

INDUCTION MOTOR IN THEORY, DESIGN AND PRACTICE.

By Herbert Vickers. N. Y., Isaac Pitman & Sons, 1925. 322 pp., diagrs., plates, tables, 9 x 6 in., cloth. $6.00.

Primarily intended to introduce the student electrical engineer to the theory and design of these motors, this is a well-balanced text-book, in which an endeavor is made to place design on a firm scientific basis. The latest developments in speed control and power-factor control are dealt with.

THE INDUSTRIAL MUSEUM.

By Charles R. Richards. N. Y., Macmillan C., 1925. 117 pp., illus., 10 x 6 in., cloth. $3.00.

During the year 1923-24, the author made a survey of foreign museums of industrial art for the American Association of Museums. The present book forms part of the report submitted and deals with industrial museums.

The museums described include the Conservatoire des Arts et Métiers, the Science Museum, the Deutsches Museum, and the Technisches Museum für Industrie und Gewerbe in Wien. There are also a chapter on industrial museums in this country and appendices on various foreign museums devoted to particular subjects, such as traffic, the marine and agriculture. The illustrations include photographs of many of the more interesting exhibits.

LOCKWOOD'S DIRECTORY OF THE PAPER AND ALLIED TRADES. 1926.

N. Y., Lockwood Trade Journal Co., 1925. 942 pp., 9 x 6 in., cloth. $7.50.

This directory lists the paper mills of North and South America, showing their locations, officers, equipment and capacity. It also contains a directory of mill officials and classified lists of the mills making different papers, of makers of paper specialties, of paper merchants, of dealers in raw materials, of paper box manufacturers, of stationers of brands and of trade associations. The book covers every brand of the industry and has long been the authority in its field.

MERCURY-ARC RECTIFIERS AND MERCURY-VAPOUR LAMPS.

By J. A. Fleming. Lond. & N. Y., Isaac Pitman & Sons, 1925. 100 pp., illus., diagrs., 7 x 5 in., cloth. $1.75.

Now that this rectifier has become available for electrical work on a large scale and has reached a durability and efficiency comparable with that of dynamos, its working and use are of interest to all electrical engineers. The mercury-vapor lamp has also important commercial and therapeutic uses. The present little book has been written to supply a small treatise on the mode of operation and the uses of these devices.

STATEMENT AND ENGINEERING REPORT SUBMITTED TO THE INTERNATIONAL JOINT COMMISSION RESPECTING THE PROPOSAL TO DEVELOP THE ST. LAWRENCE RIVER. 1921.

By Hydro-Electric Power Commission of Ontario. Toronto, 1925. 119 pp., plans, maps, tables, 10 x 7 in., cloth. $7.50.

When the International Joint Commission was empowered, in 1920, by the governments of Canada and the United States to make a special investigation respecting the improvement of the St. Lawrence River, the Hydro-Electric Power Commission of Ontario arranged that the information which it already possessed should be supplemented with the information obtained by additional research and the whole reduced to a report intended to help the International Joint Commission in its investigation.

This was done, but as the report has never appeared in print, the Hydro-Electric Power Commission has now published it. The report is directed to plans for power development, but the improvements are planned, it is stated, to safeguard navigation.

TALKS ABOUT RADIO....

By Sir Oliver Lodge. N. Y., George H. Doran Co., 1925. 267 pp., 8 x 6 in., cloth. $2.50.

Sir Oliver Lodge writes informally and interestingly of various topics connected with radio, addressing his book to the large army of amateurs. Among the subjects touched upon are broadcasting, the work of the pioneers, the discovery of the waves and the development of radiotelegraphy. The vast range of ether vibrations, the transmission of wireless waves, their peculiarities and the general theory of ether waves are discussed. The second part is concerned with some details that make for efficiency, and the third part gives advice and simple rules for various calculations that the amateur constructor needs.

TELEPHONE COMMUNICATION SYSTEMS.

By Royce Gerald Kloeffler. N. Y., Macmillan Co., 1925. (Engineering science series). 284 pp., illus., diagrs., 9 x 6 in., cloth. $4.50.

This book is intended to give the general information needed for a short college course in telephony and also to supply to the worker in telephony a knowledge of matters outside his own particular work. The text is confined to typical present day apparatus and systems.

TRANSFORMERS FOR SINGLE AND MULTIPHASE CURRENTS.

By Gisbert Kapp. 3rd edition revised by Reginald O. Kapp. N. Y., Isaac Pitman & Sons, 1925. 391 pp., illus., diagrs., plates, 9 x 6 in., cloth. $4.50.

In the last edition of this book, issued in 1908, the late Gisbert Kapp spoke of a 3500 kv-a. transformer as "one of the largest made." Today, 60,000 kv-a. transformers are in service. During the interval there has also been great development in construction, insulation and accessories, and many special types for special purposes have been introduced.

In order to keep the book of reasonable size, the reviser has had to confine himself to selected aspects of the subject. In his selection he has kept in mind the needs of students of electrical engineering and of electrical engineers in general rather than those of specialists in transformer design and those interested in the mathematics of the transformer.

The new edition omits some material on the general theory of electricity and on matters no longer of chief importance. More space has been devoted to construction, installation and maintenance. The chapters on design have been revised and new chapters on structural details and on potential and current transformers have been added.

PRINCIPLES OF SOUND SIGNALLING.

By Morris D. Hart and W. Whately Smith. Lond., Constable & Co., 1925. 139 pp., 9 x 6 in., cloth. 12/6. New York, D. Van Nostrand Company.

This book is mainly concerned with the examination of the conditions under which any required acoustical effect may be produced with the minimum expenditure of power. The treatment is theoretical, the object being to identify the factors that affect the efficiency of an acoustical system and to determine the sense in which each operates, so that it will be possible to formulate conditions for an efficient system. The authors discuss in detail the processes of sound production, transmission and reception, and the selection of the most satisfactory combination of these elements.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Philo Generating Station of the Ohio Power Company, by J. A. Bergin, Superintendent of Operation. Illustrated with slides. January 16. Attendance 90.

Boston

Latest Design and Practise in Power Plants, by V. E. Alden, Consolidated Gas, Elec. Lt. & Power Co. Joint meeting with A. S. M. E. January 14. Attendance 180.

Cincinnati

Progress in Design of Steam Turbines, by D. S. Brown, Union Gas and Electric Co., and

The New York-Chicago Telephone Cable, by J. J. Pilloid, American Telephone and Telegraph Co. Illustrated with slides and motion pictures. A demonstration showed effects which occur in the cable. January 14. Attendance 234.

Cleveland

The Engineer in Business, by S. M. Vauclain, Baldwin Locomotive Works. Joint meeting with Association of Iron and Steel Electrical Engineers, A. S. C. E., A. S. M. E., A. I. M. E. and Society of Industrial Engineers. January 21. Attendance 450.

Connecticut

Maintenance of Industrial Equipment, by F. D. Hallock, Westinghouse Elec. & Mfg. Co. January 19. Attendance 85.

The Quest of the Unknown, by Professor H. B. Smith. Illustrated with slides. January 29. Attendance 60.

Denver

Superpower, by T. R. Cuykendall;

The Photo-Electric Cell as a Photometer, by Stuart Ellis, and

Low-Intensity Photometry, by Dr. Reuben Nyswander, University of Denver. January 15. Attendance 36.

Erie

Mechanical Power and the Trend of Civilization, by C. E. Skinner, Westinghouse Elec. & Mfg. Co. January 19. Attendance 65.

Indianapolis-Lafayette

The Design, Manufacture and Test of Extra High Voltage Bushings, by Prof. C. Francis Harding, Purdue University. December 11. Attendance 33.

Recent Interesting Features in the Industrial Heating Field, by W. S. Scott, Westinghouse Elec. & Mfg. Co. February 5. Attendance 39.

Kansas City

The Application of Electricity to the Medical and Surgical Profession, by E. A. Monroe, Rosenthal X-Ray Co., and

The Indictment Against the Electrical Engineer, by B. J. George, Kansas City Power & Light Co. December 7. Attendance 19.

Application of Switching Equipment from Economical Standpoint, by J. H. Starr, Condit Electrical Mfg. Co. Illustrated with slides. January 18. Attendance 34.

Lehigh Valley

Research of Today, the Engineering of Tomorrow, by E. B. Craft, Bell Telephone Laboratories, Inc. January 20. Attendance 118.

Los Angeles

The Local Telephone Problem, by N. R. Powley, Southern California Telephone Co., and

Development and Research by Bell Telephone Laboratories, by M. B. Long, Bell Telephone Laboratories, Inc. Illustrated with stereoptican. A dinner preceded the meeting. February 2. Attendance 133.

Lynn

Inspection trip to the *Boston Globe*. December 12. Attendance 110.

Inspection trip to the South Boston Dry Dock. January 16. Attendance 250.

The Latest Design and Practises in Power Plants, by V. E. Alden, Consolidated Gas, Elec. Lt. & Power Co. Illustrated with slides. January 13. Attendance 68.

Bullets, by Dr. P. P. Quayle, U. S. Bureau of Standards. Illustrated with slides. January 26. Attendance 68.

Madison

Water Power Development with Special Reference to Automatic Generating Stations, by C. V. Seastone, Consulting Engineer. Joint with University of Wisconsin Branch. January 13. Attendance 50.

Mexico

Railroad Electrification, by E. Cox, General Electric Co. January 7. Attendance 31.

Meters, by Scott Lynn, Sangamo Meter Co., and G. Solis Payan. February 4. Attendance 25.

Minnesota

Dinner Dance. Joint with Engineers Society of St. Paul, Engineers Club of Minneapolis and the A. S. M. E. November 21. Attendance 300.

New High Bridge Station, St. Paul, by J. A. Colvin, Northern States Power Co. After the meeting an inspection trip was made through the plant. February 1. Attendance 100.

Philadelphia

Automatic Control Equipment, by Engineers of the Cutler Hammer Mfg. Co., General Electric Co. and Westinghouse Electric & Mfg. Co. Illustrated. January 11. Attendance 165.

Pittsburgh

The Invisible Service of Science, by Dr. M. I. Pupin, National President, A. I. E. E., and

Giant Power, by Dr. Farley Osgood, Past President, A. I. E. E. A dinner preceded the meeting. January 8. Attendance 368.

Pittsfield

The Electron Theory, by Dr. Saul Dushman. January 12. Attendance 80.

Analogies in Mechanics and Electricity, by Professor W. S. Franklin, Mass. Inst. of Tech. In the afternoon preceding this meeting Professor Franklin spoke to 600 ladies who were guests of the Pittsfield Section. January 19. Attendance 300.

Electric Welding, by R. E. Wagner, General Electric Co. The lecture was illustrated by actual welding, samples of various welding processes and by slides. January 26. Attendance 250.

The Pallotrope, Pallophotophone and the Panatrope, by C. A. Hoxie, General Electric Co. February 2. Attendance 520.

Portland

The Transmission of Photographs over Telephone Wires, by M. B. Long, Bell Telephone Laboratories. January 20. Attendance 150.

Rochester

Superpower, by R. M. Searle, Rochester Gas and Electric Corp. January 8. Attendance 100.

San Francisco

Mechanical Appliances in Line Erection, by J. A. Koontz, Great Western Power Co. Illustrated with moving pictures. A dinner preceded the meeting. January 15. Attendance 155.

Electrical Relays and Their Application, by E. H. Bancker, General Electric Co. Illustrated. January 29. Attendance 155.

Schenectady

Harnessing the Tides in the State of Maine, by Dexter Cooper. December 11. Attendance 400.

Mercury-Arc Rectifiers, by D. C. Prince. Illustrated with slides. January 8. Attendance 260.

Seattle

The Plant of the Seattle Cedar Lumber Company, by G. T. Thirsk. Illustrated with slides and moving pictures. November 18. Attendance 135.

The Preliminary Report of the Skagit Engineering Commission, by Major Joseph Jacobs, Chairman, S. B. Hill and W. C. Morse. Discussion followed. Joint meeting with A. S. C. E., A. S. M. E. and A. I. M. E. A dinner preceded the meeting. December 14. Attendance 250.

The Problems Confronting the Port of Portland, by J. H. Polhemus and Robert Kalim. January 20. Attendance 53.

Sharon

Long-Distance Radio, by S. M. Kintner, Westinghouse Electric & Mfg. Co. February 2. Attendance 175.

Southern Virginia

Power Development in Virginia, by J. R. Horsley, Water Power & Development Commission;

Rural Electrification, by Dr. C. E. Seitz;

Flood Control, by Dr. W. A. Nelson, and

The State Port of Hampton Roads, by members of State Port Commission. January 15. Attendance 71.

Spokane

Electrical Transmission of Pictures, by M. B. Long Bell Telephone Laboratories, Inc. January 13. Attendance 60.

Cushman Hydro-Electric Plant, by J. L. Stannard. Illustrated with slides. January 22. Attendance 56.

Syracuse

The Problem of Radio Broadcasting, by C. W. Horn, Westinghouse Electric & Mfg. Co. January 11. Attendance 135.

Better Engineers—Do We Need Them and Can We Get Them?, by W. E. Wickenden, Society for the Promotion of Engineering Education. January 18. Attendance 75.

Toledo

Telephone Projects in Toledo, by V. A. Diggs, Ohio Bell Telephone Co. Illustrated with slides. January 27. Attendance 48.

Toronto

High Voltage Switching and Phase Isolation, by W. R. Huttinger, Electric Power and Equipment Corp. Illustrated with slides. January 15. Attendance 90.

Voltage Regulation of Distribution Systems, by F. F. Ambuhl, Toronto Hydroelectric System. February 5. Attendance 65.

Urbana

Voltage Surges in Transmission Systems, by J. F. Peters, Westinghouse Electric & Mfg. Co. Illustrated. January 20. Attendance 82.

Vancouver

Operation of British Columbia Electric Power System, by J. Teasdale, British Columbia Railway Co. Illustrated with charts, maps, forms, photos, etc. February 2. Attendance 46.

Washington

The Effects of Gases as Used in the Chemical Warfare Service, by Major-General A. A. Fries. Noon-day luncheon meeting. November 24. Attendance 48.

The French Debt Problem, by Dr. H. G. Moulton, Institute of Economics. Joint with A. S. M. E. A dinner preceded the meeting. January 13. Attendance 90.

Ladies Night. February 9. Attendance 102.

Worcester

Application of Electric Heat to the Metal-Working Industry, by W. S. Scott, Westinghouse Electric & Mfg. Co. A dinner preceded the meeting. January 28. Attendance 75.

BRANCH MEETINGS

Alabama Polytechnic Institute

Talk by R. L. Shepherd, *Electrical World*. The following officers were elected: Chairman, C. W. McMullan; Vice-Chairman, J. M. Edwards; Secretary-Treasurer, J. B. Davis; Reporter, W. H. H. Putnam. January 20. Attendance 31.

University of Arizona

Motion picture, entitled "Electric Travelogue," was shown. January 9. Attendance 15.

The Arc Transmitter, by T. L. Carnes. Motion picture, entitled "Something about the Telephone," was shown. January 16. Attendance 18.

Brooklyn Polytechnic Institute

Characteristics of Electromagnetic Clutches, by M. M. Landesberg, student. Illustrated with slides; and

The Organization of the Brooklyn Edison Company, by R. V. Richard. Illustrated with slides. January 14. Attendance 45.

California Institute of Technology

Design and Performance of Auto Start Motors, by E. S. Mendenhall, U. S. Motors Corp. Illustrated with charts. January 8. Attendance 34.

Motion pictures, entitled "An Electric Travelogue," "The Story of an Electric Locomotive," and "Rolling Steel by Electricity," were shown. January 29. Attendance 195.

University of California

Talks by Robert Sibley and Jos. Le Conte. Joint meeting with A. S. M. E. January 20. Attendance 29.

Case School of Applied Science

Lightning Arresters, by K. B. McEachron, General Electric Co. January 12. Attendance 62.

Catholic University of America

Power-Plant Conditions in Florida, by M. J. Idail, Frank Weller Construction Co. January 14. Attendance 30.

University of Cincinnati

Inductive Interference, by Boris Volgovskoy, student. December 17. Attendance 35.

Measurement of Transients for Lightning-Arrester Design, by K. B. McEachron, General Electric Co. January 14. Attendance 65.

Colorado State Agricultural College

Business Meeting. February 8. Attendance 12.

University of Colorado

The Student Training Course of the General Electric Company, by A. S. Anderson. January 6. Attendance 80.

The Work of the Telephone and Associated Companies, by R. B. Bonney, Mountain States Telephone and Telegraph Co. January 23. Attendance 40.

Cooper Union

The Quest of the Unknown, by Professor H. B. Smith, Worcester Polytechnic Institute. February 6. Attendance 120.

Clarkson College of Technology

Talk by Professor Van Housen of the Potsdam Normal School. February 2. Attendance 22.

University of Denver

The Photo-Electric Cell as a Photometer, by Stuart Ellis and Earl Reed, and

Low-Intensity Photometry, by Dr. Reuben Nyswander. Illustrated with slides. January 15. Attendance 48.

Drexel Institute

Correct Amplification for Radio and Public-Address Systems, by G. B. Egge, Bell Telephone Co. Illustrated and demonstrated. January 15. Attendance 64.

University of Florida

Testing the Heat Insulation of "Insulath," by R. D. Ross. January 11. Attendance 8.

Motion picture, entitled "Coal is King," was shown. February 1. Attendance 17.

University of Idaho

Public-Service Commissions, by Marshall Blair; and

Electrical Applications Aboard Ship, by Donald Coons. January 5. Attendance 12.

State University of Iowa

Bakelite, by Frank Wiggins, and

Use of Engineering Library, by Percy Williams. January 13. Attendance 41.

Heaviside

Up-and-Down Movement of the Layer, by S. J. Lambert;

Student Course at General Electric Company, by J. M. Nelson, and

The Instant Heavisidion, by C. E. Woolridge. January 20. Attendance 49.

Business Meeting. The following officers were elected: President, Leon Dimond; Vice-President, L. A. Ware; Secretary-Treasurer, A. C. Boeke. February 3. Attendance 49.

Opportunities for Engineers at Westinghouse, by Fred Homer, and

The Long Span Across the Narrows at Tacoma, by H. G. Cox. February 10. Attendance 43.

University of Kansas

The Radio Conference in Washington, by Professor H. W. Anderson. The following officers were elected: Chairman, K. R. Krehbiel; Vice-Chairman, W. R. Becker; Secretary, K. B. Clark; Treasurer, E. Kietzman. January 7. Attendance 51.

A Trip through the General Electric Company, by C. C. Adams and Ross Parker, General Electric Co. February 4. Attendance 100.

Lafayette College

Oil Circuit Breakers, by R. M. Spurck, General Electric Co. January 14. Attendance 20.

Research and Engineering, by E. B. Craft, Bell Systems Laboratories, Inc. Joint meeting with Engineers Club of the Lehigh Valley and Lehigh Valley Section, A. I. E. E. January 20. Attendance 225.

Massachusetts Institute of Technology

Richmond Station of the Philadelphia Electric Company, by Constantine Bary, student. Illustrated with slides. January 20. Attendance 15.

Michigan State College

Characteristics of Electric Motors, by E. L. Bailey, Cleveland Electric Motor Co. Motion picture, entitled "Mans Conquest of Time," was shown. January 12. Attendance 53.

University of Michigan

Lightning Arresters, by K. B. McEachron, General Electric Co. January 18. Attendance 60.

Engineering School of Milwaukee

A motion picture, entitled "Queen of the Waves," was shown. January 22. Attendance 82.

Missouri School of Mines and Metallurgy

Switchboard Equipment of a Power Station. A motion picture entitled "The Story of the Storage Battery," was also shown. January 14. Attendance 17.

Montana State College

The General Electric Post-Graduate Course in Electrical Engineering, by M. M. Boring, General Electric Co. January 18. Attendance 170.

Opportunities Offered by the Western Electric Company, by C. W. Brotherton, Western Electric Co.; and

Opportunities in the American Telephone and Telegraph Company, by R. B. Bonney, Mountain States Telephone and Telegraph Co. January 25. Attendance 159.

University of Nevada

The Bell Telephone Laboratories, Inc., by M. B. Long. January 26. Attendance 50.

University of North Carolina

Laying a High-Tension Cable, by J. L. Cantwell, Tidewater Power Co. January 18.

The Moncure Steam Plant, by R. F. Stainback. January 28. Attendance 18.

University of Notre Dame

Theory of Rates and System of Metering, by R. H. Anders, Indiana-Michigan Co. January 18. Attendance 30.

Ohio Northern University

Fundamentals, by Professor Berger. January 14. Attendance 17.

Business Meeting. February 4. Attendance 26.

Ohio State University

Various Phases of Engineering, by Professor F. C. Caldwell. January 15. Attendance 110.

University of Oklahoma

Problems Confronting an Engineering Graduate, by W. A. Kitchen, Oklahoma Gas and Electric Co. January 21. Attendance 27.

Oregon Agricultural College

Business Meeting. January 18. Attendance 41.

Business Meeting. February 2. Attendance 35.

Pennsylvania State College

Super-Power, by D. E. Trucksess, J. H. Garbrick, M. S. Longenecker, A. P. Jackel and H. M. Patrick. January 13. Attendance 50.

The Processes of Insulating Copper Wire, by Professor D. L. Markle. A motion picture, entitled "Voice Highways in the Making," was shown. January 27. Attendance 70.

Spectacular Illumination for the Sesquicentennial, by Professor E. B. Staveley. Illustrated with slides; and

Rate Making, by E. Axman. February 10. Attendance 35.

University of Pennsylvania

Fall Dance. November 13. Attendance 100.

Business Meeting. December 18. Attendance 44.

Business Meeting. January 29. Attendance 40.

Business Meeting. February 9. Attendance 45.

University of Pittsburgh

Boiler Tests at Colfax, by R. R. Thorne, student. January 8. Attendance 26

Recent Developments in Boiler Design, by J. H. Crane. January 15. Attendance 30.

The Opportunities Afforded by the Westinghouse Electric & Mfg. Company, by D. S. Templeton. January 22. Attendance 35.

Purdue University

The Lighting Business, by F. H. Talbott, student, and

History of the Incandescent Lamp, by Professor A. N. Topping. Illustrated. February 9. Attendance 70.

Rose Polytechnic Institute

Lightning Arresters and *The Study of High-Speed Transients,* by K. B. McEachron, General Electric Co. January 13. Attendance 47.

Motion picture on Arc Welding was shown. February 11. Attendance 35.

South Dakota State School of Mines

The Development of Electrical Engineering Course, by E. E. Clark;

Valuable Statistics for the Electrical Engineer, by H. M. Johnson; and

Feild for the Electrical Engineers of the Future, by Professor J. O. Kammerman. January 19. Attendance 51.

Stanford University

The Different Grades of Brass and Bronze, by G. T. Piersol, American Brass Co. A motion picture, entitled "Brass—From Mine to Consumer," was shown. January 14. Attendance 60.

Smoker. Joint meeting with A. S. M. E. Mr. C. V. Moroney, West Coast Sugar Refining Co., gave a talk on Organization and Management. Short talks on Engineering were also given by Professor H. J. Ryan and Professor G. H. Marx. February 3. Attendance 100.

Swarthmore College

Steam Generation and Superheat, by W. H. Berry. February 11. Attendance 35.

Syracuse University

The Inverter, by F. A. Lewis. January 6. Attendance 17.

University of Utah

Accepting Engineering Responsibilities, by Lafayette Hanchet, Utah Light and Power Co. Joint meeting with Engineering Society of the University of Utah, A. S. M. E. and A. S. C. E. February 2. Attendance 523.

Virginia Military Institute

Electricity and Its Relation to Communication, by L. S. Griffith, and

Progress in the Aeronautical Industry, by L. H. von Shilling. February 3. Attendance 47.

Virginia Polytechnic Institute

Insulations, by J. S. Lapp, Lapp Insulator Co. January 15. Attendance 66.

Motion pictures, entitled respectively "The Life of Thomas Edison" and "The Revelations of the X-Ray," were shown. January 25. Attendance 300.

Advantages of the Electric over the Steam Road, by F. S. Oliver, student; *The Value of Individual Thought*, by L. B. Proctor, student; *The Duofold Oscillograph*, by H. J. Harris, student, and *Short Wave Transmission*, by E. D. Gray, student. January 27. Attendance 45.

University of Virginia

A motion picture, entitled "A Romance of Rails and Power," was shown. February 1. Attendance 20.

University of Wisconsin

Water-Power Development and Automatic Stations, by Mr. Seastone, Consulting Engineer. Illustrated with slides. January 13. Attendance 45.

Worcester Polytechnic Institute

Hydroelectric Plants of the New England Power System, by W. R. Bell, New England Power Co. Illustrated with slides. January 20. Attendance 42.

University of Wyoming

Evolution of the Telephone, by I. W. Bond, Mountain States Telephone and Telegraph Exchange. January 28. Attendance 16.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, particularly interested and experienced in relay and breaker applications and protection problems on larger power systems. Location, Pennsylvania. R-8506.

ENGINEER, with experience in design and installation of power station switching equipment. Must be able to supervise and make schematic diagrams of station layout drawings. Not a drafting job, but requires design ability. Permanent. Opportunity. Apply by letter. Location, Pennsylvania. R-8530-C.

ENGINEER, technically trained for investigation of raw materials. Young man who possesses native interest in work of this nature preferred. Ability to thoroughly analyze problems pertaining to raw materials is essential. Apply by letter, stating qualifications, age, education and salary expected. Location, Illinois. R-8535-C.

ENGINEER, technically trained, with some knowledge of accounting, must write good English and be qualified for analytical work in cost and rate department. Apply by letter and enclose photograph. Location, New York. R 8722.

ENGINEER, over 35, the executive and financial experience, for general management in electrical contracting firm. Must be capable financier. May take financial interest. Salary nominal but with participation in profits. Location, New York. R-7874.

MEN AVAILABLE

GRADUATE M. E. and E. E., age 36, wide range of engineering experience, and especially well qualified in public utility electrical engineering, power plants, substations and lines. Highly trained technically, but prefers a position requiring a combination of technical and executive ability. Now employed. B-5842.

ELECTRICAL ENGINEER, Canadian, married, age 46. Graduate McGill University. Long experience electrical and mechanical sales, also operation and construction. Desires position management or sales but consider operation or construction. Absolutely reliable, active, capable handling men. Best references. C-837.

ELECTRICAL ENGINEERING TEACHER desires research position in New York City. Salary required $4000 per annum. Graduate 1917, master's degree 1923. Four years' teaching of electrical engineering subjects, two years with public utility. Lieutenant Signal Corps U. S. B-82.

ENGINEERING EXECUTIVE, age 35, married, graduate electrical engineer. At present assistant to chief executive well known electric utility, desires executive position, department head or local manager with holding company. Present duties consist of handling budget, construction orders, scheduling, expediting and following major construction, as well as miscellaneous management, personnel problems. Capable design engineer with consulting experience. B-754.

ELECTRICAL TECHNICAL GRADUATE, age 36, married, eighteen years' experience electrical design, construction, operation ofc entral stations, substations and transmission lines. Responsible experience specifications and purchase negotiations. Capable of handling the electrical phase of central stations from inception to commercial operation. Design, construction or operation acceptable. Location immaterial but minimum travel desirable. B-2511.

YOUNG MAN, age 27, E E. and A. M. with several years' teaching and some radio laboratory experience, would like teaching or laboratory position. Work in physics or electricity desired. Available on short notice. B-3411.

ELECTRICAL ENGINEER, age 39, sixteen years' supervision design, installation, maintenance, operation various kinds electrical work large

railroad; lighting, motors, distribution, transmission (including submarine cables), substations, power plant electrical apparatus, meter surveys, etc. Desires connection with industrial in charge electrical activities, utility, or electrical sales work. Central or South location. Salary $4200 up, depending on conditions and location. B-9772.

ELECTRICAL ENGINEER, age 38, married, eight years' experience in design and drafting, checking of electrical stations and substations, two years of squad leader assistant, four years installation and operation of storage batteries, rotary converters, transformers, generators, etc. Speaks' Spanish and French. Available on two weeks' notice. C-403.

ELECTRICAL ENGINEER, age 37, desires position as power or plant engineer with large industrial concern. Fifteen years' experience industrial plant layout, installation, maintenance. Thorough knowledge all plant problems including power application, industrial lighting, heating, ventilation and air conditioning. Available immediately. Preferable location, New England States, but will consider other locations. B-5326.

CHIEF-SUPERVISING OR CONSULTING ENGINEER, thirty-five years mechanical and electrical engineering, electric railways, public utilities, engineering and industrial companies, planning and execution several steam railroad electrifications, rehabilitation steam plants, chemical process development, public utility valuations and economic reports, electrolysis research, power transmission. Railway or industrial engineering preferred. Available soon. Employed. B-3246.

ELECTRICAL GRADUATE, of Purdue University, age 28, single, one year General Electric Company test and one year industrial control engineering with General Electric Company. Two years' control experience with large light and power company. Finished Alexander Hamilton Institute Modern Business Course. Desires position in control engineering or sales. Salary $225 a month. C-890.

ELECTRICAL CONSTRUCTION ENGINEER, age 38, wide experience electrical construction, operation. Ten years construction, eight years general superintendent of railways, power plants, substations, general utility work. At present on contract for electrical construction, foreign service. Prefers connection large electrical concern as representative in Latin countries. Technical training. Speaks Spanish, English. Available after six months. C-886.

ELECTRICAL ENGINEER, graduate of Purdue University, age 31, three years General Electric test and engineering departments, three years in substation design with large public utility company. Desires position with consulting engineer, public utility or manufacturing company. Salary $2500. Available on reasonable notice. C-920.

ELECTRICAL ENGINEERING GRADUATE, five years out of college, having had experience in testing, switchboard engineering, indoor and outdoor substation layouts, transmission and distribution. Desires position in engineering work. B-8622.

ELECTRICAL ENGINEER, age 28, technical graduate, desires position with public utility, preferably in the Middlewest. One and one-half years G. E. test, four years' distribution engineering experience with public utility in East. Available on two weeks' notice. B-9040.

INDUSTRIAL ELECTRICAL ENGINEER, wide experience design, installation maintenance of electrification as applied to industrial plants, including power houses, substations, high and low voltage distribution and general motor and control applications. Desires position with large industrial concern as electrical engineer, or power superintendent. University graduate, 36, married. Available on reasonable notice to present employer. B-9113.

WANTED. Position as general superintendent, or district manager of public utility by graduate electrical engineer with ten years' varied experience; construction, maintenance, operation; power plants, substations, transmission and distribution systems, commercial and rate work. B-9480.

ENGINEERING EXECUTIVE, age 39, varied experience, technical graduate. Was machinist, inspector, foreman, engineer, superintendent in charge of 700 men. With present concern sixteen years. Had charge production, shop equipment. Designed, installed numerous labor saving devices, machine tools. Expert on application electric motors, other electric devices for special machinery. Desires sales engineering or executive position. B-8153.

ELECTRICAL ENGINEER, age 28, single, wishes position as executive or assistant electrical engineer. Good character, pleasing personality. German, English, French. Familiar theory and practice electrical and scientific measurements, electrical instruments, meters, relays. Transmission, distribution, protection, dielectric circuits. Three years research laboratory, two years designing. Location, preferably New York. Minimum salary $3500. Available on month s notice. C-930.

GRADUATE ELECTRICAL ENGINEER, 30, single, experience operation, maintenance power plants, substation design, construction work. Calculation of generators motors, transformers for special purposes. Chief of testing department. Specialties: rectifiers, mercury vapour (Brown Boveri Company) for high power, thermionic rectifiers for high voltages. Desires permanent connection public utility, or electrical consulting organization. Available on month s notice. C-924.

EXECUTIVE OR MANAGER, age 43, married, eighteen years' electrical experience: successful in organizing and directing international engineering service. Qualified for and desires position requiring greater responsibility. Salary $10,000. Any location, although slight preference South or Middlewest. B-122.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER with ten years' experience in electrical testing, drafting and designing, also two years' shop experience as department head. Desires permanent position along above lines or similar at reasonable starting salary with good future. Age 37, married. Location preferred, Ohio. C-374.

EDITOR, age 31, married, university journalistic education, and twelve years' practical experience as associate editor, co-publisher-editor, and managing editor of radio and technical publications, including trade paper. Editor and author of numerous technical papers, magazine articles and books. Available within three weeks. Location, New York. C-829.

ENGINEER, age 37, married, over fifteen years' experience industrial and power plant organization, design and operation, transmission, group substations, layout, equipment, valuation, costs. Has some financial backing to interest in a conservative utility Full time salary $7500. Location in or about New York, and the East. B-8863.

ASSISTANT ENGINEER, age 24, single, B. X. degree in electrical engineering, two years as assistant engineer with valuation department of California State Railroad Commission. Desires work with consulting engineer, or manufacturer in power, or industrial electrical field. Location, Pacific Coast. Available immediately. C869 1-A-42.

VALUATION ENGINEER specializing in reports, inventories and appraisals of public utilities and industrial plants. Formerly with New York State Public Service Commission. Good working knowledge of Spanish. Available on two weeks' notice. Salary $300 per month and expenses. B-9636.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

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FELLOW ELECTED FEBRUARY 9, 1926

HELPBRINGER, J. NELSON, Gen. Supt., Staten Island Edison Co., Staten Island, N. Y.

TRANSFERRED TO GRADE OF FELLOW FEBRUARY 9, 1926

BETTIS, ALEXANDER E., Vice-President, Kansas City Power & Light Co., Kansas City, Mo.

CURTIS, HARVEY L., Senior Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

DANN, WALTER M., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.

HOBART, K. E., Superintendent Overhead Lines, Commonwealth Edison Co., Chicago, Ill.

PRINCE, DAVID C., Research Engineer, General Electric Co., Schenectady, N. Y.

TRANSFERRED TO GRADE OF MEMBER FEBRUARY 9, 1926

EWENS, W. SYDNEY, District Manager, Alfred Collyer & Co., Toronto, Ont., Can.

HAZELTINE, HAROLD L., Engineer of Insulation, Sterling Varnish Co., Pittsburgh, Pa.

JOHNSON, EDWARD J., Member of Technical Staff, Bell Telephone Laboratories, New York., N. Y.

MEYER, A. A., Assistant General Superintendent, Detroit Edison Co., Detroit, Mich.

NOSS, MARSENA A., Chief Engineer, International Telepost Co., New York.

ROBINSON, BLIGHT S., Engineer, R. W. Cramer & Co., Inc., New York.

SHEPARD, ROBERT B., Electrical Engineer, Underwriters' Laboratories, New York.

SILSBEE, FRANCIS B., Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

SINGLETON, L. D., Senior Field Electrical Engineer, Braden Copper Co., Rancagua, Chile.

SMITH, EVERETT H., Supervising Equipment Design Engineer, Bell Telephone Laboratories, New York.

SNIDER, GEORGE E., Chief Electrical Engineer, Ohio Public Service Co., Cleveland, O.

STEVENS, ALEXANDER C., Electrical Engineer, General Electric Co., Schenectady, N. Y.

WEIGHT, JOHN W., Head, Industrial Truck and Locomotive Dept., Electric Storage Battery Co., New York.

WILKINS, ROY, Assistant Engineer, Dept. of Hydro-Elec. & Transmission Engg., Pacific Gas & Electric Co., San Francisco, Calif.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held February 5, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

FLEAGER, CLARENCE E., Chief Engineer, Pacific Telephone & Telegraph Co., San Francisco, Calif.

To Grade of Member

CLARK, JOHN A., Research Engineer, Weston Electrical Instrument Corp., Newark, N. J.

CUNNINGHAM, R. E., Operating Electrical Engineer, Southern California Edison Co., Los Angeles, Calif.

DAVIES, HAROLD C., Station Section, Elec. Engineering Dept., Hydro-Electric Power Commission, Toronto, Ontario.

FIELDS, ERNEST S., Asst. Electrical Engineer, Union Gas & Electric Co., Cincinnati, O.

GRAHAM, FRANK B., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

HALE, WILLIAM K., State Electrical Engineer, Mountain States Tel. & Tel. Co., Denver, Colo

HARRIS, IRVING C., Consulting Engineer, Cone and Harris, Los Angeles, Calif.

HEALY, EDWIN S., Transmission Engineer, Electric Bond & Share Co., New York, N. Y.

HINSON, N. B., System Planning Engineer, Southern California Edison Co., Los Angeles, Calif.

HORN, A. F. E., Manager, General Electric Co., Washington, D. C.

JOHNSON, JAMES A., Works Manager, Canadian Crocker Wheeler Co., Ltd., St. Catherines, Ont.

JONES, ARTHUR L., District Engineer, General Electric Co., Denver, Colo.

PUBLOW, CEDRIC F., Asst. Station Engineer, Hydro-Electric Power Commission, Toronto, Ont.

SIMPSON, WILLIAM L., Division Engineer, Postal Telegraph-Cable Co., Chicago, Ill.

SOULE, WILLIAM H., Electrical Superintendent, Mond Nickel Co., Coniston, Ont.

STARR, JAMES H., District Engineer, Condit Electrical Manufacturing Co., St. Louis, Mo.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1926.

Abbott, H. H., American Tel. & Tel. Co., New York, N. Y.

Amson, R. I., United Electric Light & Power Co., New York, N. Y.

Axon, W. R., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.

Axtell, H. B., American Tel. & Tel. Co., St. Louis, Mo.
Baker, A. W., American Electric Railway Association, New York, N. Y.
Baker, H. D., Sales Engineer, 602 Ford Bldg., Detroit, Mich.
Baker, H. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Barden, W. S., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Barnard, G. H., (Member), Electro-Dynamic Co., Bayonne, N. J.
Barton, H. P. S., Jr., Postal Telegraph-Cable Co., New York, N. Y.
Beach, W. C., Bell Telephone Laboratories, Inc., New York, N. Y.
Beck, A. D., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio
Bellis, A. P. S., John A. Roebling's Sons Co., Trenton, N. J.
Bingel, G. H., C. H. Stevens Co., New York, N. Y.
Bird, T. O., Line Material Co., South Milwaukee, Wis.
Black, H. M., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Blakey, L. M., Hartford Accident & Indemnity Co., Hartford, Conn.
Blois, R. K., (Member), Cons. Mining & Smelting Co. of Can., Ltd., Trail, B. C.
Bloser, W. C., Thomas E. Murray & Co., New York, N. Y.
Bonn, N. E., Leeds & Northrup Co., Philadelphia, Pa.
Bonner, W. F., Public Service Electric & Gas Co., Irvington, N. J.
Boolos, S. G., Brooklyn Edison Co., Brooklyn, N. Y.
Brake, W. J., Light & Power Dept., City of Regina, Regina, Sask., Can.
Braue, C. A., Brooklyn Edison Co., Brooklyn, N. Y.
Bressner, J., Pratt Institute, Brooklyn, N. Y.
Brice, W. A., Illinois Bell Telephone Co., Chicago, Ill.
Brown, E. C., Hartford Electric Light Co., Hartford, Conn.
Brown, E. C., E. C. Brown Co., Boston, Mass. (Applicant for re-election.)
Browne, W. H., 3rd, McCollom Geological Explorations Corp., Chevy Chase, D. C.
Burbidge, L., R. A. Lister & Co., Inc., New York, N. Y.
Burchill, G. H., Canadian General Electric Co., Peterborough, Ont., Can.
Burri, J. J., (Member), Staten Island Edison Co., Staten Island, N. Y.
Buswell, J. F., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Caldwell, E., American Rolling Mill Co., Ashland, Ky.
Camilli, G., General Electric Co., Pittsfield, Mass.
Carey, F. K., Llewellyn Iron Works, Los Angeles, Calif.
Cartland, F. W., Western State Normal School, Kalamazoo, Mich.
Case, J. W., General Electric Co., Schenectady, N. Y.
Caster, J. H., (Member), Hydro-Elec. Pr. Comm. of Ontario, Toronto, Ont., Can.
Castro, L., Jr., General Electric Co., Schenectady, N. Y.
Centeno, J. G., Brooklyn Edison Co., Brooklyn, N. Y.
Charles, D. M., Reliance Elec. & Engineering Co., Cleveland, Ohio
Cheney, M. C., Rockbestos Products Corp., New Haven, Conn.
Chun, H. H., Premier Electric Co., Chicago, Ill.
Clarke, S. O., United Electric Light & Power Co., New York, N. Y.
Coffin, L., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Cox, B. C., Carter Electric Co., Atlanta, Ga.
Craig, P. H., University of Cincinnati, Cincinnati, Ohio
Cresson, G. V., Public Service Corp. of N. J., Newark, N. J.
Crist, J. A., New York Telephone Co., New York, N. Y.
Crotty, H. F., General Electric Co., West Lynn, Mass.
Cummings, A. E., New York Telephone Co., New York, N. Y.
Daniel, T. A., Western Electric Co., Chicago, Ill.
Davies, W. B., Saskatchewan Telephone System, Saskatchewan, Can.
Dawson, L. L., Erie Railroad Co., Jersey City, N. J.
de Kay, R. D., Bell Telephone Laboratories, Inc., New York, N. Y.
de la Garrigue, J. L., School of Engg. of Milwaukee, Milwaukee, Wis.
Demerec, Mary Z., New York Telephone Co., New York, N. Y.
de Polac, L. C., Westinghouse Elec. & Mfg. Co., New York, N. Y.
De Tar, D. R., General Electric Co., Schenectady, N. Y.
Dettwiller, C. J., Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.
Dickinson, R. B., Duke Price Power Co., Ltd., Isle Maligne, Lake St. John, P. Q.
Dolton, E. G., (Member), Div. of Architecture & Construction, State of New Jersey, Trenton, N. J.
Donnelly, J. F., Pennsylvania State Sanatorium, S. Mountain, Mont Alto, Pa.
Dua, M. S., Pacific Gas & Electric Co., San Francisco, Calif.
Duvander, B. F. H., Pacific Gas & Electric Co., San Francisco, Calif.
Egli, J., American Brown Boveri Electric Corp., Camden, N. J.
Ellsworth, F. P., Western Electric Co., Inc., New York, N. Y.
Fauerbach, W. F., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Feldman, J. J., Westinghouse Elec. & Mfg. Co., Brooklyn, N. Y.
Forbes, A. H., Pennsylvania State College, State College, Pa.
Franz, A. S., Postal Telegraph-Cable Co., New York, N. Y.
Furbish, C. T., Warren Foundry & Pipe Co., Phillipsburg, N. J.
Garrison, J. D., W. A. Beile & Co., Chicago, Ill.
Gedge, W. J., New York Telephone Co., New York, N. Y.
Goard, L. C., (Member), The Ohio Public Service Co., Ashland, Ohio
Godfrey, J. H., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Golikoff, A., "Ural-Platinum Trust," New York, N. Y.
Goss, R. C., Ohio Brass Co., Philadelphia, Pa.
Graybrook, H. W., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Griffin, T. J., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Gunnarson, G. A., Electric Bond & Share Co., New York, N. Y.
Hackbush, R. A., Canadian Westinghouse Co., Ltd., Toronto, Ont., Can. (Applicant for re-election.)
Haga, J., Brooklyn Edison Co., Brooklyn, N. Y.
Hahn, W. C., General Electric Co., Chicago, Ill.
Hanstein, H. B., Brooklyn Edison Co., Brooklyn, N. Y.
Hare, J. G., East York Hydro-Electric Commission, Toronto, Ont., Can.
Harte, J. A., Dept. of Plant & Structures, New York, N. Y.
Henritze, R. J., Westinghouse Elec. & Mfg. Co., New York, N. Y. (Applicant for re-election.)
Hewlett, R. C., Pratt Institute, Brooklyn, N. Y.
Hickcox, T. W., Pratt Institute, Brooklyn, N. Y.
Hill, G. J., Western Electric Co., Inc., Washington, D. C.
Holleman, E. M., Radio Salesman, Germains, Los Angeles, Calif.
Houck, F. J., Erie Railroad Co., Jersey City, N. J.
Howlett, P. W., Sangamo Elec. Co. of Canada, Ltd., Toronto, Ont., Can.
Hughes, A. A., Radio Corp. of America, Rocky Point, L. I., N. Y.
Hunter, R. J., Brooklyn Edison Co., Brooklyn, N. Y.
Inglis, J. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Jaczko, J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Jones, H. P., Philadelphia Electric Co., Philadelphia, Pa.
Jones, R. W., Consumers Power Co., Flint, Mich.
Judge, F. G., (Member), Pierce Electric Co., Tampa, Fla.
Kaneb, B. M., American Steel & Wire Co., Worcester, Mass.
Keller, E. J., Roxborough High School, Philadelphia, Pa.
Kelly, C. R., K & K Electr Co., Perth Amboy, N. J.
Kenah, R. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kinckiner, R. A., Philadelphia Electric Co., Philadelphia, Pa.
Kinsella, R. H. F., Brooklyn Edison Co., Brooklyn, N. Y.
Krauss, R. A., Counties Gas & Electric Co., Norristown, Pa.
Kray, J. F., Bell Telephone Co. of Pa., Philadelphia, Pa.
Krueger, R. A., Wisconsin Valley Electric Co., Wausau, Wis.
Lambert, A. W., Pacific Tel. & Tel. Co., San Francisco, Calif.
Lederhause, H. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Leeson, G. E., Saskatchewan Gov't. Telephones, Yorkton, Sask., Can.
Leonard, E. M., Pittsburgh Transformer Co., Pittsburgh, Pa.
Levy, M. L., Stromberg-Carlson Tel. Co., Rochester, N. Y.
Lewis, H. G., (Member), Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Lewis, J. G., Potomac Edison Co., Cumberland, Md.
Leyden, A. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Lippincott, C. D., Adirondack Power & Light Corp., Schenectady, N. Y.
Lyster, M. S., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Lippman, W. O., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Lorje, H., Empire Companies, Bartlesville, Okla.
Low, H. M., Andes Copper Mining Co., New York, N. Y.
Mahl, J. A., Pacific Gas & Electric Co., San Francisco, Calif.
Martingell, L. W., Cansfield Electric Works, Toronto, Ont., Can.
Mathews, E. C., U. S. Shipping Board, Los Angeles, Calif.
McCormick, H. V., C. L. Stevens Co., Boston, Mass.
McKearney, J. J., Postal Telegraph-Cable Co., New York, N. Y.
Mendenhall, H. E., California Institute of Technology, Pasadena, Calif.
Michael, J. H., Allis-Chalmers Mfg. Co., West Allis, Wis.
Miller, N. O. C., Schwall Electric Works, Stockton, Calif.
Modlin, W. G., Public Service Electric & Gas Co., Newark, N. J.
Moes, G., Simplex Wire & Cable Co., Cambridge, Mass.
Molmoe, R., Knoxville Power & Light Co., Knoxville, Tenn.
Morgan, R. A., R. A. Turner & Co., Springfield, Mass.
Moxon, A. W., Pratt Institute, Brooklyn, N. Y.
Nakamoto, H., Public Service Electric & Gas Co., Newark, N. J.
Nicholson, R. F., Catholic University of America, Brookland, D. C.

Norstrand, C. O., New Amsterdam Casualty Co., New York, N. Y.
Norwig, J., Jr., United Electric Light & Power Co., New York, N. Y.
O'Brien, E. C., J. J. O'Brien & Son, New York, N. Y.
Orcutt, H. S., United Electric Light & Power Co., New York, N. Y.
Osborn, A. L., S. New England Telephone Co., New London, Conn.
Osburn, M. P., Hydro-Elec. Pr. Commission of Ontario, Toronto, Ont., Can.
Ouellette, E. F., Ford Motor Co., Detroit, Mich.
Pagano, L. A., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Painter, C. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Patrick, P. D., Philadelphia Electric Co., Philadelphia, Pa.
Paul, H. F., The Electric Controller & Mfg. Co., Cleveland, Ohio
Peters, A. W., Shawinigan Water & Power Co., Montreal, Que., Can.
Peterson, J. R., Western Union Telegraph Co., San Francisco, Calif.
Pike, A. T., Western Electric Co., Inc., New York, N. Y.
Pike, W. K., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Pollard, A. H., International General Electric Co., Schenectady, N. Y.
Purucker, R. E., University of Wisconsin, Madison, Wis.
Quededo S. A., Westinghouse Elec. International Co., Havana, Cuba
Rathgeber, M. D., Potomac Electric Co., Washington, D. C.
Ricks, H. M., Weston Electrical Instrument Corp., New York, N. Y.
Riddle, W. L., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Robb, F. H., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Robinson, J. W., Leeds & Northrup Co., Philadelphia, Pa.
Rockefeller, H. C., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Ross, R. W., Leeds & Northrup Co., Philadelphia, Pa.
Rubel, W. L., Memco Engineering & Manufacturing Co., Long Island City, N. Y.
Runcie, A. A., Lundin Electric & Machine Co., Boston, Mass.
Sampson, G. H., Nashua Manufacturing Co., Nashua, N. H.
Saurwein, V. E., Ohio Bell Telephone Co., Cleveland, Ohio
Schmeltzer, C. F., Western Electric Co., Inc., Cicero, Ill.
Schmidt, H., U. S. E. M. Co., New York, N. Y.
Scholz, C. E., (Member), Federal Telegraph Co., Palo Alto, Calif.
Schroeder, R. F., Brooklyn Edison Co., Brooklyn, N. Y.
Seaward, E. S., Gould Storage Battery Co., Depew, N. Y.
Shaw, R. H., Tampa Electric Co., Tampa, Fla.
Singer, R. H., The Union Gas & Elec. Co., Cincinnati, Ohio
Skinner, D. C., Youngstown Sheet & Tube Co., Youngstown, Ohio
Smith, A. W. S., Hydro-Electric Power Commission of Ontario, Toronto, Ont., Can.
Smith, E. C., Russell Mfg. Co., Middletown, Conn.
Spann, R. D., Capt., Coast Artillery Corps, U. S. A., New York, N. Y.
Spellmire, W. B., (Member), General Electric Co., Pittsburgh, Pa. (for re-election)
Stack, S. S., General Electric Co., Schenectady, N. Y.
Strymoe, J. E., Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Strod, A. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Stuart, B. O., 3824 Waldo Ave., New York, N. Y.
Stufft, J. W., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Suppers, H. G., John A. Roebling's Sons Co., Trenton, N. J.
Sutton, C. A., Bethelhem Steel Corp., Bethlehem, Pa.
Swazey, H. A., Philadelphia Electric Co., Philadelphia, Pa.
Taylor, S. B., Reliance Electric & Engineering Co., Cleveland, Ohio
Teker, L., Leeds & Northrup Co., Philadelphia, Pa.
Thomson, O. R., (Member), Hydro-Electric Power Commission of Ontario, Belleville, Ont., Can.
Toetz, F. W., Emsco Derrick & Equipment Co., Los Angeles, Calif.
Trachtman, H., Bronx Electric Co., Bronx, New York, N. Y.
Turner, C. M., Dept. of Public Works, State of Washington, Olympia, Wash.
Upp, J. W., Jr., (Member), Ohio Brass Co., Mansfield, Ohio
Vaden, T. H., Alabama Power Co., Anniston, Ala.
von Sneidern, A. A., General Electric Co., Schenectady, N. Y.
Wadlek, J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Waller, J. L., Rome Wire Co., Rome, N. Y.
Webber, C. W., 410 W. 43rd St., Kansas City, Mo.
Weckworth, H. F., Northern Indiana Gas & Electric Co., Hammond, Ind.
Weiner, L., Anaconda Sales Co., New York, N. Y.
Weitzman, H. A., with Edward J. Cheney, New York, N. Y.
Welsh, W. E., Penn. Power & Light Co., Ashley, Pa.
Wendler, H. J., Public Service Production Co., Newark, N. J.
White, H. G., Mancha Storage Battery Locomotive Co., St. Louis, Mo.
Wilfley, V. B., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Wilkinson, T. A., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Williams, F. R., Dixie Power Co., Cedar City, Utah
Williamson, R. B., General Railway Signal Co., Rochester, N. Y.
Wittenberg, A. J., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Wolf, A., Philadelphia Electric Co., Philadelphia, Pa.
Woodward, J. E., Standard Oil Co. of N. J., Bayway Refinery, Elizabeth, N. J.
Wurst, L. L., Public Service Co. of No. Illinois, Kankakee, Ill.
Wyatt, R. M., Western Electric Co., Inc., New York, N. Y.
Young, T. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Yount, L. E., Western Radio, Inc., Los Angeles, Calif.
Zellweger, F., Schweitzer & Conrad, Inc., Chicago, Ill.
Zimmermann, A. G., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Total 217

Foreign

Beaumont, L., Shanghai Municipal Electricity Dept., Shanghai, China
Brown, F. W., Public Works Dept., Mangahao Pr. Sta., Shannon, N. Z.
Cangucu, O. G., Paulista Railway, Sao Paula, Brazil, S. A.
Coulson, W., The Electrical Installation & Repairing Co., Belfast, Ireland
Dennis, W. E., Bombay Baroda & Central India Railway, Bombay, India
Deronne, M., S. F. de M. d'e. A. Tekka, Gopeng, Perak, F. M. States
Dunham, D., Southland Electric Power Board, Invercargill, N. Zealand
Forrest, F., 14 Dale End, Birmingham, Eng.
Garnett, H. S., Messrs. Merz & McLellan, Westminster, London, Eng.
Heffelman, M. C., Chile Exploration Co., Chuquicamata, Chile, S. A.
Liebert, S. F. E., Chief Elec. Engineer's Branch, Postmaster-General's Dept., Melbourne, Aust.
Mackay, A., Ferranti, Ltd., Hollinwood, Lancashire, Eng.
Matel,, M. T. H., A. B. Bergslagens Gemensamma, Kraftforvaltning, Vasteras, Sweden
McLauchlan, C. D., (Member), Telegraphs & Country Telephones, Perth, W. Australia
Pistorius, L. H., British Thomson-Houston Co., Ltd., Rugby, Eng.
Pitt, F. E., S. Wales Electrical Power Distribution Co., Cwmbran, Monmouth Co., Eng.
Ponday, G. P., Chaba, Simla Municipality Pr. Station, Simla Dist., Punjab, India
Raju, M. G., (Member), The Andhra Elec. Lighting Scheme, Guntur, S. India
Riseley, R. L., Chile Exploration Co., Chuquicamata, Chile, S. A.
Roth, A., The Ateleirs de Constructions electriques de Delle., Lyon-Villeurcanne, France
Steukvist, K. E., Allmanna Svenska Electric Co., Ludvika, Sweden
Thompson, S., Westinghouse Elec. International Co., Johannesburg, S. Africa
Tsou, T. Y,, Anderson & Meyer Co., Shanghai, China
Total 23

STUDENTS ENROLLED

Abbott, Frank R., Stanford Univ.
Adair, George P., Texas A. & M. College
Albert, William H., Jr., Cooper Union
Apsley, William J. E., Johns Hopkins Univ.
Ashby, Rulon S., Univ. of Delaware
Ball, Roderick, Worcester Poly. Inst.
Bailey, John W., Cornell Univ.
Baumgartner, Rupert P., Missouri School of Mines
Beckwith, Sterling, Stanford Univ.
Behrens, Chester C., Ohio State Univ.
Bell, Donald S., Cooper Union
Bell, Theron S., Rose Poly. Inst.
Bergmann, J. S., Northeastern Univ.
Berry, Robert U., Mass. Inst. of Tech.
Black, John B., Georgia Tech.
Blackstone, Harry W., Northeastern Univ.
Blatz, Irving H., Brooklyn Poly. Inst.
Bogert, William M., Cooper Union
Bradbury, Lauris J., Northeastern Univ.
Briggs, Rufus L., Mass. Inst. of Technology
Brittingham, Harry H., Missouri School of Mines
Brooking, James M., Virginia Poly. Inst.
Brooks, Norman M., Va. Poly. Inst.
Brown, Otis, Colorado Univ.
Byrne, John F., Ohio State Univ.
Cacciola, Joseph, Milwaukee School of Engg.
Campbell, Charles S., Univ. of Colorado
Campbell, Stuart M., Univ. of Michigan
Caris, Darl F., Univ. of Michigan
Carpenter, Donald W., Northeastern Univ.
Carroll, William J., Univ. of Delaware
Carter, Earle H., Univ. of Colorado
Childers, Joseph W., Univ. of Idaho
Clark, Howard D., Cornell Univ.
Coleman, John B., Mass. Inst. of Tech.
Constantino, Angelo J., Cooper Union
Cramer, Harold, Cooper Union
Crawford, James O., Mass. Inst. of Technology
Crumbaugh, Daniel, Mo. School of Mines
Dalzelle, Robert C., Johns Hopkins Univ.
D'Aniello, John P., Brooklyn Poly. Inst.
Davis, Darrell M., Texas A. & M. College
Davis, Enoch A., Jr., Virginia Poly. Inst.
Day, Charlie B., Clemson College
Dill, Robert C., Clemson College
Ditsch, John F., Newark Technical School
Doat, Irvin T., Ohio State Univ.
Dunn, Raymond E., Univ. of Michigan
Eckart, Kurt G., Cooper Union
Ellis, Stanley W., Northeastern Univ.
Evangelides, Christopher E., Brooklyn Poly. Inst.
Evans, Norman H., Carnegie Inst. of Tech.
Fankuchen, Isidore, Cooper Union
Fife, Samuel, Univ. of Cincinnati

Foster, Edwin L., Ohio State Univ.
Garrett, James E., Virginia Poly. Inst.
Gibson, Floyd L., Virginia Poly. Inst.
Glover, Arthur B., Univ. of Missouri
Grace, William J., Rice Institute
Graves, Edward, Univ. of Cincinnati
Green, Alfred R., Virginia Poly. Inst.
Gullion, Guy, Univ. of Colorado
Hanckel, John S., Washington & Lee Univ.
Harrelson, Ottis M., Clemson College
Helprin, Sydney, Cooper Union
Henderson, Edward H., Ohio Univ.
Herbert, Loren P., Ohio University
Hinkston, Donald R., California Inst. of Tech.
Hogan, Benjamin W., Virginia Poly. Inst.
Hollingsworth, Clarence T., Ohio University
Hoskin, Benjamin P., Iowa State College
Hovick, Robert L., Univ. of Wyoming
Hughes, John G., Virginia Poly. Inst.
Jain, Everett W., Univ. of Colorado
Jarvis, Henry O., Johns Hopkins Univ.
Johantges, Frank A., Purdue Univ.
Judson, Walter G., Cooper Union
Kalb, Robert M., Ohio State Univ.
Kelley, Edward F., Rose Poly. Inst.
Kelley, James B., Marquette Univ.
Ketay, Morris F., Cooper Union
Kimpton, Charles D., Univ. of Mich.
Knowles, Harold E., Univ. of Mich.
Koontz, Lawrence F., Virginia Poly. Inst.
Kritt, Raymond B., Univ. of Cincinnati
Kuenne, Kuno R., Milwaukee School of Engg.
Kunkel, Joseph M., Virginia Poly. Inst.
Lafore, Robert W., Swarthmore College
Lambert, Standish J., State Univ. of Iowa
LeBaron, George I., Carnegie Inst. of Technology
Levin, Morris J., Univ. of Cincinnati,
Liacos, Stavros J., Cooper Union
Light, G. Gordon, Virginia Poly. Inst.
Lindsay, Andrew W., Washington & Lee Univ.
Lo, Hsiao C., Purdue Univ.
Lord, Samuel E., Jr., Northeastern Univ.
Lorraine, Richard, Univ. of Colorado
Lubkin, Samuel, Cooper Union
Lusk, Robert R., Missouri School of Mines
Lynch, Edwin L., Marquette Univ.
Marks, George F., Brooklyn Poly. Inst.
Martin, Samuel M., Virginia Poly. Inst.
Masonick, Louis F., Lewis Inst.
Matthias, Lynn H., Univ. of Wisconsin
Metcalf, William L., Mo. School of Mines
Mikula, Charley R., Ohio Univ.
Miller, Carlyle W., Cooper Union
Miller, Frederic H., Cooper Union
Miller, Max I., Virginia Poly. Inst.
Morgan, Frank, Ohio Univ.
Morrison, Howard, Worcester Poly. Inst.
Murch, John A., Univ. of Maine
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St. Auburn, Wilford M., Cornell Univ.
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Stephens, Donald L., Virginia Poly. Inst.
Stocker, C. Paul, Ohio Univ.
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See the January issue for the latest published list. The Institute now has 51 Sections and 86 Branches.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Electricity on Battle Ships.—Bulletin GEA-306, 12 pp., entitled "The Electric Fleet." Describes the electrified first line battle ships and airplane carriers in the United States Navy. The General Electric Company, Schenectady, N. Y.

Machine Vibration Isolation.—Bulletin, 12 pp., entitled "How to Isolate Machine Vibrations." Describes Korfund treated cork plates used in foundations to absorb vibration of machinery. The Korfund Co., Inc., 11 Waverly Place, New York.

Motors.—Bulletin 100, 4 pp. Describes squirrel cage induction motors for general purpose applications, ½ to 50 h. p. Bulletin 101, 4 pp. describes fire pump motors, a-c. open and enclosed types, for the operation of direct connected centrifugal fire pumps. Northwestern Manufacturing Company. Milwaukee, Wis.

Insulator Flashover Values.—The Delta-Star Monthly Message (Vol. 2, No. 7) contains an article on standardization giving comparative flashover values on insulators, by M. M. Samuels, which should be of particular interest to designing engineers. The Delta-Star Electric Company, 2400 Block Fulton Street, Chicago, Ill.

Switching Equipment for Alternating-Current Power Stations.—Publication 1541-C, 112 pp. This special publication deals with the general fundamentals that should be borne in mind in laying out a switchboard, and describes in detail the various types of switching equipment. It is profusely illustrated with diagrams and halftone illustrations. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

NOTES OF THE INDUSTRY

The American Steel & Wire Company, Chicago, announces the appointment of H. S. Durant as manager of the Cold Rolled Strip and Spring Sales Department, Chicago, vice Lewis Johnson, deceased.

New Oscillating Fan.—The Wagner Electric Corporation, of St. Louis, has developed and is placing on the market a new three-speed, ten inch, oscillating fan to retail at a popular price.

New Plant for Ajax Furnaces.—The Ajax Electrothermic Corporation, Trenton, N. J., has purchased 25 acres of land on the Reading Railroad where the erection of a new factory has been begun. The company manufactures high-frequency induction furnaces developed by Dr. E. F. Northrup.

The Belden Manufacturing Company, Chicago, announces the appointment of Edward A. Sipp as aviation research engineer for the development of special cables for airplane and similar work. The increased demand for special wiring harnesses or cables for airplane applications has made it necessary for the company to organize a separate department to design and manufacture such products.

Pressed Steel Plate Field Rheostats.—The Ward Leonard Electric Company, Mount Vernon, N. Y. is now building its vitrohm circular-plate generator and motor field rheostats with pressed-steel instead of cast-iron plates. The new design permits lighter and much stronger plate to be supplied for the same duty. Accessories furnish provision for all desirable combinations of plates with direct, concentric or sprocket drive, floor, wall or ceiling mounting, and for front or rear-of-switchboard mounting.

New French Allis-Chalmers Organization.—Allis-Chalmers business in continental Europe will be handled through an organization recently incorporated as Allis-Chalmers (France) with headquarters at 3 rue Taitbout, Paris. H. I. Keen, who has been manager of European sales through the company's district office in P[illegible] the managing director of the new organization. [illegible]s maintained for many years an office in [illegible] House, London Wall, E. C. 2.

Large Street Lighting Contract to Westinghouse.—The Westinghouse Electric & Manufacturing Company has secured an order for 1500 ornamental lighting units to be installed in the Davis Islands, Tampa-in-the-Bay, Florida, a new real estate development. Westinghouse Hollowspun concrete standards will be used. More than 300,000 feet of cable will be required, which will be laid at a depth of twelve inches along the curbway and put down at the same time as the pavement to facilitate construction.

Supplementary Compensation to G. E. Employees.—The sum of $1,367,426 07 was paid in February by the General Electric Company to employees who have been with the company for five years or more. These payments, termed supplementary compensation, represent 5 per cent of each individual's earnings for the six months ending December 31,1925. Payments were made in General Electric Employes' Securities Bonds or cash, as desired. About one-third of the total amount was distributed in the Schenectady works.

Promotions in Hazard Mfg. Company.—The Hazard Manufacturing Company, Wilkes-Barre, Pa., manufacturers of wire rope and electrical cables, announces the appointment of Laurence W. Bevan as general manager. Mr. Bevan entered the employ of the company thirteen years ago as metallurgical engineer. William S. Hart has been appointed special representative in charge of Hazard sales in the oils field of the United States with headquarters in Wilkes Barre. He has been in the employ of the company since 1888. Thomas A. Keefe was appointed district manager of the Chicago branch. Mr. Keefe came to the company in 1913 as a salesman.

Ohio Brass Company Develops New Iron.—The Ohio Brass Company, Mansfield, Ohio, has developed a new metal which it calls "Flecto" iron. This is a type of malleable iron which by virtue of a heat treating process, is freed from all tendency toward embrittlement when hot-dip galvanized. While retaining all of the desirable characteristics of malleable iron, the Flecto process so improves the metal with added valuable properties that it is considered to be practically a new metal. The announcement is made only now, but it is understood that all malleable iron castings produced by this manufacturer during the past two years have been treated by this process, the company having withheld announcement until the metallurgy of this new metal had been thoroughly proved by its use in the field.

The process for making Flecto iron is patented, but is available to other manufacturers under a liberal license arrangement.

Century Electric Expands. The Century Electric Company, St. Louis, Mo., has purchased an eight acre factory site located on a branch of the Wabash R. R. at Spring Avenue, on which it will erect buildings for manufacturing and warehousing. The present factories will be retained. The growth of the Century Electric Company, one of the pioneers in single-phase motor development, has been remarkable. Starting in 1903 in a small building at 1011 Locust Street, the company's factories, of modern construction, now occupy more than eleven acres of floor space, giving employment to over 3,000. The founders of the company are still actively directing all phases of the business. The officers include: E. S. Pillsbury, Prest.; S. M. Jones, and E. W. Collins, Vice-Prests.; R. J. Russell, Vice-Prest. and Secy.; B. M. Whittemore, Treas. and J. L. Woodress, Sales Manager.

The Company has arranged to distribute as a bonus from 1925 earnings, $190,000.00 in the common stock of the company at $120 per share to those of its 3,000 employees who have been connected with the company during the entire year of 1925, and who are still with the company on March 15, 1926. This means that each of those who are entitled to participate will receive at least 7 per cent of his salary or earnings.

JOURNAL OF THE A·I·E·E·

APRIL — 1926

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Annual Business Meeting, New York, N. Y., May 21

Annual Convention, White Sulphur Springs, W. Va., June 21-25

Pacific Coast Convention, Salt Lake City, Utah, (Sometime in September)

Regional Meetings

Great Lakes District, Madison, Wis., May 6-7

Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

International Electrotechnical Commission, Engineering Societies Bldg., New York, April 13-22

National Electric Light Association, Atlantic City, May 17-21

Middle West Division, N. E. L. A., Ft. Des Moines Hotel, Des Moines, Ia., April 7-9

Southwestern Division, N. E. L. A., Galveston, Texas, April 13-16

Southeastern Division, N. E. L. A., Pinehurst, N. C., April 27-29

Nebraska Section, N. E. L. A., Lincoln, April 29-30

JOURNAL

OF THE

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Current Electrical Articles Published by Other Societies

National Electric Light Association Bulletin, February 1926

Electrical Progress as Related to Industry, by P. S. Clapp

Electrical Decade, 1920-1930—Review and Forecast, by R. M. Davis

Engineering Developments of the Electrical Decade, by H. P. Liversidge

Where the Money Comes From for Light and Power Financing, by H. V. Bozell

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV APRIL, 1926 Number 4

The Ideals of the American University*

What, then, is the mission of the American University? Comparing the American college with the American university one is reminded of Janus, the old Roman deity, the guardian of the entrance to the Roman home. In the early dawn of Roman history this deity had one face only, but as the Roman home grew bigger a second face appeared. The American college and the American university are the two faces of the same guardian angel; one face contemplating reverently the familiar past and the other anxiously exploring the unknown future of this nation. The college perpetuates the national idealism of the past, the university prepares its future expansion. This idealism is the bond between the two, and without this bond they lose their spiritual meaning.

Lincoln closed his Gettysburg speech with the following warning:

> "It is rather for us to be dedicated to the task remaining before us . . . . that this nation, under God, shall have a new birth of freedom,—and that government of the people, by the people, for the people, shall not perish from the earth."

A dedication to so exalted a task demanded an expansion of our inherited national idealism. It is not surprising that the generation which heard this warning saw also the birth of the first real American university. The most comforting response to Lincoln's warning was a series of events which should be recorded with red letters in American history. The earliest among these events is the foundation, under a Congressional Charter, of the National Academy of Sciences in the same year in which Lincoln delivered his immortal speech. Lincoln, our greatest idealist in political philosophy, and Joseph Henry, his personal friend, our greatest idealist in science in those days, were the sponsors of this national organization whose members were always devoted to the cultivation of idealism in American learning. Some of the most distinguished members of this organization like Joseph Henry, John William Draper, Frederick Barnard, and Andrew White started that great movement for higher endeavor which found its first visible expression in the foundation of Johns Hopkins University in 1876, the first real university in the United States. Every student of the history of American idealism should know the life of Daniel Coit Gilman, at one time president of the University of California, who became the first president of Johns Hopkins University and presided over a faculty of idealists of the highest order of magnitude.

The aim of these idealists was the cultivation of idealism in every department of American learning, in order to prepare this nation for the expansion of the early American idealism which Lincoln glorified in the first lines of his Gettysburg ode. How did the nation respond? In less than a decade a score of American universities sprang into existence and followed the example of the idealists of Baltimore. This sudden outburst in the higher intellectual activities of our young universities encourages the belief that the period inaugurated by the termination of the Civil War witnessed an Intellectual Renaissance in the United States. The catalogue of its achievements during the last fifty years is as long as Homer's catalogue of the ships which carried the Greek heroes to the plains of Troy. Neither time nor purpose permit its recital here. There is one achievement, however, which I must mention.

Nothing resists a change as obstinately as the mental attitude of man. The history of science from Archimedes to Newton offers many illustrations of this wellknown fact. The change in the mental attitude of our age is one of the greatest achievements of our Intellectual Renaissance. Less than two generations ago educational training was expected by many to operate like a penny in the slot machine, that is, learn your lesson and convert your learning into cash without much delay. The so-called practical man who managed our American industries was at that time an ardent advocate of this utilitarian theory. He worshipped the art of making a living. Franklin and Lincoln, my patron saints, had no sympathy with this theory. The art of making a living was not the determining factor in their schooling, but the art of making life worth living was everything to them. They would find no fault with the American college, because its diploma does not testify that college graduates are loaded with a knowledge of the art of making a living, provided, however, that they carry with them some definite ideas about the art of making life worth living, not only their own individual life but also the life of our nation. The expansion of these ideas is the gospel of the American university. The Philistines, the so-called practical men of two generations ago, could not resist the power of this gospel; they have been converted, and this conversion is a great triumph of the apostles of our American universities.

The idealism of the Christian gospel which St. Paul and St. Peter preached was not clearly understood until the world had seen it in operation in the lives of those who had embraced it. The idealism of the American university was not clearly understood by the so-called practical man until he had seen it in operation in his dearly beloved industries. Motive, mental attitude, and method of work form the tripod upon which this idealism rests. But a motive which means unselfish search of the truth; a mental attitude which demands open minded communion with nature and freedom from prejudice; a method of work which in the hands of men like Archimedes, Galileo, Newton, Faraday and their disciples conferred innumerable blessings upon mankind; all these things were too abstract for the socalled practical man. But presently industrial problems arose the solution of which demanded the subtle touch of the university idealist; the stubby hand of the practical man had tried to handle them and it failed. The idealist showed the way, and from that time on the American industries began to worship at their altar of idealism of the American universities. Today that idealism is their patron saint who guides them in their progress; it will soon perform a similar service in all the activities of our nation, including our national politics, and lead us to that ideal democracy which was the dream of Lincoln.

Your distinguished fellow citizen of California, Secretary Hoover, is a practical man, but he has nothing in common with our practical men of two generations ago. In his recent appeal to this nation he preached a gospel which may be summed up as follows; Cultivate the fundamentals in the research laboratories as well as in the lecture rooms. This will lead us to the truth which will give this nation a new birth of freedom, and will raise our democracy to the lofty level of Lincoln's ideal.

M. I. PUPIN

*Abstract from a Charter Day address delivered at the University of California, March 23, 1926.

Some Leaders of the A. I. E. E.

Ralph Davenport Mershon, the twenty-fifth President of the A. I. E. E. was born in Zanesville, Ohio, July 14th, 1868. He was educated in the public schools of his native place, and began his engineering career at the age of 17 as a member of an engineering corps engaged in railway location and construction. In 1886 he entered the Ohio State University, from which institution he graduated in 1890 with the degree of M. E. During the last year of his University course, he was Student-Assistant in Physics and Electrical Engineering, and for one year after graduation, (1890-91), he was Assistant instructor of Electrical Engineering.

During 1891-1900, he was employed by the Westinghouse Electrical and Manufacturing Company of Pittsburgh. While with this company, Mr. Mershon became experienced in all branches of electrical work;—research work, both theoretical and practical,—experimental work, designing, factory engineering, field engineering and installation, patent expert work and patent experimental work, commercial work and selling. The transformers for which the Westinghouse Company received an award at the World's Columbian Exposition at Chicago in 1893 were of his design.

In 1893-95, he had charge of certain work being done by the Westinghouse Company in connection with the extension of the transmission plant of the Telluride Power Transmission Company of Telluride, Colorado. This was a single-phase, alternating-current transmission, employing single-phase, synchronous motors.

In 1896-97 for the Telluride Power Transmission Company and the Westinghouse Electric and Manufacturing Company he carried on at Telluride an investigation of the phenomena which occur between conductors at high voltages. This investigation was made on a transmission line about two and one-half miles long, and was the first investigation in which quantitative measurements of the ionization and other atmospheric losses occurring between conductors at high voltages were obtained. Original methods of investigation were devised by Mr. Mershon for this work, and special apparatus designed and built by him, by means of which quantitative measurements were made up to 72,000 volts. At the completion of the quantitative work, the voltage was carried up to 133,000 volts, at that time by far the highest voltage that had ever been impressed on an outdoor line.

In 1897-98, securing leave of absence from the Westinghouse Company, he acted as chief engineer of the Colorado Electric Power Company, during the designing and installation of their transmission plant which generates current by steam at Canon City, Colorado, and transmits power at 25,000 volts to Cripple Creek, Colorado, (a distance of 25 miles), where it is used for mining.

From 1898 to 1900, Mr. Mershon was engineer of the New York office of the Westinghouse Electric and Manufacturing Company, but during the latter year he resigned to enter upon private practise as a Consulting Electrical and Mechanical Engineer in New York City.

Some of the more important pieces of engineering work accomplished by him since entering practise as a Consulting Engineer are:

The reconstruction and enlargement of the water wheel, generating, transforming and transmitting equipment of the Montreal and St. Lawrence Light and Power Company (now a part of the Montreal Light, Heat and Power Company), transmitting to Montreal, a distance of 17 miles, 20,000 horse power at 25,000 volts;

The design and supervision of the first transmission plant of the Shawinigan Water and Power Company, transmitting power at 50,000 volts a distance of 85 miles to the City of Montreal.

The design and installation of the substation equipments of the Montreal Street Railway Company, having an aggregate capacity of about 12,000 horse power, for utilizing power transmitted to Montreal from various hydraulic plants;

The design and supervision of the transmission plant of the Niagara, Lockport and Ontario Power Company for transmitting power at 60,000 volts from Niagara Falls to various points in New York State. This plant is the largest transmission plant ever undertaken anywhere in point of capacity, and is one of the most important in point of distance of transmission. Its initial capacity was 60,000 horse power, and it is laid out for an increase to 180,000 horse power. At present its longest feeder is 160 miles.

The electrical design of the generating station, transmission line and receiving stations of the Inawashiro Hydroelectric Power Company, transmitting power at 115,000 volts from Lake Inawashiro to Tokyo, Japan, for use in the latter place,—a distance of 140 miles. The initial installation was for 45,000 kw.

In 1905, and for several years thereafter, he was retained on the work of the Victoria Falls Power Company, in connection with the installation of their steam stations near Johannesburg for supplying power to the gold mines of the Witwatersrand, and in connection with the proposed transmission of power from Victoria Falls on the Zambesi River, Rhodesia, South Africa, to the Rand, for operation in connection with these steam stations; being then the only American engineer so retained.

Mr. Mershon is the author of a number of technical papers, among which are "The Output of Polyphase Generators and Rotary Transformers," 1895. This paper contained the first published analysis of the effect upon the output of closed coil windings, when the number of phases is varied.

"Drop in Alternating Current Lines," 1897; treating of the calculation of drop and giving a table and chart by means of which such calculations can be quickly and accurately made.

"The Maximum Distance to which Power can be Economically Transmitted, 1904. This paper was presented at the International Electrical Congress at St. Louis in 1904, and was read before the American Institute of Electrical Engineers the same year. In presenting this paper at the International Electrical Congress, Mr. Mershon represented the American Institute of Electrical Engineers, acting as its delegate to the Congress.

"High Voltage Measurements at Niagara," his paper read before the American Institute of Electrical Engineers, June 30th, 1908, gives the result of some three years of investigation of the ionization and other atmospheric losses occurring between line conductors at high voltages. This was a continuation of the work previously done by Mr. Mershon at Telluride.

Previous to the entry of the United States into the World War, Mr. Mershon actively cooperated with those who formulated, and procured the passage of, the legislation creating the Reserve Officers Training Corps. Subsequently, when a Joint Committee of the National Engineering Societies was formed to work for the establishment of an Officers Reserve Corps he was a member of that Committee and active in the work which led to the passage of legislation creating the Corps. He was among the first of the Majors—then the highest rank in the Corps—commissioned in the Engineer Officers Reserve Corps.

When the United States entered the War, he was called to service and detailed to the Naval Consulting Board for the especial purpose of directing the work of the Special Problems Committee of the Board, which had principally to do with the problem of submarine detection. At the time of his retirement from military service he had the rank of Lieut. Colonel of Engineers.

He is a member and past president of the Inventors Guild and also a member of many American and foreign technical Societies.

The Development of the Sectional Paper-Machine Drive

BY H. W. ROGERS[1]
Associate, A. I. E. E.

Synopsis.—*To an increasing degree, large machines designed for quantity production are being subdivided into their elements, each section being driven by a separate motor as contrasted with former practise of driving these machines, as a whole, from a single unit. With the paper machine, this is called the sectional-electric drive.*

In this paper, the author has confined himself largely to the history and development of the several types of the sectional drive and the relative merits of each particular type.

An attempt has been made to set forth clearly the advantages of the sectional drive and to show that its field of application should increase with a fuller understanding of its advantages as to increased production, improved product and lower operating cost.

* * * * *

THE sectional drive, as it is commonly called, consists of a number of individual motors driving the various sections of a single machine with provision for maintaining a definite speed relationship between the sections, and while it is not limited in its application to paper machines, the use of it in this industry has been so extensive that it is impossible to mention sectional drives without immediately thinking of the paper industry.

The sectional drive is an extremely interesting engineering problem and is very important commercially, especially to the pulp and paper industry. Of approximately 1600 paper machines in use at the present time, probably 80 per cent are still being driven by means of the old type mechanical drive and steam engine, which would indicate that, in spite of the progress already made, the field of application for the electric drive has barely been entered.

The advantages of the electric motor are recognized, as practically all new mills are 100 per cent electrically equipped and most old mills use motors to a limited extent on pumps, beaters, jordans, screens, etc. However, the paper machine, the most important machine in the mill and the heart of a billion dollar industry, has been neglected. A vast amount of time and thought, research and development work, has been devoted to this problem by the engineers of some of the larger electrical manufacturers and, like all other new applications, developments, changes and refinements have taken place.

In a sense, these changes have come as the result of a broader knowledge of the problem and an honest endeavor to meet all of the requirements, but it is equally true that the paper manufacturers have gradually become more exacting in their requirements. In any event, change and development go hand in hand with progress; it is a natural process and should not be held out as a criticism.

To appreciate fully the problem which confronted the electrical manufacturer in 1919, it is necessary to consider the details of the paper machine and its requirements.

There are certain parts of every paper machine which run at a constant speed, regardless of the speed at which paper is being produced, and these parts, consisting of screens, pumps, suction and agitators constitute what is commonly called the constant-speed end of the paper machine. The driving of this end of the machine presents no difficulty whatever in its application and requires very little attention.

The variable-speed end of the machine consists of a number of separate sections, which have been in the past and are very largely at the present time being driven from a single line shaft through a system of cone pulleys and bevel gears with friction clutches for starting and stopping each individual section separately if occasion requires.

The stock enters the machine at the wet end on the wire and consists of 99½ per cent water and ½ per cent stock. Here the sheet is formed and, in three seconds, 99 per cent of the water is removed after which the sheet passes through one or more press rolls and over the dryers to the calenders, reel and rewinder as finished paper with about 8 per cent moisture, the whole operation requiring probably 40 seconds.

A continuous sheet must, therefore, be maintained throughout the machine and owing to its condition, there is a slight difference in speed between each section which must be maintained absolutely. This difference in speed is called "draw" and varies from time to time with the condition of the stock and the grade of paper and must, therefore, be capable of adjustment.

The drive must not only permit of a very close speed regulation, but must also permit of adjusting the "draw" between sections and at the same time absolutely maintain the relative speeds of the various sections.

The quality of the product depends very much upon the type of drive selected and the proper application of it with respect to the machine. Speed regulation, flexibility of control and uninterrupted service are all important factors and must be given careful considera-

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tion. For this reason it is desirable to have the paper machine and its drive a complete unit in itself, independent of the rest of the mill, so that trouble in the rest of the mill will not result in any interruption in the actual production of paper.

The line drawing, Fig. 1, illustrates the more common form of paper machine, consisting of the following sections:

1. Couch (either suction or standard)
2. First press (either suction or standard)
3. Second press
4. Third press
5. First dryer
6. Second dryer
7. Calender
8. Reel.

A fourth, and even a fifth press is sometimes encountered, and it is not uncommon to find a smoothing press with one or two breaker stacks and two or three calendar stacks, making a total of twelve or thirteen sections on one single machine. These sections, however, are practically independent of each other so that they are readily controlled, but on machines which involve felts common to two or more sections, the problem becomes complicated and both the paper manufacturer and the electrical manufacturer begin to court trouble.

The "draws" or slight variations in speed between consecutive sections are not fixed but are subject to modification due to the condition of the stock, kind of paper and suction; consequently, provision must be made to vary the speed of each individual section within certain limits (approximately 20 per cent) and still maintain a definite speed relationship between all of the sections. The approximate draws are indicated in Fig. 1.

The driving of a single machine with a multiplicity of motors, or a sectional drive as it has come to be known, is not a new idea, although the demand for it is relatively recent, beginning in 1919.

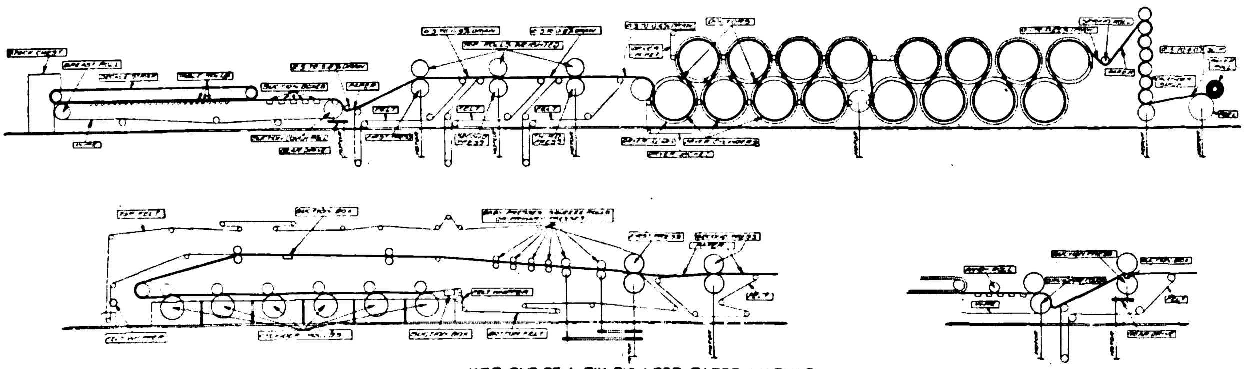
In 1909 the first real sectional drive was installed at the Chisholm Falls plant of the International Paper Company, consisting of d-c. motors with quarter-phase collector rings and mechanical speed changers for "draw" adjustment and, although it operated successfully for months, it was evidently in advance of the times and was eventually taken out.

In 1919 the enormous demand for paper, which had been aggravated by the curtailment of paper machine production during the war, started a controversy regarding the relative merits of wide, slow-speed machines and narrow, high-speed machines. Needless to say, the high-speed machine won out, although there is now a mild tendency to reverse that decision, and the demand for sectional drives was born at a time when most of the electrical manufacturers were not fully prepared to receive it.

It was frankly admitted among machine builders and operators that while the mechanical drive was a possibility on high speed machines, it was not at all practical on account of the high maintenance and this condition magnified the necessity for a solution to the problem.

There was no reliable power data available, since it was practically impossible to obtain any with mechanical drives; nor was there any accurate data on "draws" for the same reason. However, the need was urgent and the first so-called synchronous tie-in type of paper-machine drive, in spite of adverse criticisms and prophesies to the contrary at the Crown-Willamette Paper Company's Mill was built and put into successful operation. This drive was really the forerunner of the ever increasing demand that has spread over the entire country, including Canada, and its success has had a marked bearing upon the development of the industry and the attitude of the trade toward sectional drives in general. A failure at that time would have been a reflection upon the electrical industry as a whole and undoubtedly would have been a serious set-back to the sectional drive as such.

In theory this type of drive was all that could be desired; in practise it fulfilled all expectations and its success was duplicated in eleven other orders during the same year. These drives made it possible to secure a vast amount of valuable data heretofore unavailable, the careful analysis of which has had a great deal to do with the developments that have followed since their creation.



WET END OF A SIX CYLINDER PAPER MACHINE

FIG. 1—FOURDRINIER PAPER MACHINE

During this period drives of an entirely different character were being exploited, although not in such large numbers.

Strictly speaking, there are but two types of sectional drive on the market today:

I. The synchronous tie-in type of drive, wherein there is an actual interchange of energy between the various machine sections and where the relative speeds are held constant by synchronous motors. This, truly, is preventative rather than corrective.

II. The regulator type of drive, wherein the speed of the various sections is maintained by shunt field adjustment on the motors. It will operate on an angular displacement similar to Type I, if the regulator element is of the synchronous type, but there is no actual restraining power to hold the motor in place and the success or failure of this type is determined by the amount of angular displacement which causes the regulator to function and by the time element of the motor field.

The real difference between these two types of drive can readily be appreciated when the peculiar characteristics of the d-c. motor, operating at reduced voltages and speeds, are considered. The speed regulation at full voltage and full speed may be three or four per cent or even less, but, owing to the armature drop, it becomes extremely poor when operating at low speeds on low armature voltage. To maintain a constant speed under these conditions with a varying load requires a very wide change in the field strength which detracts from the motor torque at low speeds. In other words, a d-c. motor will not deliver as much torque under reduced armature voltages and this demands the use of over-capacity motors where the regulator type of control is used.

With the synchronous tie-in type of drive, the motor capacity need not be increased because the synchronous motors absorb the change in load and the d-c. motors may be operated at a fixed field. This type of drive, therefore, while higher in cost and space requirements has the advantage of smaller capacity motors and will hold the motor speed within extremely close limits even where instantaneous load changes are encountered, whereas the regulator type of drive requires a certain time element between the change in load and the correction. However, the regulator type of drive, which will be fully treated later in this paper, has been improved to a point where it meets the most exacting requirements of commercial operation and, despite the larger capacity driving motors which it requires for wide range machines, offers advantages as to first cost and space requirements.

Coincident with the development of the regulator type of drive, the synchronous tie-in drive, while remaining fundamentally the same, has passed through several stages of improvement.

I. The original type consisted of slow-speed d-c. motors with high-speed synchronous tie-in motors connected to the d-c. motor through a pair of cone pulleys and a gear reduction.

II. In the second development the cone pulleys and belts were eliminated and a high-speed synchronous motor with revolving stator frame was used, the stator frame being driven by a small adjustable-speed d-c. motor. This change reduced the space requirements and overcame the objection to belts.

III. The final development of this type of drive utilizes a slow-speed synchronous motor mounted on the d-c. motor shaft, thus eliminating the gear reduction.

On all three of these drives the synchronous motors were 20 per cent of the capacity of the main driving unit with 200 per cent pull-out torque either as a motor or as a generator; consequently, they could take care of a maximum load change of 40 per cent without exceeding their normal rating and still hold the speed within very close limits. The development of this type of drive is shown in Fig. 2.

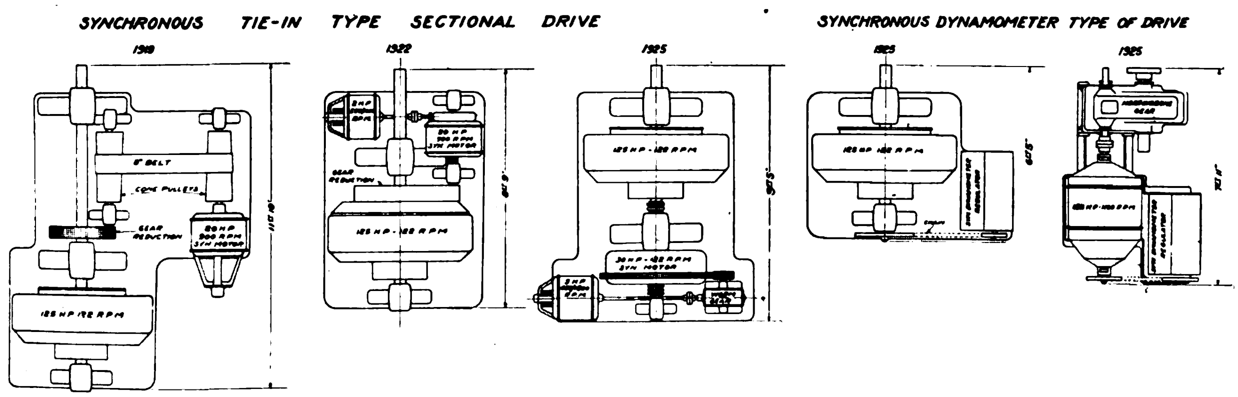


Fig. 2

It is a well-known fact that the synchronous motor operates at a fixed speed which is dependent upon, the frequency of the system to which it is connected and the speed cannot be changed so long as it operates within its capacity. The use of a multiplicity of synchronous motors connected to the same source of supply or interconnected between each other is analogous to a mechan-

ical line shaft and gears connecting the various sections of a machine together.

It is true that the loading of a synchronous motor is accomplished by an angular displacement between the rotor and stator, but it is equally true that a mechanical shaft with gears is subject to angular displacement under load.

The angular displacement in a synchronous motor is perhaps 10 or 12 electrical deg. under full-load conditions which corresponds to an angular displacement on the main driving motor of less than one-half of a mechanical degree. This displacement affects the sheet of paper that is passing over the roll at the time the load change occurs, and is present in all types of drive whether mechanical or electrical. It, however, is a negligible quantity and has no bearing upon the operation.

The original type of drive which has been so successful from the beginning has been installed on twelve paper machines, although one of them has since been

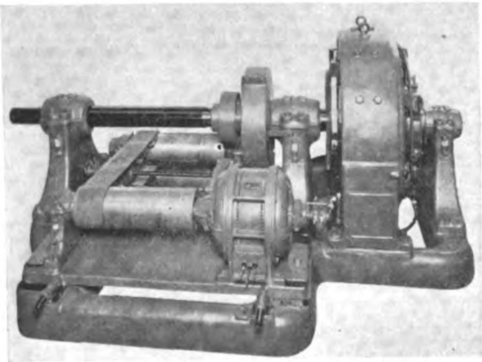


Fig. 3—First Development of Synchronous Tie-in Type of Drive Showing Moderate-Speed Synchronous Motor Connected to Main Motor Through Gear Reduction and Cone Pulleys

modified to the regulator type for the sake of uniformity in equipment. The use of cone pulleys and belts between the main driving d-c. motors and the synchronous tie-in motors has been questioned in a few instances on the basis that belts in ordinary commercial service operate with a slip of two or three per cent. However, the belts used on these drives are very much over capacity and under actual test show a maximum slip of $\frac{30}{100}$ of one per cent. The load on a paper machine is very constant and under normal operating conditions will not vary more than 10 per cent. Consequently, the speed is maintained with $\frac{15}{100}$ of one per cent or less, whereas the same load change on a mechanical drive would be twice this amount or even more depending upon the condition of the belts. Each synchronous motor is free to act as a motor or a generator with an actual transfer of energy between it and the balance of the synchronous motors. A load change on one section, therefore, may affect the speed of that section $\frac{15}{100}$ of one per cent, but the effect on the remaining sections, which must of necessity supply or absorb the energy, is only $\frac{2}{100}$ of one per cent on an eight section machine.

The second development of synchronous tie-in drive

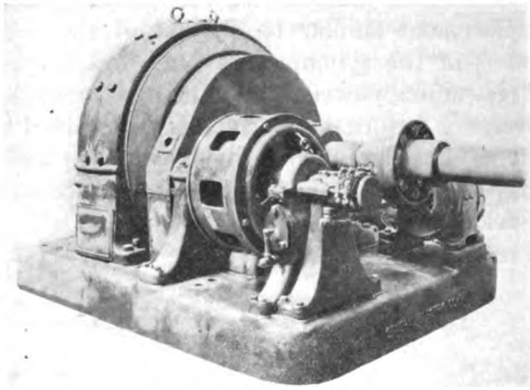


Fig. 4—Second Development of Synchronous Tie-In Type of Drive Showing Moderate-Speed-Geared, Synchronous Motor with Revolving Stator Frame

utilized a slow-speed d-c. motor to which a moderate-speed synchronous motor was connected through a gear reduction. The "draw" adjustments or speed changes,

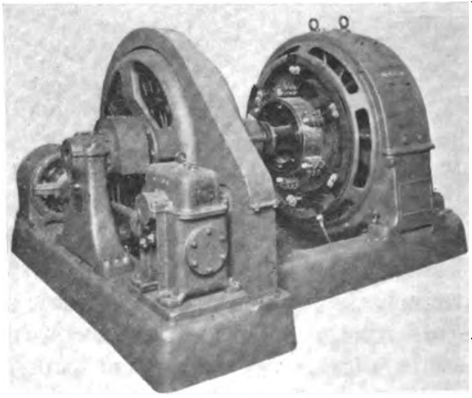


Fig. 5—Third Development of Synchronous Tie-in Type of Drive Showing Slow-Speed, Direct-Connected Synchronous Motor with Revolving Stator Frame

were obtained by rotating the stator frame of the synchronous motor by means of a small adjustable speed d-c. motor. This change eliminated the cone pulleys and belts and had the advantages of smaller space requirements and "draw" adjustment through the medium of a field rheostat rather than the shifting of a belt.

This type has been in successful operation since 1922 and has also been furnished on two other machines.

The third and final development of the synchronous tie-in drive utilizes a slow-speed d-c. motor and a slow-speed synchronous motor mounted on the same shaft. The "draw" adjustment is obtained by rotating the stator frame of the synchronous motor by means of a small adjustable speed d-c. motor. In this drive the cone pulleys, belt and the gear reduction are eliminated. This drive has been furnished for four paper machines which are motored for 1440 ft. per min., a speed far in excess of anything that has ever been attempted in the past on any machine.

In both of these developments where revolving-frame synchronous motors are used, the stator frame revolves at an extremely low speed compared with the rotor and consequently a speed change on the adjustable speed motors, which drive the stator frame, has little effect upon the speed of the section. In reality the regulation of the small d-c. motor only affects the speed of the stator which is but a small percentage of the synchronous speed. Consequently, the synchronous speed or the speed of the main driving motor will be maintained within $\frac{15}{100}$ of one per cent or less for the load changes ordinarily encountered on a paper machine.

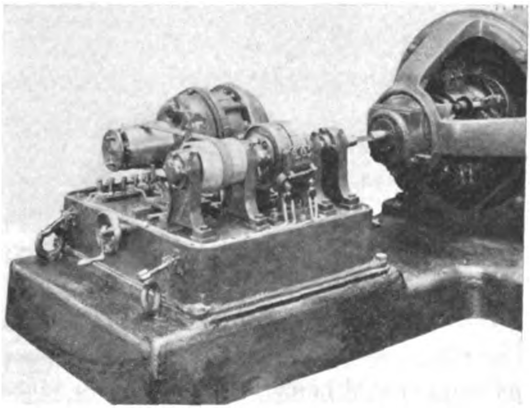


Fig. 6—Disk-Type Speed Regulator
As installed on sectional paper-machine drives

Fifteen of these drives are now in successful operation and most of them have been operating for five years with practically no maintenance.

The Synchronous Dynamometer (Regulator) Type

The possibilities of a speed regulator which operates on the shunt field of a d-c. motor have been fully appreciated and as early as 1920 a synchronous dynamometer type of speed regulator was built by the company with which the writer is connected.

This regulator consisted of a small synchronous motor, the rotor of which was driven from the motor on which the speed was to be held constant through a pair of small cone pulleys and a small belt. The stator was excited from a master generator in such a way that it remained stationary unless there was a tendency for the controlled motor to change in speed, thereby causing the stator to rotate and alter its field to maintain the speed constant. It operated on an angular displacement and handled the field current direct through a commutator type of rheostat, the brush mechanism of which was connected direct to the synchronous motor stator.

In 1921-1922, the disk-type regulator with synchronous motor actuating element followed closely on this development operating on the principle of a voltage regulator, except that the contacts were revolving instead of stationary. In its developmental stage the disks were modified to give a total angular displacement of 180 degrees and were so constructed as to cut the motor field resistance in and out of the field circuit twice every revolution or twenty times a second, the effective field resistance being determined by the angular displacement between the disks, one of which was driven by the motor to be controlled and the other by the synchronous motor. Subsequently, the brush mechanism was altered to cut the resistance in and out in three steps rather than one.

During 1922-23 this final form was furnished with ten paper machine drives, making newsprint, book, kraft, tissue, crepe and glassine; on high-speed machines and low-speed machines, for narrow-range and wide-range speeds. The regulator was subject to limitations in its operating range, under some conditions necessitating adjustments in an auxiliary field rheostat. This feature, however, only applied to wide-range machines and the endeavor to overcome it and make the adjustment of the auxiliary rheostat automatic resulted in one more development in which a mechanical differential was added to the disks to automatically adjust the external field rheostat. It was built and tested under actual operating conditions but has never been furnished on any drive.

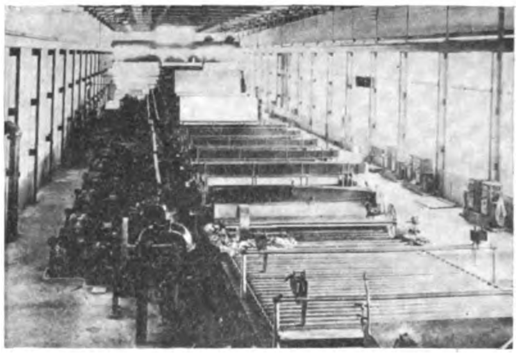


Fig. 7—Synchronous Tie-in Type of Drive with Cone Pulleys and Belts
As installed on a 164-in., 1200-ft.-per-min. paper machine

As a result of past experience with all kinds of paper machines making all grades of paper, it is believed that the speed regulator which will best satisfy the exacting conditions of operation and appearance is the development and refinement of the synchronous dynamometer regulator built and tested in 1920 and known as a synchronous dynamometer. It consists of a small synchronous motor, the rotor of which is driven from

the motor to be controlled through a pair of cone pulleys and a belt which gives 20 per cent "draw" adjustment. The stator frame, mounted on ball bearings is excited from a master generator and is free to rotate. It actuates the brush mechanism of a commutator type rheostat which has a total movement of 180 deg. The rheostat has both coarse and fine steps and gives the equivalent of 450 operating points.

This regulator combines a number of features not found in any other type of regulator:

1. Is of the synchronous type
2. It operates on an angular displacement corresponding to approximately 0.05 per cent change in speed of the controlled motor
3. Has 450 operating points
4. Has anti-hunting features
5. Has an absolute minimum of moving parts as the rotor of the synchronous motor, which is mounted on ball bearings, is the only moving part
6. The rheostat mechanism is stationary except when load changes demand action. It is not of the make and break contact type
7. Remains stationary, maintaining its operating position when the master generator is shut down or when the synchronous motor is disconnected from its power supply, thus overcoming any possibility of a "wild" machine
8. Has a wide operating range
9. Low maintenance
10. Minimum space requirements
11. Is totally enclosed
12. Is mounted direct on the motor base
13. Presents a neat compact appearance
14. Is readily accessible
15. Is rugged in design
16. Has motor-operated "draw" adjustment.

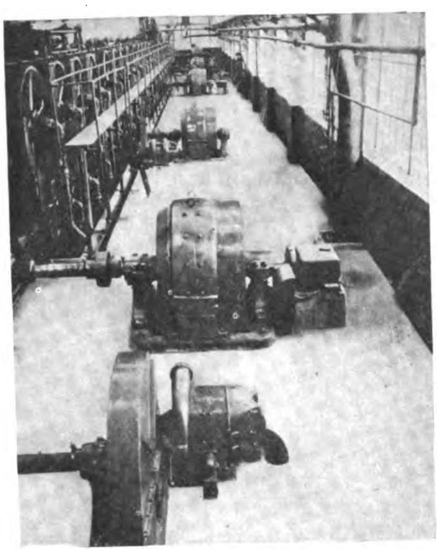


FIG. 8—REGULATOR TYPE OF SECTIONAL DRIVE
As installed on a 170-in., 700-ft-per-min. machine

It would seem that there has been an unusual number of modifications in the sectional drive but a careful analysis of the situation will reveal that there have been from the very beginning but two distinct types. The changes that have taken place are a natural process of development and do not affect the fundamental principle of operation.

Thus far only the development of the two types of drive and their characteristics as separate units have been given consideration, without any particular reference to the machine as a whole.

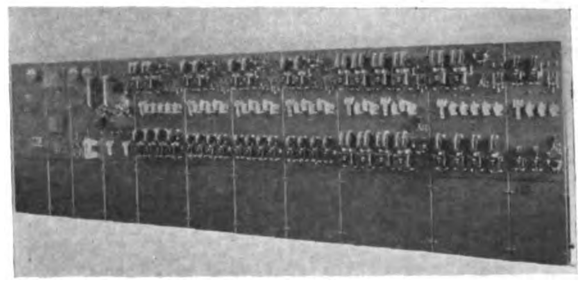


FIG. 9—CONTROL SWITCHBOARD FOR SECTIONAL PAPER MACHINE DRIVE

The sectional drive usually consists of the various parts as enumerated below.

I. A Turbo Generator Set.

(a) This has a separately excited shunt-wound d-c. variable voltage generator and a non-condensing steam turbine with a direct-connected exciter of sufficient capacity to excite the generator and all of the sectional motor units.

Exhaust steam is utilized to dry the paper and the turbine is designed to operate at back pressures to meet the required conditions. In some instance an a-c. generator is also furnished as a part of the turbine unit to furnish power to the constant speed end of the paper machine or to float on the mill system and thereby insure a perfect steam balance under all conditions of operation.

Synchronous motor-generator sets are sometimes used as prime movers and in such cases either live steam or exhaust steam from some other source is used to dry the paper.

(b) A generator-control panel

(c) A voltage-regulator panel with

1. A voltage regulator for the main generator
2. A voltage regulator for the exciter

(d) An auxiliary control panel for controlling the generator voltage and the speed of the machine as a unit.

II. Motor Equipment.

(a) An adjustable speed, d-c. motor for each section of the paper machine. This may be of the slow speed direct-connected type or of the moderate speed geared type. Both the open type motor and the enclosed, externally ventilated type motors have been furnished,

but this is entirely a matter of preference with the paper manufacturer.

(b) A regulator.

III. Mechanical Parts.

All motors are furnished with base, shaft, bearings, couplings, shaft extensions, and all necessary equipment not included as a part of the paper machine.

IV. Control.

(a) A five-point, full automatic-contactor control panel with overload and under voltage protection and indicating meters for each sectional motor unit.

(b) A continuous duty starting and regulating rheostat designed for 75 per cent speed reduction for each sectional motor unit.

V. Master Generator Set.

The master generator set which supplies a-c. power to the speed regulators consists of a 10-kw., 1200-rev. per min., three-phase, 60-cycle generator, direct connected to an over capacity d-c. motor which is controlled from the main generator panel and automatically comes up to speed when the voltage is brought up on the generator.

It controls the speed of the paper machine as a unit and its speed is adjustable within certain limits although it depends primarily upon the voltage at which the main generator is operating.

When the synchronous tie-in type of drive is used, the master generator is not necessary because any one or more sections which happen to be running constitute a master for controlling the speed of the other sections.

VI. Draw Adjustment.

Provision is made on each sectional unit for a sufficient "draw" adjustment to take care of all operating conditions such as variations in stock, grade of paper, grinding press rolls and the like.

The "draw" adjustment is motor operated and may be made from the front side of the machine.

VII. Temperature.

All equipment is based on 40 deg. cent. rise under normal load.

VIII. Location of Equipment.

The power unit should preferably be located in the basement under the paper machine and in close proximity to this unit the generator control and all of the motor control units may be lined up as a single switchboard. This arrangement leaves nothing in the machine room except the motor equipment and the control buttons.

IX. Operation.

In starting up the paper machine it is to be assumed that the motor-generator set or turbo generator set is running and that there is a proper voltage supply available. Each section of the paper machine may be started up in succession, starting with couch, by merely pressing a button after which the motor automatically comes up to its full speed or to a speed corresponding to the supply voltage and the speed regulator is automatically connected to the master generator bus and begins to function immediately.

Provision is made to operate the motors at slow speeds for washing felts, changing wires or spearing broke.

The individual control of the motors permits of operating any section of the paper machine independent of any other section and at the same time assures an absolute synchronous tie-in between the sections when all motors are operating at their full speed.

Slow-Speed Motors

It is not difficult to design for this service either slow-speed direct-connected motors or moderate speed motors with herring-bone gear reductions. Either type of motor is satisfactory and it is simply a matter of capitalizing the higher maintenance and increased space requirements of the moderate-speed geared motor as against the slightly higher first cost of the slow-speed direct-connected motor.

VARIOUS APPLICATIONS OF THE PHOTOELECTRIC CELL WITH AMPLIFIER TO PHOTOMETRY

At the Montreal meeting of the American Physical Society, February 26-27, Doctor Clayton H. Sharp presented a paper entitled "Various Applications of the Photoelectric Cell with Amplifier to Photometry" of which the following are excerpts:

A.—An arrangement whereby a photoelectric cell with a vacuum tube amplifier supplants the ordinary photometer head in making a photometric balance has been described before the Illuminating Engineering Society in September 1925. A rotating glass disk, one-half of which is silvered, throws in alternation the light of the "X" lamp and the light of the comparison lamp on to the photoelectric cell, the cathode surface of which is connected to the grid of an amplifying tube. If the two lamps differ in their effect on the cell, variations in the plate current are produced which act through a transformer and through a rectifying device upon a d-c. galvanometer.

B.—Spectrophotometry.

The filament of an incandescent lamp is focussed on a spectrometer slit, the beam passing through a variable sector. The photoelectric cell with amplifier is the detector. A circuit connection is used such that the galvanometer shows only the changes in the plate current. Spectrophotometric measurements of transmission are made by noting the deflection of the galvanometer when the filter is interposed in the beam, and then by means of the sector bringing the galvanometer to the same deflection when the filter has been removed.

C.—Temperature of Lamps.

The ratio of light transmitted by a blue filter to that transmitted by an amber filter as shown by the photoelectric cell varies with the temperature of the source of light. The temperature of incandescent bodies can thereby be determined, using a calibration curve.

The Use of Vibration Instruments on Electrical Machinery

BY J. ORMONDROYD[1]
Non-member

Synopsis.—*Several mechanical vibration instruments are described and actual problems which these instruments have helped to solve are mentioned. The theory of the seismographic instruments is developed to show the relation between the record or indication and the motion being measured. The limitations in the accuracy of amplitudes recorded or indicated are brought out.*

INTRODUCTION

VIBRATION problems in the shop have frequently been left to the care of "penny balancers," men whose practical judgment was not tempered by any accurate knowledge of the vibration properties of bodies or the possible causes of vibration. Their opinions were based on data gathered by the unaided senses of touch, sight and sound. The effects of vibration on the senses of touch and hearing depend on amplitude and frequency together; and it is well known that the eye exaggerates any vibratory motion it observes. Subjective data almost always fail in accuracy. Knowledge is useful only when it becomes quantitative. The question "How much" must be answered explicitly or implicitly before any action can be undertaken.

In any vibration problem there are five things which should be known:

1. Frequency of vibration.
2. Amplitude of vibration.
3. Type of vibration—simple-harmonic or complex.
4. The elastic properties and mass distribution of the vibrating body.
5. A general knowledge of the possible mechanical and electrical forces acting on the body.

The first three must be gotten by quantitative measurement. Observations of these three without measurement is usually valueless. The fourth is gotten from a knowledge of the materials and dimensions of the body. The fifth involves a clear understanding of the mechanical and electrical functioning of the body. This usually must go beyond the knowledge used to design the body since that knowledge, generally speaking, does not take into account the possibilities of vibration. No instrument can supply four and five. Trained human intelligence is necessary here.

It is proposed to show that this problem can be studied quantitatively in the shop and field. The theory and use of a few instruments suitable for this study will be taken up. Only mechanical instruments will be discussed. While electrical methods for measuring vibrations are well known the inconveniences attending the use of the oscillograph have always discouraged any extended application of these methods on machines in production and in operation. Mechanical instruments have the following advantages over electrical vibration measuring devices which depend on the use of an oscillograph:

1. They are easily portable.
2. They can be applied to the job quickly, easily and cheaply.
3. The record or indication is available for immediate use.
4. The record or indication can be taken over a long period of time.
5. No complicated electric circuits are needed.

It should be stated, however, that electrical circuits can be devised to give space-, velocity- and acceleration-time effects; while mechanical instruments are limited to space-time effects. Very high frequencies demand the use of electrical methods.

The theory and practise of five instruments will be given.

Indicating Instruments.

1. The vibrating reed.
2. The vibration amplitude indicator.

Recording Instruments.

3. The directly connected vibrograph.
4. The vibrograph.
5. The torsiograph.

The vibration amplitude meter as described in the paper was developed by engineers of the Westinghouse Company; although forms of this meter can be bought on the market. The other devices are commercial instruments widely used in Europe and slowly coming to the attention of American engineers. The use of each instrument is illustrated in the following pages by concrete examples.

The theory of the instruments is given in the appendices. Mechanical vibration-measuring instruments as they now stand cannot be used safely unless their limitations are clearly appreciated. The relationship between the record or indication and the actual motion is not a simple one. Knowledge of the theory of this relationship must be considered a necessary tool to the man who uses the instruments.

LINEAR VIBRATIONS

Most of the vibrations in electrical machinery are linear in nature. Four of the five instruments dis-

1. Motor Engineering Department, Westinghouse Electric & Manufacturing Company.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

cussed are for the study of linear vibrations. In general, the fields of application of these four instruments are:

1. The vibrating reed—for measuring frequency only.
2. The amplitude meter—for measuring amplitudes only.
3. The seismic vibrograph—used where a complete analysis of the motion is desired. Applicable where the instrument cannot be attached to a fixed reference point.
4. The directly connected vibrograph—used where a complete analysis is wanted. Applicable where the instrument can be attached to some fixed reference point.

Measuring Frequencies—the Vibrating Reed

The properties of resonance in a thin cantilever beam have long been used in turbo generator tachometers and electrical frequency meters. Fig. 1 shows a reed which can be varied in length and which can be attached to

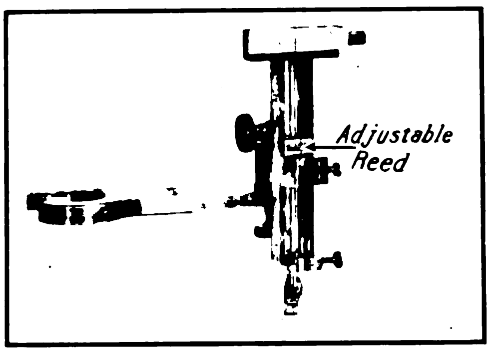


Fig. 1—Reed Vibrometer

any vibrating body. The body should have a weight considerably larger than the weight of the instrument, say ten times as great, to preclude the possibility of the instrument affecting the motion of the vibrating body.

The instrument shown in Fig. 1 consists of a claw to be clamped under a bolt head, two joints rotatable at right angles to each other, a main frame bearing a reed length scale on the side, an amplitude scale across the top and a long screw. A clamp carriage rides on the main frame; its position being adjusted by the screw. The reed is held tightly in a fixed clamp at the bottom of the frame and its free length is varied by the position of the movable clamp on the carriage.

The instrument is bolted to the vibrating machine and the free length of the reed is adjusted until the largest amplitude of motion is obtained at the end of the reed. This is read on the transverse scale. The instrument then is in resonance with the impressed frequency. This frequency can be determined by measuring the free length of the reed.

This device is so highly selective (damping forces extremely small) that it can be used only on vibrations with almost absolutely constant frequency. The least variation in frequency near the resonant point will give very large fluctuation in amplitude. This limits the instrument to uses on turbo generators and to cases where the cause of the vibration lies in magnetic pulls or in torque pulsations. These latter have frequencies depending on the voltage frequency of the line which varies slightly.

Given the same frequency, the amplitudes can be compared. Turbo generator balancing can be controlled by the use of a reed under these conditions.

A knowledge of the frequency of a vibration will often point to its cause. Unfortunately, the vibrating reed is too sensitive to be generally used for this purpose; since in most cases the frequencies vary enough to spoil the accurate setting of the reed.

The Measurement of Amplitudes Only—Amplitude Meter

In many cases the frequency of vibration is known and the magnitude of its amplitude is of importance. Here the amplitude meter is a handy tool. This instrument consists of a mass suspended from a frame by a spring. (See Fig. 12.) The frame is held against or attached to the vibrating body. The relative motion between the spring-suspended mass and the frame is equal to the total range of the vibratory motion when the frequency of the motion is above a certain value. This relative motion is transmitted through levers to an indicator which makes a band image over a calibrated scale.

The most important use for the instrument is in field balancing of turbo generators. The instrument is attached to the bearing pedestal and four amplitude readings are taken—one with the original unbalance; the other three with an arbitrary unbalance applied successively in three different points of the balancing plane. The amplitude readings determine a system of vectors which give the amount and direction of the original unbalance. This rational procedure saves time and is more accurate than the old cut-and-try methods.

In cases where periodic forces have set stators of electrical machines in vibration, the amplitude meter has been used to determine the nodes or points at which the stator motion amplitude was zero. A check on the number and position of the nodes, along with a measurement of the frequency, indicates the curative measures to be taken. It also indicates the accuracy of design calculations.

The comparative roughness of commutators can be gaged with a small amplitude meter by holding it on the brushes. Where a definite minimum roughness is permissible on a given line of motors, this is a simple means of inspection.

Where large numbers of any one motor have to be made with a given minimum of vibration, the amplitude meter again serves as a means of objective inspection.

Application of the Seismic Vibrograph

The seismic vibrograph is shown in Fig. 2. It consists of a heavy pendulum suspended between two springs. (See Fig. 13.) The pendulum is placed at right angles to the direction of the motion to be measured. The frame of the instrument is attached to the vibrating body and moves with it. The spring-borne pendulum stands still in space when the frequency of motion is above a certain value and the relative motion between the frame and the pendulum bob is transmitted through a system of levers to a recording pen. A strip of paper actuated by clockwork moves under the pen and a record of the motion shows as a wave on the paper. A timing device records equal time

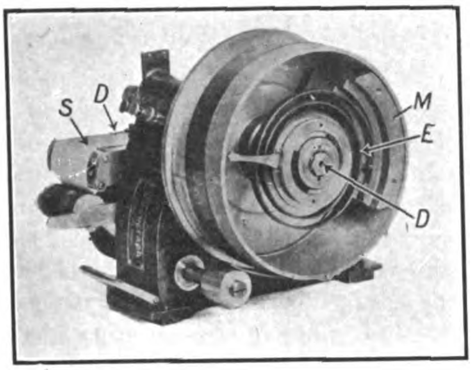


Fig. 2—Seismic Vibrograph

intervals on the same strip. The record can be analyzed for frequency, amplitude and type of motion.

The seismic vibrograph finds its chief application in the measurement of floor vibrations in buildings and electric locomotives. The absence of any fixed reference point in cases like these necessitates the use of a seismic instrument.

Although the cause of troublesome vibrations on factory floors or office buildings usually can be traced to its source without the help of instruments, there are cases where the cause is entirely elusive until vibration measurements are made. This is true where many pieces of rotating apparatus exist near together. A vibrograph record will show the frequency of the strongest vibration and this knowledge will usually point to the cause.

A common cure for floor vibration is mounting the machine which causes the disturbance on cork pads or springs. The design of a flexible mounting is determined by the weight of the machine and the frequency of the disturbance which it causes.[2] It is entirely possible to design a flexible mounting in such a manner that the transmitted vibrations become worse instead of better. In a rational design of flexible mounting the vibrograph supplies the necessary data on frequencies.

In gas or Diesel Electric Locomotives the floor vibrations may come from many sources. Unbalance in the reciprocating parts of the prime mover or in the rotating parts of the engine, generator and numerous auxiliaries—any one of these may be causing the objectionable disturbance. Usually they must all run simultaneously so no successive elimination of causes is possible. Another source of noticeable linear vibrations may be the periodic twist in the common foundation of the generator and engine due to the inherently varying torque of the prime mover. A vibrograph record usually shows up the troublesome frequency and leads to the proper remedy. This remedy may consist in the correcting of a bad unbalance, the changing of frame work structure to avoid local resonance, or the avoidance of resonance in the entire cab-spring system.

Application of the Directly Connected Vibrograph

Fig. 3 shows a side view of this instrument and Fig. 16 shows a top view. The instrument is clamped tightly to a body assumed to be absolutely stationary. A light rod transmits the motion from the vibrating body (See Fig. 16) to a bell crank which magnifies the motion and actuates the pen-push rod. The pen system, paper drive and timing device are all the same as on the seismic vibrograph (See Fig. 16).

The entire region close to a vibrating machine is often vibrating with the machine. In cases where this is so bad that the assumption of a stationary reference point cannot be approached even approximately special mountings for the instrument must be used. In power houses a heavy weight—a ton or more

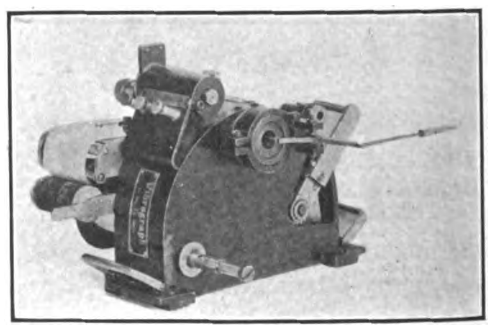


Fig. 3—Directly Connected Vibrograph

—is suspended from the crane and the instrument is mounted on the weight (See Fig. 4). On the test floor a heavy mass mounted on springs has been used. In both cases a seismic system is formed, having a low natural frequency which does not respond to the small high frequency forces transmitted through the bell crank. Usually the floor vibrations are small enough so that any object near the vibrating machine may be considered stationary enough to serve as a mounting for the instrument.

The Study of Critical Speeds

In rotating apparatus the critical speeds are the most important objects of vibration study. Existing methods

2. See C. R. Soderberg, *Elec. Journal*, Vol. XXI, 1924, p. 160.

of balancing rotors are accurate enough to eliminate violent vibrations at any speeds except those in the region of the critical speeds. The directly connected vibrograph finds its most extensive use in the study of the critical speeds of structures and machines.

Experimental Determination of Natural Frequencies

Any structure which is deformed by the application of external forces will return to its natural conformation, when these forces are removed, assuming deformations within the elastic limit of the structure. If the applied force is in the form of a blow the return to the position of static equilibrium is made through damped oscillations having the natural frequency of the structure. This fact is used in determining the natural frequencies of bodies too complicated in shape to be calculated. The

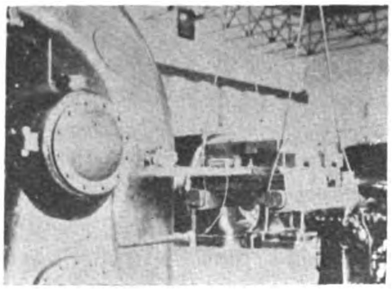


Fig. 4—Vibrograph for Powerhouse

body is clamped in its natural position, a blow is struck and the vibrograph records the ensuing damped oscillation.

The calculation of the natural frequency of turbo generator field structure is complicated by the presence of field winding slots. A method of calculating this frequency was devised analytically and checked experimentally by means of the vibrograph. The mass of the generator rotor is too large to be affected by a blow; so the principle of resonance was used. A small d. c. motor with a badly unbalanced rotor was mounted on the top center of the large rotor which was held in pedestals mounted on the test floor. The vibrograph was mounted below the center of the field. The motor speed was varied until the amplitudes of vibration of the whole field became a maximum. A curve of the amplitudes read from the records indicated the critical speed very distinctly and a check between theory and practise was possible.

Effects of Structural Parts on Critical Speeds

Perhaps the most valuable service which the directly connected vibrograph has performed has been in the emphasizing of the tremendous differences which can exist between the critical speed in rotating apparatus, as calculated on the rotor alone and the actual critical speed of the completed and installed machine. When a draftsman in the ordinary course of design calculates the critical speed of his rotor he tacitly assumes that the bearings in which it will rotate are held rigidly fixed in space and that his calculated critical speed will be the critical speed of the completed machine. But the action of the bearing under the influence of unbalanced forces depends on the flexibilities of the pedestals, bed-plate and ultimate foundation. These additional flexibilities, usually neglected, all tend to make the actual critical speed lower than the calculated speed.[3] This fact is of importance since all small and medium sized machines are usually built to run below their calculated critical speeds.

The effects of parts of the structure external to the rotor shaft may range all the way from complete control of the actual critical speed (as in the case of all modern balancing machines, where the flexibility connected to the vibrating bed determines the frequency of the system) to the case where the bearing is in extremely rigid pedestals attached to an extremely rigid foundation. In this latter case the critical speed as calculated would be the actual critical speed in service.

An extensive series of tests were run by Dr. S. Timoshenko and Mr. L. S. Jacobsen on an experimental synchronous condensor to prove that the effects of structural flexibilities could be predetermined accurately. The machine was rated 5000 kv-a. at 750 rev. per min. They tried three shafts of different diameters and two different bed-plates—all other conditions remaining constant. Bed-Plate B was 40 per cent heavier and twice as stiff as Bed-Plate A (See Table I). The results are shown in Table I.

TABLE I

			Bed-plate A		Bed-plate B	
Direction of Vibration	Diameter of Shaft	Critical Rev. per min. Calculated on Rotor Alone	Actual Critical Rev. per min. No Field Excitation	Per Cent Lower	Actual Critical Rev. per min. No Field Excitation	Per Cent Lower
Horizontal	10.5 in.	1270	1050	17%	1110	12.5%
	12.5 in.	1470	1180	20%	1270	13.5%
	15.5 in.	1820	1325	27%	1460	20.5%
Vertical	10.5 in.	1270	1010	21%	1110	12.5%
	12.5 in.	1470	1130	23%	1280	13. %
	15.5 in.	1820	1220	33%	1410	22.5%

Another interesting case was an experimental elevator motor generator set consisting of two standard d-c. machines, the rotors of which were on a common shaft and the stators being mounted separately on a common bed plate. The critical speed calculated on the rotor alone was about 3200 rev. per min. The actual critical speed was found to be at 1850 rev. per min. due to the combined additional flexibility of the feet and bed-plate. The system in reality was one with several degrees of freedom instead of one. By tying the two stators together with a brace, the feet flexibilities were elimin-

3. See C. R. Soderberg, *Elec. Journal*, Vol. XXI, No. 12, p. 579.

ated and the critical speed became 2800 rev. per min. (See Fig. 5.) When the inboard holding down bolts of one of the machines in the unbraced set were loosened only half of the foot material of that machine was acting as a restraint on its motion. This increase of foot flexibility lowered the critical speed to 950 rev. per min.

It can be seen that errors of critical speed calculation in the order of 40 per cent are possible in the ordinary course of design. This becomes important in case the designer thinks that he is running not far below the critical speed as he calculates it in the ordinary way.

Effects of Foundation. Synchronous machines have been tested on the test floor and in the field which showed a difference of 12 per cent. in the critical speed on account of the differences in foundations under the bed-plate. And in turbo generators, mounted as they are in power houses, several critical speeds are passed through in going up to the running speed some of which are due to flexibilities in the foundation itself. This problem is one of extreme difficulty and it is being studied by means of the vibrograph.

Effect of Magnetic Pull. Unbalanced magnetic pull also lowers the critical speed.[4] A mechanical spring always tends to return to its position of equilibrium

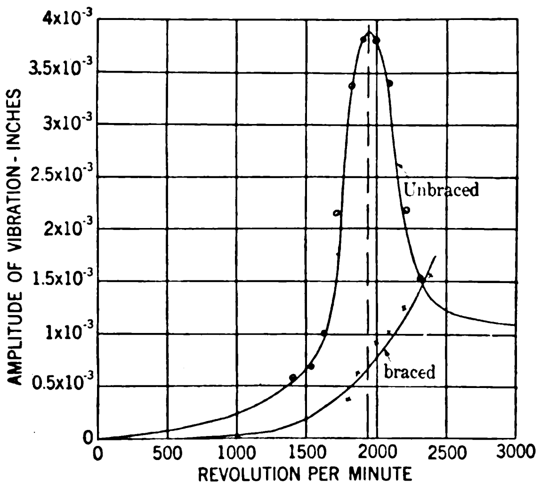


Fig. 5—Amplitude Curve—Rev. per Min. M. G. Set Vibration of Experimental M. G. Set with and without Brace

when stretched or compressed. A body in between the poles of a magnet is pulled away from its equilibrium position more and more, the farther it gets from the position of equilibrium. An unbalanced magnetic pull has a negative spring effect which decreases the total spring constant of the whole system.[5] For a given machine this can be calculated. For a certain field excitation, it reaches a maximum effect, for stronger fields its effect falls off again. In the case of the synchronous condenser mentioned before the maximum effect was at 30 amperes, field current. Table II shows the effects at this maximum taken from vibrograph records.

4. Rosenberg, Trans. A. I. E. E., 1918, p. 1425.
5. C. R. Soderberg, *Elec. Jour.*, Vol. XXI, No. 12, p. 582.

TABLE II

Direction of Vibration	Shaft Dia.	Bed-Plate A: Critical R.P.M. No. Field	Bed-Plate A: Critical R.P.M. 30 Amperes	Bed-Plate A: Per Cent Lower	Bed-Plate B: Critical R.P.M. No. Field	Bed-Plate B: Critical R.P.M. 30 Amperes	Bed-Plate B: Per Cent Lower
Horizontal	10.5	1050	930	11.5	1110	994	10.5
	12.5	1180	1070	9.0	1270	1165	8.0
	15.5	1325	1230	7.0	1460	1375	6.0
Vertical	10.5	1010	883	12.5	1110	994	10.5
	12.5	1130	1015	10.0	1280	1175	8.0
	15.5	1220	1120	8.0	1410	1320	6.0

Vibrations not due to Critical Speeds

Noisy and violent vibrations cannot always be attributed to critical speeds. The case of an induction regulator standard for single-phase 60-cycles, but applied and rated for 25 cycles shows this very clearly. The machine was noisy on the test floor, due to impact between the segment teeth and the worm. The diagnosis of critical speed in resonance with the single-phase torque was made and the usual remedy of changing the shaft diameter was tried, but without diminishing the noise. The vibrograph was mounted to measure the tangential motion of the regulator gear segment. The supply frequency was varied and the kv-a. was kept constant. The resultant torsional vibration amplitude plotted from the records are shown in Fig. 6. Instead of resonance at 25-cycle voltage (50-cycle torque variation) the amplitudes tend

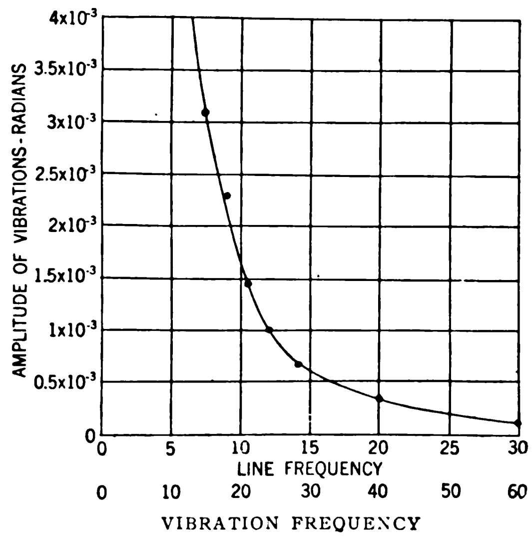


Fig. 6—Amplitude-Frequency Curve—Induction Regulator Vibration Frequency Cycles per Second

to increase toward infinity at zero frequency—or to some extremely low frequency resonance amplitude due to the clearances in the worm and segment system.

The rotor was acting very similarly to a rotor free to rotate in bearings acted upon by a periodic torque.

The amplitude of torsional vibration of such a body is in general

$$\theta_0 = - \frac{\phi_0}{I\,\omega^2}$$

θ_0 = amplitude of torsional motion
ϕ_0 = amplitude of applied torque (proportional to the kv-a. in this case.)
I = the moment of inertia of rotor
ω = $4\pi \times$ line voltage frequency

The only fundamental way to limit the oscillation was shown to be by the application of a fly-wheel to increase the inertia of the rotor. Since this could not be done gracefully or conveniently (and the idea of a fly-wheel on an induction regulator being revolutionary to say the least) the noise was cut out by putting longitudinal flexibility in the worm and making the segment from a non-metallic material. This decreased

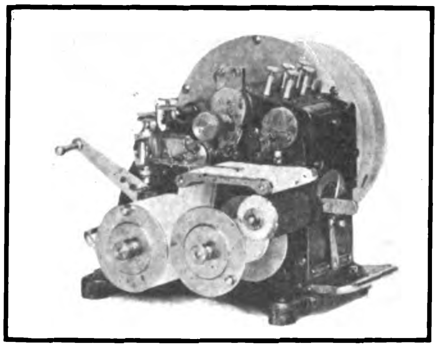


FIG. 7—TORSIOGRAPH

the deceleration value of the impact and completely eliminated the trouble.

The direct connected vibrograph has been used extensively in field balancing and in the study of magnetic noises due to stator vibrations.

TORSIONAL VIBRATIONS

Torsional vibrations although of common occurrence cannot be observed very readily even when they are of destructive magnitude. These small periodic angles of lead and lag superimposed on the constant advance of rotating parts are only noticeable when they cause chattering in gear teeth or give rise to linear vibrations on the foundation due to stator reactions. Most shaft and coupling breakage can be attributed to the dynamical stresses induced by unnoticed torsional vibrations. Where torsional critical speeds occur these stresses become very large. Although it is much easier to calculate torsional critical speeds than linear critical speeds, very few designers check this important point. Torsional vibrations being hidden are ignored.

The torsiograph has an important educational mission in emphasizing the existence of these oscillations in a concrete way. Its chief uses are in the study of torsional critical speeds, in the location of the causes of vibration and in the checking of design theories.

The torsiograph consists of a light pulley and a fly-wheel mounted concentrically on the same axis. (See Figs. 7 and 8.) The fly-wheel is held in a definite static relationship to the pulley by means of two opposing springs. (See Fig. 14.) Relative motion between the pulley and the fly-wheel about this position of equilibrium is possible. The relative motion actuates a system of bell cranks which move a recording pen push rod. The recording-paper drive and timing device are exactly the same as for the vibrograph. In addition to the timer there is a pen actuated by a solenoid which is excited by the making of a contact once every revolution of the body being tested. This indicates the instantaneous angular position of the body.

The pulley is belted to the shaft to be tested and follows its motions. The fly-wheel tends to rotate at a uniform average speed for frequencies above a certain value. The relative motion between the irregularly moving pulley and the steadily moving fly-wheel produces the record.

TORSIONAL VIBRATIONS DUE TO MECHANICAL CAUSES

Gear vibrations have been studied with the torsiograph—the most interesting conclusion drawn being that torsional vibration with a steady tooth contact frequency only occur when the gears are heavily loaded. This points to the fact that any dynamical theory of gearing must take into account the effects of deflections in the gear structure (the only thing that changes with load) as well as geometrical errors in tooth form and spacing.

GAS ELECTRIC DRIVE VIBRATIONS

The torque delivered by an internal combustion engine is inherently irregular, consisting of a constant average torque with a periodically varying torque superimposed. The relationship between the magni-

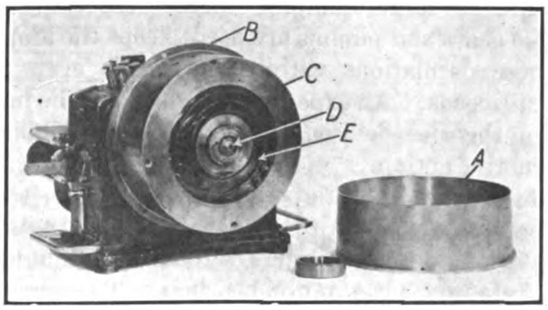


FIG. 8—TORSIOGRAPH

tudes of these two torques depends on the number of cylinders and the number of strokes per combustion cycle. The fundamental of the periodic torque has the firing frequency and all other higher harmonics also exist. The mechanical system consisting of generator rotor, fly-wheel and crankshaft with its attached reciprocating masses, has many natural frequencies. Theoretically the combination of the harmonics of the variable torque and the many natural frequencies of the rotational system lead to an infinite number of possible critical rev. per min. of the generating unit. Practically resonance with the fundamental and perhaps the second harmonic have given the im-

portant critical speeds. The other harmonics are usually too small to produce noticeable effects.

Several gas electric generating units have been investigated by means of the torsiograph—the critical speeds determined and operating speed limits have been established. The theories for precalculating the critical speeds have been checked experimentally by means of the instrument.

Where flexible couplings have been used on gas electric units records on both sides of the coupling have shown how the coupling acts as a wave filter, only the lowest harmonic of the variable torque being prominent on the generator side of the coupling and at speeds far above the lowest critical speed of the rotational system even the fundamental gets very small.

TORSIONAL OSCILLATIONS IN SIDE-ROD ELECTRIC LOCOMOTIVES

The torsional oscillation of the rotating system of a side rod electric locomotive is an important problem where locomotive frames, rods and cab structure are very light as in European practise. In the heavier American designs this problem loses much of its importance; but the careful designer attempts to make the possibilities of destructive torsional vibrations remote. The torsiograph has been used extensively in Europe in checking the numerous theories which have been developed on this subject. Theoretically, errors in side rod length (or "tram") errors in crank length and quarter, and pin clearances, can give rise to oscillation having driver rotational frequency, and the second and fourth harmonic of this frequency. Torsiograph records show that these exist; but the presence of large damping forces (especially where flexible gears and pinions are used) keeps the amplitude of these oscillations within safe limits even at the critical speeds. An experimental check can be made on design theories devised to lessen the possibilities of destructive action.

Where gears are interposed between the motors and drivers, resonance with the tooth frequency vibrations must be avoided on all parts of the motors and locomotive frame near the motor bearings. The torsiograph records show what conditions of load are necessary to bring about large amplitude of these gear frequency oscillations.

TORSIONAL VIBRATION FROM ELECTRICAL CAUSES

It is a well-known fact that single-phase rotating machines vibrate torsionally with double line-voltage frequency[6] and amplitudes proportional to the kv-a. The reaction of these single-phase torques through the stators of large machines have made it advisable in some cases to go to special spring mounting to protect the foundation of the machine from the double-line frequency forces.[7] The torsiograph makes a very convenient means of studying these oscillations.

It is generally assumed that polyphase motors rotate uniformly under all conditions. Torsiograph records in many instances show double line frequency torsional oscillation just as in the case of single-phase machines—the amplitudes being much smaller. Experimentally this was shown to be due to unbalance in the primary winding—unbalanced voltage or unbalanced impedance being equally effective. It can be shown theoretically by the use of symmetrical coordinates,[8] that the positive and negative sequence currents and voltage due to electrical unbalance produce a small torque of double line frequency superimposed on the average constant torque expected. The amplitude of the resultant vibrations is proportional to the amount of unbalance. Similarly it has been shown theoretically and experimentally that unbalanced resistances in the secondary of a wound rotor motor can produce destructive torsional vibrations on the rotor[9].

Unbalance in the secondary currents which have a fundamental frequency equal to the slip frequency will induce currents in the primary circuit having a frequency of $f - (n + 1)\, s$ where

f = line frequency
n = number of unbalanced secondary harmonic
s = slip frequency

Torques produced by a current having a frequency $f - (n + 1)\, s$ and a flux with frequency f will be of two frequencies $2 f - (n + 1)\, s$ and $(n + 1)\, s$.

This theory was developed by C. R. Soderberg and tested by him by means of the torsiograph and oscillograph.

In tying any a-c. motor onto a common shaft bearing other rotating masses the designer must be careful to avoid resonance with double the line frequency of the a-c. supply. This is especially necessary if the motor is single-phase; but should not be neglected even in the case of polyphase motors.

DIAMOND MINING AT NIGHT

An interesting application of modern electric flood lighting is in the Premier Mine in Transvaal, Africa, where the work of removing diamond-bearing earth is carried on twenty-four hours a day.

The mine extends over some 78 acres and at present has been dug out to a depth of about 500 ft. Excavations of diamond-bearing earth in the volcanic vent where diamonds are usually found are done in a series of terraces of 50-ft. depth. Since the mine has had to be worked day and night, it was necessary to supply efficient illumination. Arc lighting was tried but the blasting proved detrimental to the delicate mechanism of the arc lamps resulting in expensive maintenance. Now, electric flood lights housed in 14 huts are situated on the rim of the mine, with the rays projected from the rim to the working surface at distances ranging from 900 to 1600 ft.

6. A. L. Kimball and P. L. Alger, TRANS. A. I. E. E., 1924 p. 730.
7. C. R. Soderberg, *Elec. Journ.*, Vol. XXI, No. 8, p. 383.
8. C. L. Fortescue, TRANS. A. I. E. E., 1918, p. 1027.
9. A. F. Kenyon, *Elec. Journ.*, Vol. XXII, No. 9, p. 435.

Ionization Studies in Paper-Insulated Cables—I.

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Member, A. I. E. E.

and

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***Synopsis.**—A research investigation of the ionization phenomena which occur in paper-insulated, high-voltage power cables is being made at the Harvard Engineering School under the auspices of the Impregnated Paper-Insulated Cable Research Committee. The paper presents some of the preliminary results which have been obtained, certain tentative conclusions that are suggested by the data and a description of the method developed for making the measurements. It is a preliminary report and in subsequent papers it is intended to record the progress of the investigation as it proceeds.*

The paper consists essentially of four parts as follows.

(a) A number of curves of power, power factor and capacitance taken on samples of cable at two frequencies and over a wide range of temperature. These curves show well-known characteristics, but in order to exaggerate these effects, cable models were made up to simulate the general conditions in a cable—one model consisting of glass and air only and another of glass, air and paper. Tests of these cable models gave very interesting results, particularly with reference to power factor. They also show rather clearly the baffling action of paper and the effects on power, power factor and capacitance when this baffling action is eliminated. In practically all the curves, the power and power factor begin to increase rapidly at a lower voltage gradient than the capacitance.

(b) Discussion of the results obtained and certain tentative conclusions which may be drawn from the results so far obtained and reported herein.

1. Ionization in the dielectric of an air condenser increases its capacitance slightly at first and then rapidly as the electron is separated from the atom. In our measurements we accordingly found that the power and power factor increase rapidly at a lower voltage gradient than the capacitance.

2. Ionization which occurs within air spaces in a dielectric may be called "restricted ionization" in that the current is limited because of the remainder of the dielectric in series.

3. With "restricted ionization," the voltage across each air space reaches a constant finite value with indefinite increase in the over-all voltage. The resistance of the ionized space, therefore, must be inversely as the current.

4. Consequently when this condition is reached, the ionization loss may be proportional to the charging current.

5. The increase of power factor with increase in voltage gradient with subsequent decrease of power factor is due to the fact that the capacitance of the solid dielectric, which is substantially constant, is in series with ionized air spaces whose resistances are inversely as the current. A simple mathematical analysis of this type of electric circuit shows that power-factor curves should have the form obtained in the measurements. Hence power factor alone is not a criterion of the degree of the completeness of saturation by compound.

6. Ionization by its bombarding action may destroy the baffling action of paper.

7. Ionization may produce potential gradients tangential to the surface of the layers of paper which, in conjunction with the bombarding action, may be the cause of the so-called "tree designs."

(c) Discussion of methods for measurements of this sort and a description of a new type of bridge which was devised for the measurement of dielectric losses at these extremely low power factors with the necessary high degree of accuracy. A large air condenser used as a standard and a vibration galvanometer of unusually high sensitivity and wide range of tuning were designed for use as a detector. The bridge is quickly and accurately balanced by varying a resistance and a mutual inductance. The angle of defect of the standard air condenser, although extremely small, is nevertheless very important in measurements of this character. This angle was measured by a substitution method and corrections made accordingly.

(d) Four appendixes discussing respectively (1) method of measuring defect angle of the standard air condenser, (2) mathematical analysis of a condenser of composite dielectric consisting of air and solid homogeneous material, (3) measurement of the high-voltage ratio, and (4) measurements of the capacitance, and other electrical constants of an ionized air space in series with a solid dielectric.

INTRODUCTION

THIS paper presents some of the results of research work being carried on at the Harvard Engineering School on the subject of Ionization Phenomena in the Insulation of High-Voltage Paper Cables. The work is conducted under the auspices of the Cable Research Committee, which is a subcommittee of the appropriate committees of the National Electric Light Association, the American Institute of Electrical Engineers, and the Association of Edison Illuminating Companies. The National Electric Light Association provides the Research Fellow for the work. The work is under the immediate supervision of a Cable Research Committee made up of members of the Faculty of the Harvard Engineering School, and one of the authors is Chairman of this Committee.

A summary of the more important results which have been obtained up to the present time is presented together with suggested explanations based upon the modern theory of ionization. However, an important object in presenting these results at this time is to invite discussion, from which it is hoped to obtain ideas which will aid in the further prosecution of the investigation.

PROCEDURE

The fact that ionization or breakdown of occluded air and other gaseous films exists in laminated insulation, such as impregnated paper as used in cables, has been known for some time. However, opinions and theories differ as to the exact nature of this ionization and its effects on the insulation of the cable as a whole. A fundamental object of our investigation is to determine, so far as possible, the exact nature of these ionization phenomena and to suggest in explanation a rationa

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theory which can be substantiated by experimental data.

Naturally, our first procedure was to obtain experimental data on samples of commercial cables under various conditions of temperature, of frequency and of voltage gradient. From the analysis of these data it was hoped that some of the laws of the ionization taking place within the cables could be determined and a theory suggested to account for them.

In order to study such laws it is necessary to make measurements with a degree of precision much higher than is required for commercial testing. To obtain high precision in measuring such losses is not easy, especially at the present time when cables are designed particularly to have low dielectric loss and low power factor. Accordingly, before beginning the work, it was necessary to devise a satisfactory method of making the measurements. The authors investigated the various methods which have been described up to the present time and tried many of them. However, they were all found to be unsatisfactory because of their lack of precision or the difficulty in manipulation. After considerable experimenting, during which two or three promising methods were discarded, the one shown in the diagram of Fig. 1 was found to be the most satisfactory as regards accuracy, simplicity and ease of manipulation.

A simplified diagram of the bridge is given in Fig. 2. Referring to Fig. 1, the cable and a resistance R_2 of the order of 50 to 100 ohms for a 10 ft. length of cable, form one side of the bridge, while a standard air condenser C_1 and a resistance R_1 of the order of 1000 ohms form the other side. The primary of a mutual inductance M is inserted in series with the cable. The galvanometer G is connected in series with the secondary of the mutual inductance between points $c\ d$ of the bridge. The voltage drops across R_1 and R_2 are small, being of the order of one volt, so that no difficulty is experienced from the effects of the capacitance to ground of the detector. A simplified diagram of this bridge is given in Fig. 2. The cable is represented by the capacitance, C_2, and its equivalent series resistance, r_2. The standard air condenser is represented by the capacitance, C_1, and its equivalent series resistance is shown as r_1.

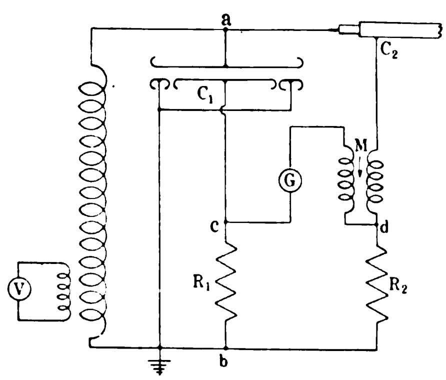

FIG. 1

The self-inductance L of the primary of the mutual inductance M is approximately 10 millihenrys, so that its impedance is small compared with that of the cable. Hence, in developing the equations for this bridge, the impedance of the primary of the mutual inductance M is neglected. In the equations for the bridge, let

$$\eta_1 = (R_1 + r_1)\, C_1\, \omega = \operatorname{Tan} \psi_1$$
$$\eta_2 = (R_2 + r_2)\, C_2\, \omega = \operatorname{Tan} \psi_2$$

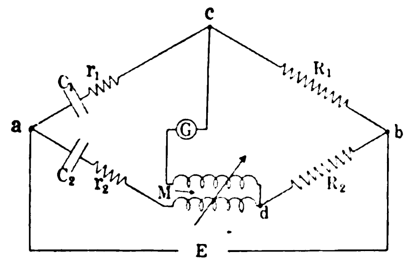

FIG. 2

A simple calculation gives for the conditions of balance:

$$C_1 R_1 = C_2 R_2 \frac{(\eta_1^2 + 1)}{(\eta_1 \eta_2 + 1)} \tag{1}$$

and

$$\frac{M\, \omega}{R_2} = \frac{\eta_2 - \eta_1}{\eta_1 \eta_2 + 1} \tag{2}$$

Since η_1 and η_2 are small compared to unity, the second order terms may be neglected and

$$C_1 R_1 = C_2 R_2 \tag{3}$$

and

$$\operatorname{Tan} \psi_2 - \operatorname{Tan} \psi_1 = \frac{M\, \omega}{R_2}$$

or

$$\operatorname{Tan} \psi_2 = \frac{M\, \omega}{R_2} + \operatorname{Tan} \psi_1 \tag{4}$$

If the condenser C_1 is a perfect air condenser, $\operatorname{Tan} \psi_1 = 0$, and ψ_2 is the angle of phase defect of the cable. If ψ_1 is not zero, the correction is simple.

Careful check measurements showed that our air condenser, although carefully insulated and guarded, did not have a phase angle of 90 deg. After considerable difficulty, the authors were able to obtain this angle at the lower voltages by a substitution method which is described in Appendix I. It was not possible for the writers to determine the angle at the higher voltages as they did not have a high voltage air condenser whose loss would remain constant when its capacitance was varied.

The bridge was balanced by varying R_1 and M, R_2 remaining constant. If the air condenser be assumed perfect.

$$\operatorname{Tan} \psi_2 = \frac{M\, \omega}{R_2} = \sin \psi_2$$

The power factor of the cable = cosine θ = sin ψ_2 which is sensibly equal to tan $\psi_2 = \dfrac{M\,\omega}{R_2}$, since ψ_2 is a small angle. Hence, for approximate work with the higher power factors the mutual inductance may be calibrated directly in power factor for any given frequency. This is a distinct advantage both in research work and in routine testing.

Considerable difficulty was experienced in obtaining a suitable detector. The detector must not only be sensitive but must have moderately high impedance in order to work properly with the bridge. The various standard types of vibration galvanometer were tried, but none was found satisfactory. Therefore, it became necessary to design and construct one. The moving iron-vane type, having an electromagnet for excitation, was found to be the most satisfactory.

With low voltages, or with small samples, the detector itself would not give the desired sensitivity. We, therefore, designed and constructed a three-stage resistance-coupled vacuum tube amplifier, which increases the sensitivity by something like 1000 times.[4]

With the foregoing apparatus it is possible to balance the bridge to measure phase angles to 0.001 per cent and detect even smaller changes. In view of the fact that the dielectric properties of the insulation which were measured are not constant, the foregoing precision is much greater than is necessary.

The voltage was measured by means of a voltmeter coil in the high-voltage winding of the 100-kv., 15 kv-a., 60-cycle transformer which supplied the power. The multiplying factor of the voltmeter coil was determined by a null method described in Appendix III.

The standard condenser consisted of two polished copper plates with rounded edges and corners. The low-voltage plate is guarded as is indicated in Fig. 1. The area of the working plate is 4 ft. × 5 ft. (1.219 m. × 1.525 m.). The distance between plates can be adjusted to suit the voltage, hence constant sensitivity is obtained.

The capacitance C_1 of the standard condenser was measured with a precision capacitance bridge. Knowing this capacitance and the resistance R_1, the capacitance C_2 of the cable is determined. It is then a simple matter to calculate the power, since the power

$$P = E^2\,C_2\,\omega \sin \psi_2$$

where ψ_2 is the angle of phase-defect of the cable. If ψ_2 is small, the power

$$P = \frac{E^2\,C_2\,M\,\omega^2}{R_2}$$

A 15-kv-a., 220-volt, 60-cycle alternator known to have a reasonably good sine wave[5] was used in all these measurements. Its voltage was controlled with a motor-driven field rheostat.

Measurements. Measurements were made at first on single-conductor cables having walls of insulation of approximately 20/32 in. thickness (16 mm.). Such cables would ordinarily be rated at 33 kv. Fig. 3 shows a typical power-factor curve obtained with a 500,000-cir. mils. cable having this thickness of wall. We noticed that at 50 kv. the rate of increase of the power factor became less. This has been observed by others[6]. At 60 kv. it apparently reached a maximum and then decreased slightly. This decrease of power factor in high-voltage cables after a maximum is reached has been known for some time among engineers.[7] So far as we know, however, no satisfactory explanation has been given for this character of power-factor curve. In fact, this decrease in power factor appeared to be contrary to the well-known explanations heretofore given to account for the increasing power factor

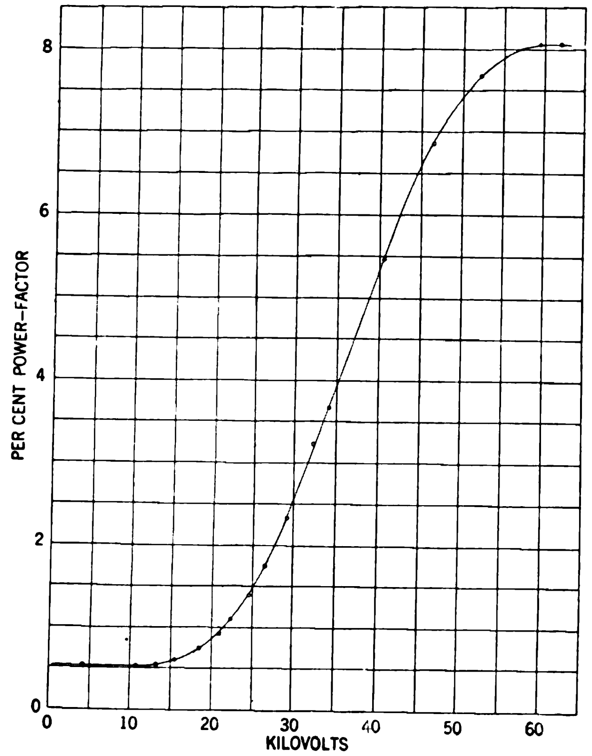

Fig. 3—5,000,000-Cir. Mils, Single Conductor Cable
20/32 inch insulation. 1/8-inch lead
20 deg. cent. 60 cycles per second

4. See Trans. A. I. E. E., 1925, p. 122, Discussion by C. L. Dawes.

5. For an oscillogram of this voltage wave, see "Artificial Transmission Lines," Kennelly & Lieberknecht, Trans. A. I. E. E., Vol. XXXI, 1912, p. 1138.

6. C. F. Proos. "Some Considerations on the Dielectric Losses in High-Tension Cables." Report to Ass. of Managers of Electrical Works in the Netherlands, 1921. (Proos plotted P/E^2, or equivalent conductance, against voltage which gives the same character of curves as power factor against voltage, provided the capacitance of the cable does not change very much.)

7. D. W. Roper. Trans. A. I. E. E., 1925, p. 116. Curve E, Fig. 4. Also *Electric World*, Feb. 21, 1925, p. 399.

with increasing potential gradient. That is, the ionization commences in the air spaces adjacent to the conductors and occurs progressively in the air spaces from the center outwards as the potential is raised. In view of these uncertainties, it appeared to us that further study of this phenomenon might give some additional information as to the nature and effects of ionization in cables.

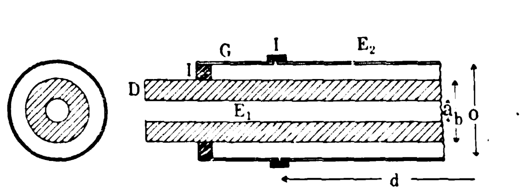

FIG. 4

E_1	Mercury electrode
E_2	Brass tube
I	Bakelite rings
G	Guard Rings
D	Glass tube
a	3.1 mm.
b	9.3 mm.
c	14.3 mm.
d	31.5 cm.

Schrader[8] also found with small air spaces in flat dielectrics that the power factor increased to a maximum and then decreased to a low value with increase of voltage.

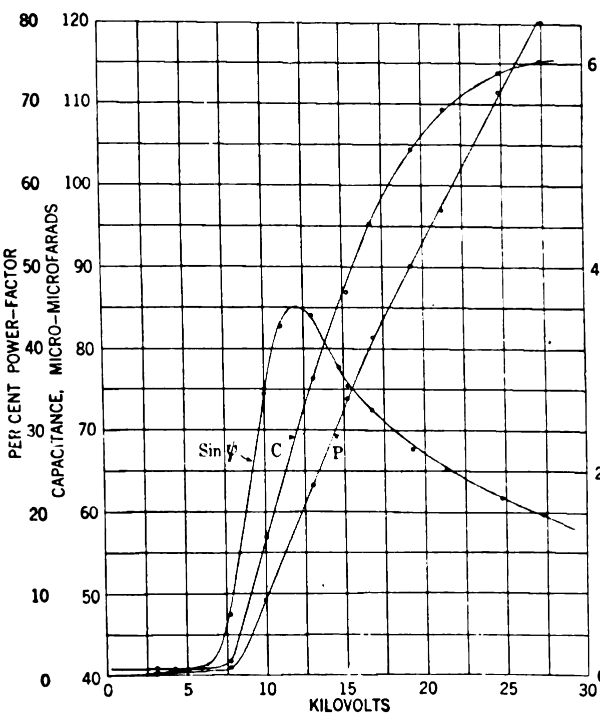

FIG. 5—CABLE MODEL. GLASS-AIR DIELECTRIC

20 deg. cent. 60 cycles per second

For purposes of study, we made a small cable model, Fig. 4 in which the ionization effects occurring in actual cables would be exaggerated. A glass tube having an inside diameter of 3.1 mm. and an outside diameter of 9.3 mm. was filled with mercury, the mercury forming the center electrode. A brass tube having an inside diameter of 14.3 mm. was placed concentric with this glass tube and insulated from it. The length of the brass tube between guard rings was 31.5 cm. Fig. 5 shows the curves of power factor, capacitance and watts loss obtained with this cable model at room temperature and at a frequency of 60 cycles per second. This is the character of curves which we expected the cables would have.

In order that we might obtain sufficiently high voltage gradients in cables to produce similar effects, it was found desirable to use smaller cable. Accordingly, a 00 A. w. g. (diameter = 0.418 in. = 10.6 mm.) single-conductor cable with a 9/32 in. (7.1 mm.) wall of insulation was used. In accordance with ordinary

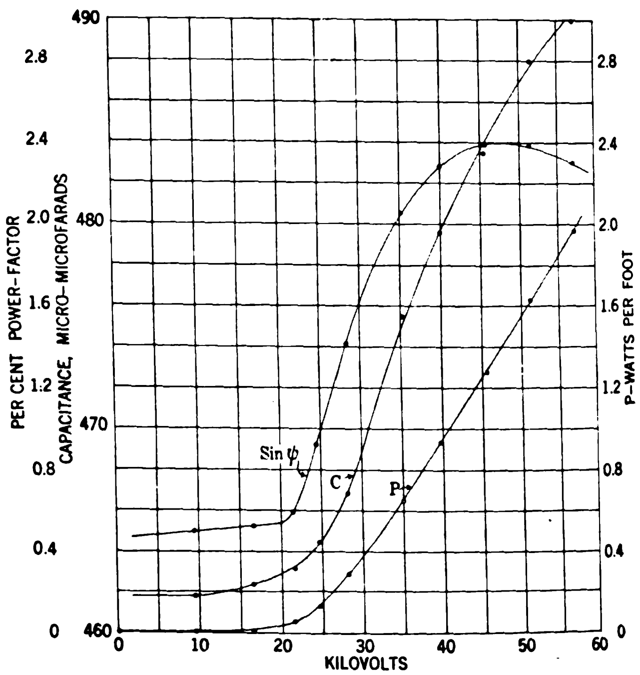

FIG. 6—IMPREGNATED PAPER CABLE. NO. 00 SINGLE CONDUCTOR

9/32-inch insulation. 20.4 deg. cent. 60 cycles per second

American practise, this cable would probably operate at 12 kv. The cable was guarded at its ends and end-bells filled with impregnating compound were fastened to the ends to prevent the compound from oozing out and air entering with change in temperature. The net length of cable tested was 7½ ft. (2.3 m.). Curves taken for this cable under various conditions are shown in Figs. 6 to 10 inclusive.

In Fig. 6, curves of power factor, capacitance and watts per foot are given for a frequency of 60 cycles per second and at a temperature of 20.4 deg. cent. as shown. At each reading sufficient time was allowed for the reading to become constant. It will be noted that the power factor after reaching a maximum value of 2.4 per cent actually does begin to decrease, as had been anticipated.

8. Schrader. "Corona in Air Spaces in a Dielectric." TRANS. A. I. E. E., Vol. 41, 1922, p. 583.

The difficulties in obtaining quantitative data on cable samples under these conditions of test are illustrated in Fig. 7, which shows curves taken at a frequency of 60 cycles per second and at a temperature of 53.8 deg. cent. The potential was first increased as before, readings being taken at frequent voltage intervals, and only after conditions had apparently become constant. When 58 kv. was reached the potential was decreased and readings taken at inter-

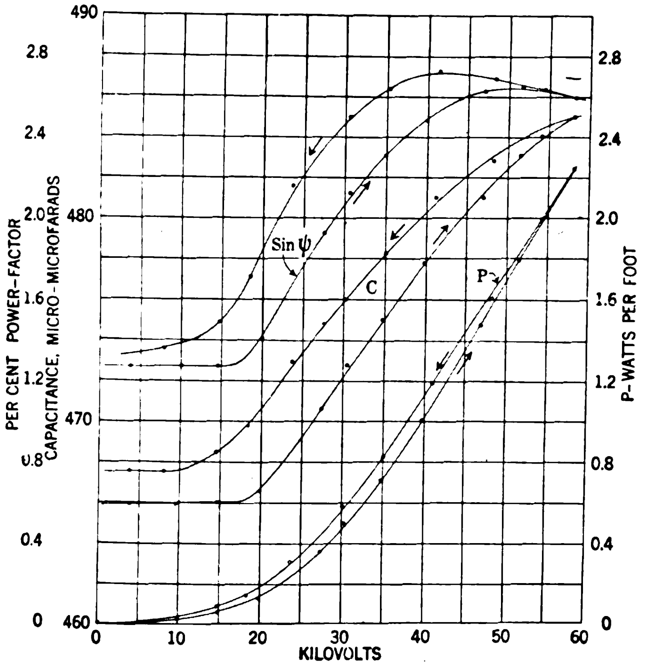

Fig. 7—Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 53.8 deg. cent. 60 cycles per second

vals to zero voltage. These readings, however, were taken immediately following each adjustment of voltage, a pause of only two or three minutes being necessary for taking each reading. Hence the dielectric was not given time to attain constant condition. It will be noted that the values of power factor, watts per foot and capacitance are all considerably greater for decreasing voltage than for increasing voltage. It should also be noted that with increasing voltage the watt curve and the power-factor curve begin to increase at a considerably lower voltage than the capacitance curve. Moreover, with decreasing voltage the curves reach constant values at lower values of voltage than they do with increasing voltage. Before taking each reading with decreasing voltage, if sufficient time for conditions to become constant be allowed, the values obtained are in most cases only slightly greater than the corresponding results with increasing voltage. In some instances, however, it has been found even when steady conditions are reached that the values with decreasing voltage are less than corresponding values for increasing voltage. We have also found that measurements vary considerably from time to time, even when taken under the same conditions. With impregnated paper insulation, for example, dielectric measurements frequently do not repeat themselves. On one occasion after completing a 60-cycle test, we found that the 25-cycle losses were greater than the 60-cycle losses even though sufficient time had been allowed for the cable to reach constant conditions. Due to such variations in the cable dielectric, great care must be taken if quantitative data are to be of value.

In Fig. 8 the solid lines are the curves of power factor and capacitance taken at 60 cycles but at a temperature of 88 deg. cent. It will be noted that the power factor increases rapidly when the potential is increased from 2 to 8.5 kv., at which point it reaches a first maximum. It then decreases, reaching a minimum at 15 kv. and again increases in the ordinary manner. This peculiar effect cannot be due to errors in measurement, since this portion of the curve was checked carefully. Moreover, this effect occurs only at high temperatures. It appears again in Fig. 9 taken at a temperature of

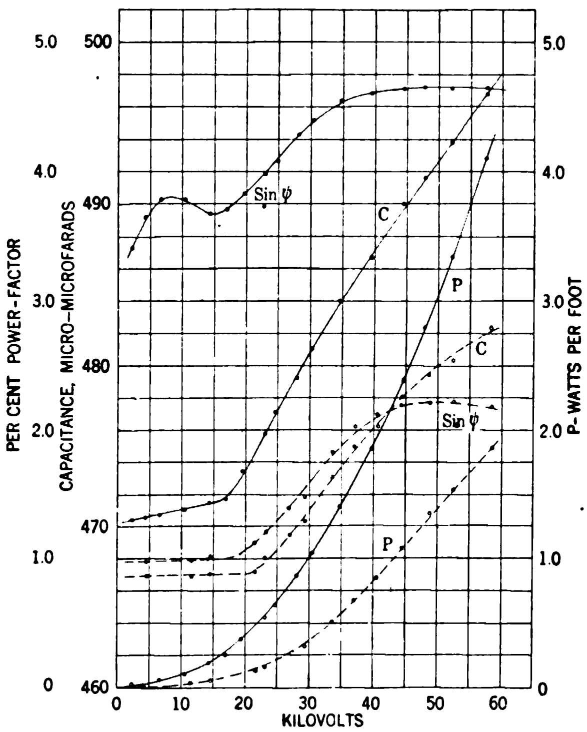

Fig. 8 —Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 60 cycles per second. 88 deg. cent. (Dotted curves are Fig. 10)

98.5 deg. cent. and at a frequency of 32 cycles per second. The authors are not prepared at this time to offer a definite explanation of this sudden variation in the power factor.

It will be observed at the higher temperatures that the range of maximum power factor is greater than at lower temperatures; also the power factor does not begin to decrease at as low a voltage as it does at the

lower temperatures, and further the decrease in power factor is not so marked.

In Fig. 9 the solid lines are curves taken at a frequency of 32 cycles per second and a temperature of 98.5 deg. cent. It will be observed that this power-factor curve has the same peculiar characteristic which appears in the 60-cycle curve, Fig. 8.

Fig. 10 shows a set of curves in which the watts per foot are plotted as a function of temperature, each curve being taken at a constant voltage. The frequency throughout is 60 cycles per second.

Analysis of Ionization Phenomena

Since the curves taken with our glass-tube cable model (Fig. 5) have all the dielectric characteristics

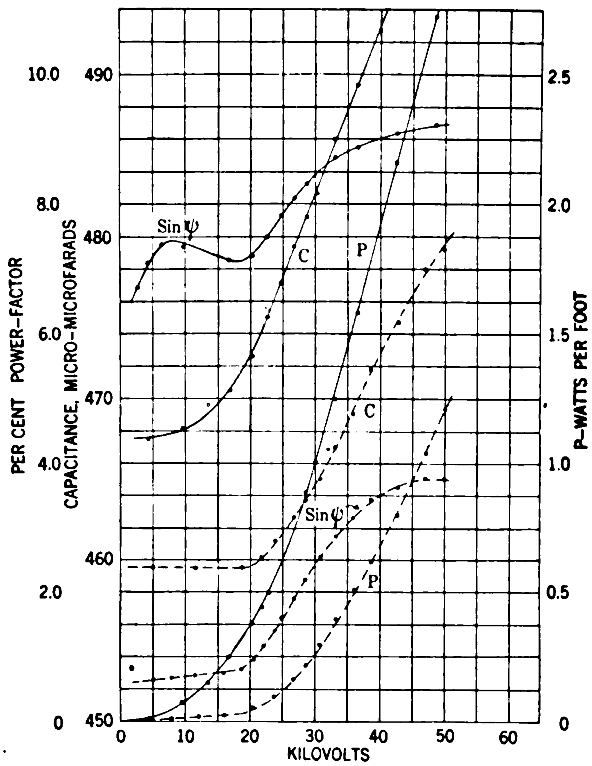

Fig. 9—Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 32 cycles per second. 98.5 deg. cent. (Dotted curves are Fig. 12)

of the actual cable, it seemed as if further data taken with such models might be of considerable assistance in the analysis of cable phenomena, particularly in view of the fact that the composite dielectric of glass and air is much simpler than that of paper, a compound of low viscosity, and air. Accordingly, another model similar to that of Fig. 4 was made and curves taken, Fig. 11. The glass of this model was slightly different from that of the first model, the curves for which are shown in Fig. 5. Aside from slight quantitative differences, these curves are similar to those of Fig. 5.

In attempting to analyze our own results, as well as those of Schrader, we found it necessary to know the effect of corona formation on the voltage gradient in air spaces and on the capacitance of air spaces. With the formation of corona about cylindrical conductors,

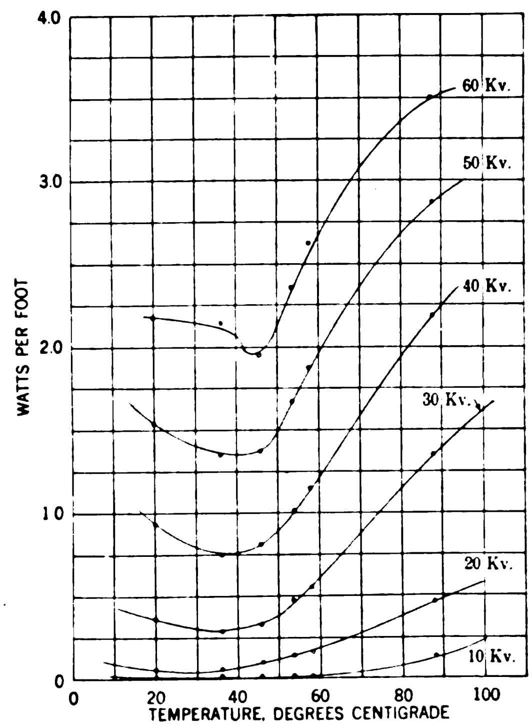

Fig. 10—Impregnated Paper Cable. No. 00 Single Conductor

9/32-inch insulation. 60 cycles per second

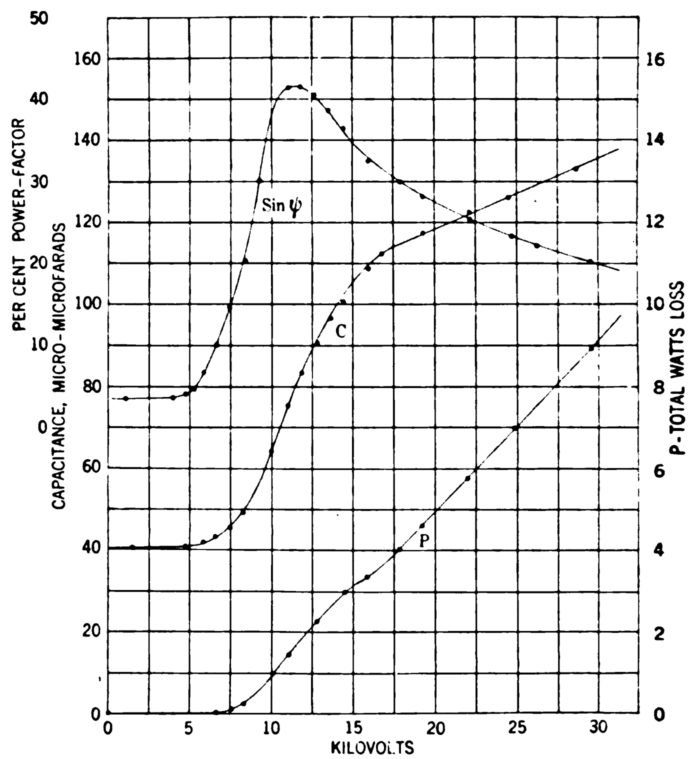

Fig. 11—Cable Model. Glass-Air Dielectric

20 deg. cent. 60 cycles per second

it has frequently been assumed that corona increases the effective diameter of the electrode[10]. This may

be true, but certainly this assumption must be qualified to the extent that this corona formation is not equivalent to increasing the diameter of the electrode in the sense that the voltage across the corona formation is negligible. Peek[10], later in his book, recognizes this fact for on page 85 he states: "Hence, corona seems to be either in *effect* a 'series resistance,' or it grades or distributes the flux density."

If, for example, in a composite dielectric of solid material and air, the voltage across the air spaces were neglected after corona is formed, the capacitance would increase abruptly at the critical gradient and immediately attain a nearly constant value. With our glass cable models, the capacitance should behave in almost this same manner when the gradient is sufficient to cause corona throughout the air space between the glass tube and brass cylinder. A study of Figs. 5 and 11 shows that this is not true.

So far as is known, no attempt has been made to determine the law connecting change in capacitance and ionization. Accordingly, some preliminary investigations of this phenomenon have been made by the authors and some of the results are given in Appendix IV. These results show that with a flat air space 2 mm. thick the capacitance of the air space when ionized reaches a value which is 28 times the capacitance for the non-ionized condition.

In addition to the increase in capacitance in the air films, when ionization takes place, the relation of voltage gradient to current also changes. To show in more detail the effects of this relationship, a reproduction of some curves given on page 267 of Townsend's "Electricity in Gases," is shown in Fig. 12. These curves show the current-voltage relation of air with parallel plate electrodes. The curves are taken for spacings of 2, 1, and 0.5 cm. The pressure in each case was 1.1 mm. of mercury and the initial ionization was produced by X-rays. These curves represent some of the first data taken in experimental work on ionization phenomena and are now considered quite elementary. Nevertheless, they are important in that they appear to offer explanations of some of the ionization phenomena which we have observed.

At low voltages, a current which, although very small, is finite flows through the air space. This current is due to the motion of the free ions and is practically independent of the voltage. In air, under ordinary conditions, this so-called "saturation current" is very small, and is practically negligible.

With increasing voltage the velocity of the moving ions increase and ionization by collision begins. As a result, the current increases rapidly, but there is no discontinuity in the curve. The curves have sharp bends, however, and after a certain voltage gradient is reached, the current density increases so rapidly with slight increases in voltage that we usually regard these curves as discontinuous and consider that the air has a definite breakdown gradient. It is important to remember that although the curves are not discontinuous with voltage gradients beyond the bend, the current density increases enormously with further slight increase in gradient. In the limit the current density becomes so great that sparkover or arc discharge results and the curve then takes a negative slope. With air films in solid dielectrics, the current is restricted by the solid dielectric in series with the air film, and the discharge does not go beyond the glow or corona

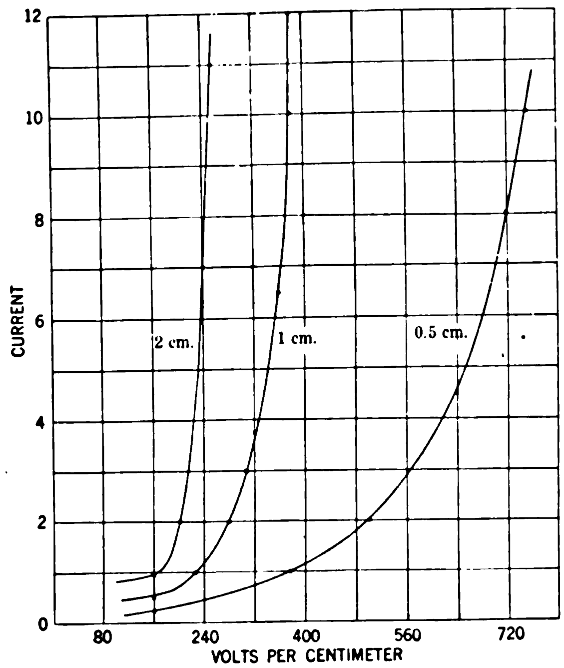

FIG. 12—CURRENT-VOLTAGE CURVES FOR AIR. PARALLEL ELECTRODES

1.1 mm. Hg. (Data from Townsend "Electricity in Gasses," page 267.)

formation, unless rupture of the entire dielectric occurs.[12]

From the curves, Fig. 12 it is apparent that for each spacing of electrodes the voltage gradient *increases* with the ionization current density until a limiting voltage gradient, which cannot be exceeded, is reached. With the 2 cm. spacing, Fig. 12 this gradient is approximately 180 volts per cm. and with the 1 cm. spacing it is approximately 300 volts per cm. With air, under ordinary conditions of temperature and pressure, this gradient is 30 kv. per cm. (maximum), except with very thin films.[13] With any current whose

10. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," p. 27.

M. F., Gardner, "Corona Investigations on an Artificial Line," JOUR. A. I. E. E., Aug. 1925, p. 813.

J. J Ryan, and H. H. Henline, "The Hysteresis Character of Corona Formation," JOUR. A. I. E. E., Sept. 1924, p. 826. (The statement, however, is omitted in the "TRANSACTIONS.")

12. A. L. Atherton, "1922 Developments in Autovalve Lightning Arresters," TRANS. A. I. E. E., Vol. XLII, (1923) p. 179.

13. F. Dubsky, "The Dielectric Strength of Air Films Entrapped in Solid Insulation," TRANS. A. I. E. E., Vol. XXXVIII, 1919, p. 537.

magnitude is consistent with values of currents existing in dielectrics, such as are given in Fig. 12, the voltage gradient in the air is never zero. On the contrary, the gradient increases with increasing current density, approaching a definite maximum gradient for that particular air film. These effects have been verified by the tests made on ionized air, the results of which are given in Appendix IV.

Returning now to the cable models, let e_1 be the potential across the air dielectric, and e_2 the potential across the glass dielectric. Until the ionization voltage is reached, the potentials e_1 and e_2 will be inversely proportional to the normal capacitances c_1 and c_2 of the air and glass. Beyond this voltage, however, the potential e_1 cannot increase appreciably but must remain substantially constant. Hence, any further increase in the total voltage must be taken by the capacitance c_2. Curves illustrating this effect are given in Fig. 13, in which the voltages e_1 and e_2 are plotted as functions of the total voltage E. Each of the voltages e_1 and e_2 increases proportionately to E until 7.5 kv. is reached, beyond which point e_1 remains constant. For voltages greater than this critical voltage, any increase in E produces in equal increase in e_2. This assumes that e_1 and e_2 are substantially in phase. This is not strictly true, particularly at large values of E, as e_1 tends to come in phase with the current because of ionization losses in the air space. This would only change the slope of e_2 without changing its general character.

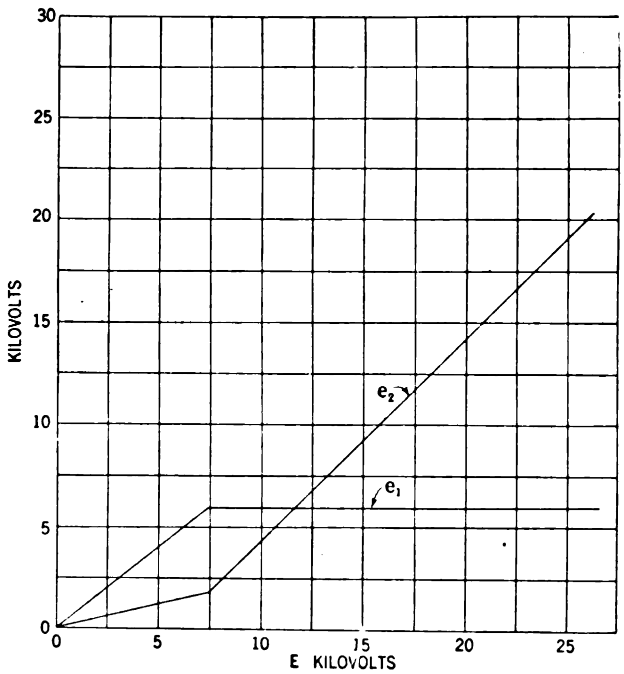

FIG. 13—VARIATION OF e_1 WITH TOTAL VOLTAGE, E

It seems reasonable, therefore, to conclude that corona in gaseous films produces a definite limiting gradient in the film, which depends on the nature of the gas, the pressure, the temperature and the geometry of the film. The current density in such an ionized gas does not depend on the voltage across the film, but rather on the impressed voltage and the remainder of the dielectric circuit. That is, the solid or non-ionized dielectric will limit the current density and it cannot increase indefinitely, as is indicated by the curves of Fig. 12 until rupture of the entire dielectric occurs.

This gives a condition which may be considered as *restricted ionization.*

Decreasing Power Factor. Schrader,[8] in explaining the decreasing power-factor with increasing voltage, which he obtained, states that it "indicates that saturation of ionization is approached." Our ordinary understanding of the statement "saturation of ionization" is that practically all the molecules have become ionized and the resulting ions and electrons are acting as carriers of electricity across the gaseous film. Calculation shows that this condition cannot exist in such air films. For example, if it be assumed that there is but one electron per molecule carrying the ionization current, the current density through the ionized gas would be several amperes per sq. cm. Obviously, no such current density is possible in air films within dielectrics.

Proos[6] plotted conductance against kilovolts and obtained curves very similar to power-factor curves. but consisting of three straight lines.

Clark and Shanklin[9] plotted "specific resistivity (effective)" or P/E^2, or the equivalent shunt resistance of the cable, against kilovolts. (This is the reciprocal of the quantity which Proos plotted.) They explain the lesser rate of decrease of their curves as follows:

> "Gradually a point of saturation is reached and the energy consumed by ionization approaches more nearly a true ohmic loss."

Shanklin and Matson[14] explain similar characteristics as follows:

> "Complete saturation is not yet reached, but the curve is flattening out, showing that the majority of the gas spaces have been ionized."

Although these statements are in a sense correct, we do not feel that they are adequate explanations of the phenomena. Even though ionization is a contributing cause, the character of these curves is not determined solely by the degree of ionization, but rather by the changes, due to ionization, in the constants of the series condensers consisting of the solid dielectric and the air films.

The equivalent circuit of the solid dielectric and air space is shown in Fig. 14, in which c_1 is the capacitance of the air space and r_1 is its equivalent shunted resistance; c_2 is the capacitance of the solid dielectric and r_2 is its equivalent shunted resistance. It can be shown

14. Shanklin and Matson, "Ionization of Occluded Gases in High-Tension Insulation," TRANS. A. I. E. E., Vol. XXXVIII, 1919, p. 489—See page 494.

that the sine of the angle of phase defect of the combination is

$$\sin \psi = \frac{e_2 \sin \psi_2 + e_1 \sqrt{1 - \dfrac{(e_1 c_1)^2}{(e_2 c_2)^2}}}{E} \qquad (5)$$

where e_1 and e_2 are the voltages across c_1 and c_2, E is the total voltage and ψ_2 is the angle of phase-defect of the solid dielectric. (See Appendix II.)

Below the ionization voltage, $e_1 c_1 = e_2 c_2$ since e_1 and e_2 are substantially in phase with each other, hence the radical is equal to zero and the power factor equals

$$\sin \psi = \frac{e_2 \sin \psi_2}{E}.$$

Above the ionization voltage, e_1 and c_2 remain nearly constant. c_1 and e_2 both increase very rapidly (Fig. 13.) From our experimental data with both the cable models and with flat air spaces (Appendix IV) we know that immediately above the ionization voltage e_2 increases more rapidly than c_1. Hence, the expression under the radical sign increases rapidly, which causes a rapid increase in sine ψ or in the power factor of the combination. Also, when ionization commences, the left-hand term becomes small in comparison with the right-hand term. At higher values of the voltage E, c_1 commences to increase very rapidly also, and the rate of increase of the right-hand expression becomes less than the rate of increase in E. As a result, with further increase in E. sin ψ and hence the power factor of the combination commences to decrease. Therefore, above the ionization voltage, sin ψ at first increases rapidly, reaches a maximum and then decreases.

We realize that in a cable the air films are not all ionized simultaneously, but the films nearest the conductor probably ionize first, due to the higher gradient there, and a greater and greater number further from the conductor become ionized as the voltage is increased. Hence, the power factor is determined by the summation of the effects of the separate films. This results in power-factor curves which rise less rapidly and which have more gradual changes in slope, as is shown by comparing the curves taken with actual cables with those of model cables.

Determining as closely as possible the constants of our glass cable models, we have calculated the power factor for the model whose curves are shown in Fig. 5 using the foregoing equation. We assumed that the ionization voltage began at a definite value of 7.5 kv. In Fig. 15 the experimental curve and the calculated curve are plotted. In our opinion, the agreement between the curves is unusually good, particularly for dielectric phenomena of this character. These curves show that the foregoing theories are correct not only in a qualitative sense, but substantially so in a quantitative sense as well. They also show that the decreasing power factor is not caused by such phenomena as saturation of ionization but is merely the natural result of a combination of series capacitances, of this character. We conclude from this that when ionization exists in cables the power factor alone cannot be used to determine the degree of ionization in any one cable or to compare the ionization characteristics of different cables.

It is apparent that it is possible to calculate with a fair degree of precision the effects which may be expected in solid and gaseous dielectrics, provided we know the constants of the solid medium and the con stants of the gaseous films.

It has been recognized for some time past that, although the paper itself has lower dielectric strength than the impregnating compound, the dielectric strength of the cable is increased by using paper in combination with the compound. This is probably

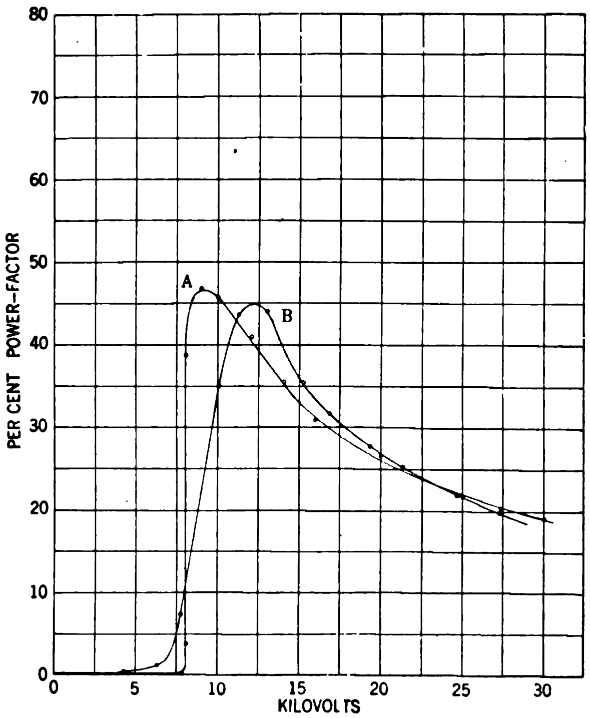

FIG. 15—CABLE MODEL. GLASS-AIR DIELECTRIC

A. Calculated
B. Experimental

due to a considerable extent to the fact that the paper acts as a barrier,[15] which prevents or restricts the motion of the ions through the insulation. We felt it worth while to study these effects with our cable models. The glass tube of the model whose characteristics are shown in Fig. 11 was wrapped tightly with dry manila paper, such as is used for insulating cables. The brass tube was then slid over the paper. Thus we produced a cable model having a composite insulation of glass, air and paper.

Fig. 16 shows the curves of power factor, watts loss and capacitance plotted with kilovolts which we obtained with this model cable. The ionization point

15. William A. Del Mar, Electric Cables, p. 84.

started at a lower voltage than with air and glass alone as the dielectric. This would be expected. The power factor increased to a first maximum of 24 per cent at 7 kv. When the voltage was increased above 7 kv. the power factor decreased to a minimum of 18 per cent at 16 kv., after which it increased again to a second maximum of 27.5 per cent at 22 kv. Beyond this the power factor continued to decrease, reaching at 32.5 kv. nearly a constant value. The capacitance curve increases steadily with increased kilovolts, but shows changes in slopes corresponding to the maxima and minima of the power-factor curve. The watts loss curve begins to increase with the first increase of power factor and then increases suddenly when the power-factor curve begins to increase for the second time at 16 kv.

Fig. 16 indicates that this composite cable has a second ionization voltage. The paper was removed and examined, and found to be pierced throughout by numerous fine pinholes. This effect could not be found unless the voltage were carried up beyond the second ionization voltage. The explanation of the second ionization voltage is now obvious.

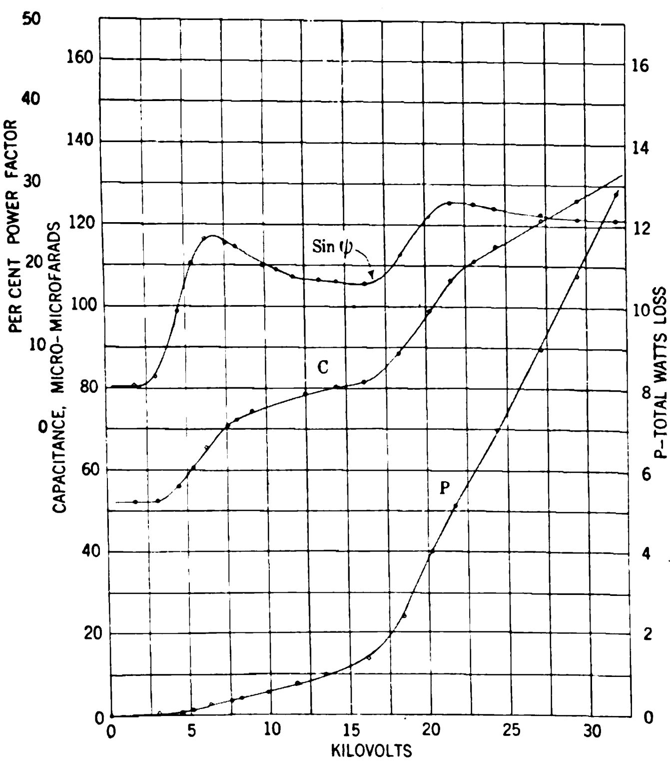

Fig. 16—Cable Model. Glass-Air-Paper Dielectric
20 deg. cent. 60 cycles per second

As the impressed voltage is increased, the voltage across the air spaces reaches its maximum value and does not increase further. Hence the gradient in the paper and the gradient in the glass increase more rapidly with further increase in impressed voltage. When the gradient in the paper becomes sufficiently high, the ions striking its surface are drawn through causing perforations. A number of ions concentrating at one point causes a pinhole. The restricted ionization current density prevents dynamic rupture. Because of the perforations, the dielectric and the barrier actions of the paper are in part destroyed. Any increase in impressed voltage now occurs almost entirely across the glass tube and the power factor begins to increase and then decrease again in the manner which was discussed in connection with Figs. 5 and 11.

This suggests that one of the requisite qualities of paper which is to be used for cable insulation may be its barrier action under conditions similar to the foregoing.

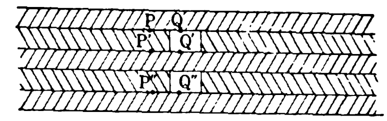

Fig. 17

The foregoing experiments and the resulting analyses suggest hypotheses which may explain the origin of "tree designs" and the incipient causes of breakdown. Fig. 17 shows a magnified and perhaps exaggerated section of paper insulation in which two spaces, one on each side of a paper tape, happen to occur directly opposite each other, due to the tapes not touching. Owing to the fact that the tapes do not quite touch and the compound does not quite fill all the voids so formed, gas films exist in spaces Q' Q and Q' Q''. At low voltages, below the ionization voltage, the potential gradient across the air films and the corresponding layer of paper will be equal in most cases. Hence no potential difference will exist between points P and Q, P' and Q', P'' and Q''. Above the ionization voltage the gradient through the paper increases. The gradient through the air-spaces cannot increase beyond a limiting value as already demonstrated. This causes a potential difference to exist between points P and Q, P' and Q', P'' and Q''. Therefore, there will be voltage gradients tangential to the surfaces of the paper which may cause creepage or tangential currents which carbonize the surfaces and ultimately result in "tree designs." This creepage may be followed by discharges over the edges of the tape, and these discharges are likely to be more or less oscillating in character and of high frequency. These discharges cause further local heating and further destruction of insulation. The barrier action of the paper at Q' may also be destroyed, as with the authors' paper-glass models, causing increase in the watts loss (Fig. 16), and ultimately producing hot spots. Hence, these effects are all cumulative, and eventually rupture will occur at this point.

Conclusions

1. When corona occurs in air spaces, the increase in energy loss begins at a lower voltage gradient than the increase in capacitance.

2. With ionization in a gas, the voltage gradient must always be greater than zero.

3. The gradient in an ionized gaseous dielectric is finite but cannot exceed a definite maximum value. This maximum value is the breakdown gradient for each particular condition.

4. The ionization current is limited or restricted by the solid dielectric.

5. When the voltage gradient in cables has reached a value sufficiently high to ionize all the gas films in the dielectric, the ionization loss becomes proportional to the cable charging current.

6. The power factor is a direct function of the relative capacitance of the solid dielectric and air spaces in series. Hence, power factor of itself does not show the degree of ionization which exists in a cable.

7. The power factor due to a combined solid and ionized gaseous dielectric can be calculated if the constants of the two dielectrics are known.

8. Restricted ionization effect has been called "the barrier action of paper" in high-voltage cables and a method is suggested whereby it can be measured and the relative quality of cable papers be determined.

9. "Tree designs" are probably due to tangential gradients set up in the cable as a direct result of ionization.

10. Ionization causes progressive deterioration due to the high-frequency oscillations accompanying these internal discharges. The increased local temperatures or hot spots, due to ionization, tend to exaggerate these effects.

The authors are indebted to the members of the electrical engineering staff of the Harvard Engineering School for their cooperation in this research and particularly to Professor H. E. Clifford for his suggestions in the preparation of the paper.

Abridgment of Paper on Concluding Study of Ventilation of Turbo Alternators Multiple Path Radial System

BY C. J. FECHHEIMER[1] and G. W. PENNEY[1]

Synopsis.—*In 1924 two papers were presented before the A. I. E. E. on Turbo Alternator Ventilation. In one of the papers tests on two models for two methods of ventilation were described, and data from the tests were given. The other paper contained a mathematical treatment for one system of ventilation, which was based upon the data obtained from the tests. It was recognized that the tests were not sufficiently accurate to evaluate the loss coefficients, nor was it possible to obtain data on the distribution of volumes for the intake vents. For that system, (see Fig. 1), it was found that the influence of rotation upon total volumes and their distribution could be neglected; consequently the investigation could be continued on stationary models. Those tests, the methods of determining the losses and the equations derived therefrom are given in this paper.*

Since the effect of rotation could be neglected, the test could be reduced to a model which represented only one axial row of vent ducts. On this model the stator vent ducts were imitated by square brass tubes with a plaster of paris restriction cast in one end to imitate the vent duct restriction so that the pressure drop obtained for either direction of flow was approximately the same as in a stator vent. A long steel channel or duct represented the section of the air-gap. Some of these brass tubes, representing intake vents, lead from a large sheet metal box to the gap channel. Other tubes, representing discharge vents, lead from the gap channel to the atmosphere. The gap channels could be inter-changed readily to represent various sizes of air-gaps. Any desired number of intake and discharge tubes could be used so as to represent any desired layout of the machine.

The volumes in individual intake tubes were measured by reading on a manometer the drop in pressure from the intake chamber to a point a little ways down the tube. For the discharge tubes small impact tubes were employed. Each tube was carefully calibrated before making any other tests; a thermal volume meter was used for calibrating an orifice, and the orifice was used for the tube calibrations. Various difficulties arose, and the means of overcoming them are given.

Tests were made with a group of intake vents, and the losses were separated into (1) those in the tubes; (2) those accompanying a right angle turn; (3) those due to a stream of one velocity impinging upon a stream of another velocity; (4) those due to sudden increase in velocity; (5) those due to surface frictions. Similar tests on the discharge side showed that the losses there could be separated into (1) those in the tubes; (2) those accompanying a right angle turn; (3) those due to sudden decrease in velocity; (4) those due to surface friction.

The losses were put, for the most part, into comparatively simple expressions. They were then combined in order to obtain final solutions. There was no difficulty on the intake side in obtaining a differential equation which admitted of ready integration. On the discharge side, however, it was necessary to use approximations. With the aid of the final equations the total volumes and their distribution can be calculated for a given pressure drop. One difficulty is that the equations include trigonometric and hyperbolic functions of quantities involving the distance between the point where the gap velocity is maximum to the points where the gap velocity is zero. The latter point, called the "balance point" is not known, and a simultaneous solution of the transcendental equations needed for its determination, is impossible. Suggestions for a direct simple approximate solution are given, which may be followed by trial and error methods. In most of the applications, only one or two trials were required.

The equations were checked for accuracy by comparison with tests made on the tubes, on the turbo model of 1922 and 1923, and with those on an actual machine. The agreement in total volumes was very close, and is considered to be quite good for distribution also.

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1. Both of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies upon request.

Introduction and Purpose

At the 1924 Midwinter Convention of the American Institute of Electrical Engineers, two companion papers were presented on the general subject of Ventilation of Turbo Alternators[2]. One dealt with a description of two models on which the experiments were made, the methods of conducting tests, together with representative data and the important conclusions. The other paper (by D. Bratt) was mathematical, the equations being derived from an ideal system, in which all losses in the air-gap were neglected; he increased the losses empirically on the discharge side, so that the measured and calculated total pressure drops agreed. Bratt's equations applied to the system of ventilation in which the air flows axially in the air-gap, shown schematically in Fig. 1. That system was the one adopted by the Westinghouse Company, as tests on the turbo models indicated its superiority over the other system in which the air flows circumferentially in the air-gap.

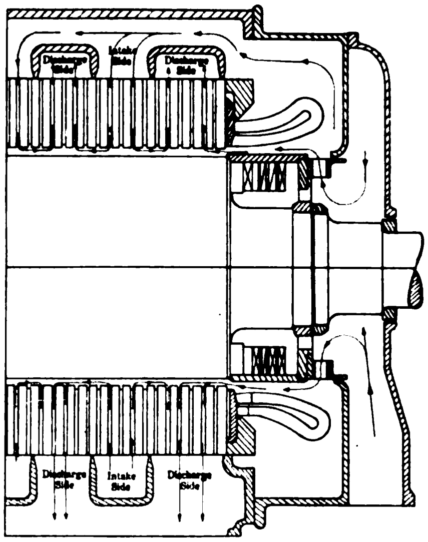


Fig. 1—Scheme of Ventilation of Turbo Alternator

The experimental data obtained from the large wooden models were too inaccurate to enable an evaluation to be made of the losses of head at the turns and other parts of the air circuit so as to incorporate them in the equations. Furthermore, no method was then, or is now, available for measuring the volumes in the individual intake vent ducts. It was recognized then that it was an erroneous assumption to consider that all of the additional losses were on the discharge side, as some were on the intake side as well. In order to enable the designer to calculate the volumes of air and their distribution, further experiments were made as described in this paper.

2. "An Experimental Study of Ventilation of Turbo Alternators" by C. J. Fechheimer, and "Multiple-Radial System of Cooling Large Turbo Generators" by Donald Bratt, A. I. E. E., 1924, pp. 476 and 467.

Perhaps the most important conclusion reached as a result of the earlier experiments was that with a ventilation system as shown in Fig. 1, the influence of rotation upon the total volume of air is nearly negligible. Thus, the total volumes with the rotor vents closed, and with pressures of the order of five inches of water, were reduced about four per cent by changing the rotor speed from 0 to 3600 rev. per min. (surface velocity of 24,600 ft. per min.) With the rotor vents open, and with higher pressures, there was even a smaller reduction in volume; consequently the change between standstill and normal speed could be ignored in machines as are ordinarily built, with pressures of 10 in. of water or more.

A second important conclusion was that on the discharge side the axial distribution of volume in the vent ducts was made somewhat more uniform by the influence of rotation. The influence is less the larger the air-gap and for the air-gaps usually employed the effect of rotation upon axial distribution is quite small.[3] Undoubtedly on the intake side, there is likewise a modification in axial volume distribution due to rotation, but now, from theoretical considerations, there are probably greater differences between maximum and minimum vent-duct velocities than at standstill. But the change is doubtless quite small with the usual size of air-gap. In the large machines the coils are sunk so that there is an axial passage above them in which the flow is not disturbed appreciably by rotation. (This may be seen from the outlet vents by a comparison of Figs. 33 and 34 in the 1924 paper). Also, the tests on the turbo model were made at the reduced total end-bell pressure of about 3.3 in. of water. In the large modern machines, the end-bell pressure is considerably higher, 10 in. and more. Then all the velocities in the vents and gap are greater, and the influence of rotation upon vent duct volume distribution becomes still less. Certainly, whatever the influence of rotation is, it is sufficiently small to justify the assumption that it may be neglected.

This then meant that the study could be continued on stationary models. They could be of such reduced size that the tests could be made in a laboratory instead of in a factory, and thus not conflict with production. The conditions that obtain in a machine with axial flow in the gap are the same for all positions, circumferentially, so that a study of flow with one set of vents would be sufficient. The construction of the laboratory apparatus and the manner of conducting the experiments have been fully justified by the close agreement between the wooden turbo model and machine data and the laboratory data.

Apparatus

The vent ducts were imitated by square, brass tubes, two of which are shown in Fig. 2. From a knowledge

3. See Figs. 34 and 35 on pp. 495 and 496 of 1924 A. I. E. E. Transactions.

of the pressure drops in vent ducts obtained from earlier laboratory tests on small ducts, it was possible, by calculation, to determine how to shape the sections within the square tubes, so that the pressure drop in the individual tube would approximate the drop in a vent duct for either direction of flow. A special mandrel was made and plaster of paris was cast about this mandrel on the inside of the tubes.[4] It was found that because of lack of uniformity at the ends of the plaster of

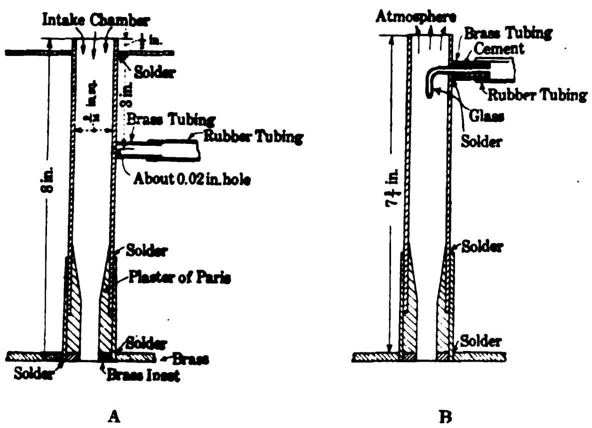


FIG. 2—CONSTRUCTION OF SQUARE TUBES USED IN THE EXPERIMENTS
(a) Tube representing intake vent duct
(b) Tube representing discharge vent duct

paris, there were many irregularities in the test results. Consequently, small brass insets were made as shown in Fig. 2, and the plaster of paris behind them was formed accurately to dimensions.

Fig. 2A shows one of the intake tubes and Fig. 2B one of the outlet tubes. The air enters the intake tubes from a relatively large chamber and there is a loss of head at and just beyond the entrance of air to the tube

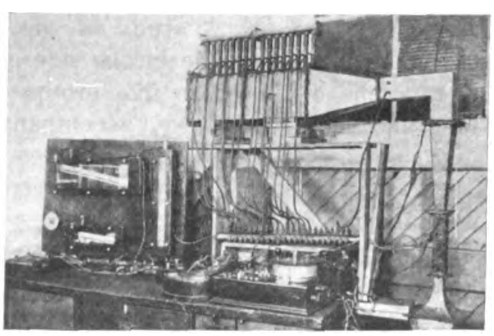


FIG. 3—FIRST SET-UP, IMITATING THE INTAKE SIDE OF A TURBO ALTERNATOR

In addition, there is the velocity head itself ($v^2/2\,g$) so that the total difference in pressure from the large intake chamber to a point a little distance down the tube is approximately 1.5 $v^2/2\,g$. Hence, if a manometer is connected between the large intake chamber and a point down the tube, the readings should be of of approximately one-half of a velocity head ($1/2\,v^2/2\,g$).

4. Metals of various kinds had been tried, but had been abandoned.

such order that they could be observed with considerable accuracy. That was the principle used for measuring the volumes in the intake tubes the construction being indicated in Fig. 2A. A sample tube was tried out before all the tubes were made and the method was found to be satisfactory.

On the outlet side, the air discharges from the individual tube directly into the atmosphere. Neglecting what small friction drop there is in the tube, the static pressure a short distance from the end is nearly the same as that of the surrounding atmosphere. Consequently, the method used for measuring volumes on the intake side could not be applied to the discharge side. The construction that was adopted is shown in Fig. 2B. Inside the large square brass tube was a small impact tube which was connected by the usual rubber tubing to a manometer, the other side of the manometer being open to the atmosphere.

In using the intake tubes, the manometer was connected by means of rubber tubing between the round brass tube soldered to the square tube and the relatively large intake chamber in which latter the velocities were so low that the influence of velocity head could

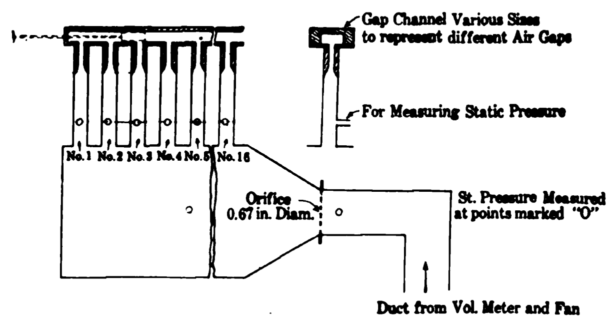


FIG. 4—SCHEME OF FIRST SET-UP, IMITATING THE INTAKE SIDE OF A TURBO ALTERNATOR

be neglected. On the discharge side, the manometer was connected to the impact tube. Each tube was carefully calibrated before any other tests were made. Due to small errors in construction which necessitated referring to the calibration data when the final data were used, the calibrations differed slightly from one another.

All tubes were soldered into brass plates about 0.25 in. thick, and were assembled in several combinations. Channels of various sections to imitate different air-gaps were made to bolt to the brass plates, rubber gaskets being used to eliminate leakage. Groups of tubes could be joined together at their ends, for which suitable flanges and bolts were provided.

There were three set-ups, two of which are shown clearly in the illustrations, Figs. 3 and 6. In Fig. 3, which shows the first set-up, intake conditions only are imitated. In Fig. 4 it is shown schematically. The second set-up imitated the discharge only and it is shown schematically in Fig. 5. In Fig. 6, for the third set-up, the ventilating system of one-half of

a generator, with one intake chamber at either side of the center line is simulated.

The apparatus was constructed so that any desired combination of intake and discharge vents could be obtained, thereby imitating the ventilating system of a machine, either in part or whole. The blower used does not appear in the photographs. It was capable of delivering the volumes required at pressures up to 10 in. of water.

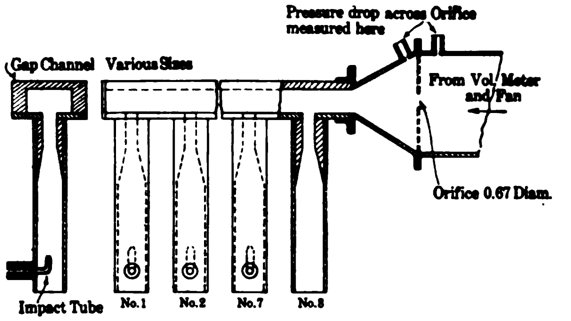


FIG. 5—SCHEME OF SECOND SET-UP, IMITATING THE DISCHARGE SIDE OF A TURBO ALTERNATOR

DIFFICULTIES IN MEASUREMENT

1. Measurement of volumes. It was at first thought that the impact tube method of measuring volumes as used for the discharge tubes would be more reliable than the entrance pressure drop method used for the intake tubes, since impact measurements are usually from which the glass impact tube had been removed. The ratio of readings taken with them did not remain position just beyond one of the square discharge tubes

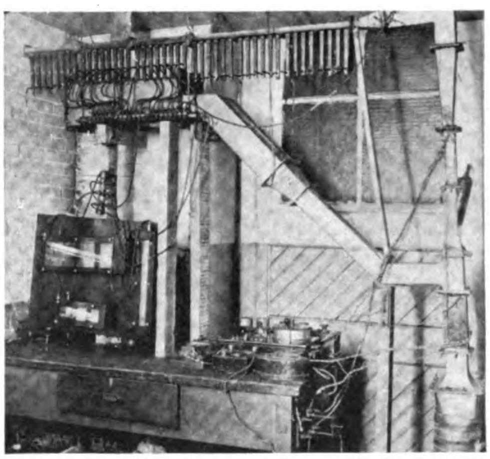


FIG. 6—THIRD SET-UP, IMITATING THE VENTILATING SYSTEM OF HALF OF A TURBO ALTERNATOR

more dependable than are those for static pressure. It was found, however, that the reverse was the case in these experiments. Thus, when taking observations of discharge volume distribution with several tubes open, some of the points did not lie on a smooth curve, which was not the case for the intake tubes. The discrepancy was of the order of three or four per cent. Four small impact tubes were supported in fixed, showing that the character of flow changed, and the other impact tubes undoubtedly were similarly affected. Apparently, the highly turbulent state in the gap channel, and immediately after entrance to the square tube was not entirely eliminated before the impact tube was reached. It is well known that, with some turbulent states, the flow may change and be periodic. These tests also proved that the character of flow in the tube is affected by the magnitude of the gap velocity. This was indicated by the fact that the volume in a duct depended somewhat upon the gap velocity, as well as upon the square root of the static pressure difference. Subsequent reference to this will be made. For the intake tubes the velocity in the large chamber was negligible, so that any flow there did not influence the drop to a point where the readings were taken.

2. Pressures in the air-gap. In order to determine where the losses of head occurred, it was necessary to know the static pressure in the air-gap as well as the average velocity there. The tests made by the "toy balloon" method described on page 496 and shown in Fig. 37 in the 1924 A. I. E. E. TRANSACTIONS, indicated that a reasonably accurate measure of the gap static pressure could be obtained by closing a vent and then observing the pressure in the vent some distance from the gap. That method was tried in these tests also. To determine the air-gap pressure at a given tube, the two adjacent tubes were closed at their far ends. The manometer readings were then the static pressure in the gap. The average of these readings for the two adjacent tubes was taken to be the desired static pressure. That this method was satisfactory was proven by subsequent tests. It was used chiefly for the discharge tubes, but it was found to check on the intake side also.

DETERMINATION OF LOSSES

A. On the Intake Side. A study of the possible sources of losses of head on the intake side indicated that they could be divided into five groups: 1, loss within the radial vent duct; 2, loss accompanying the turning of a right angle; 3, loss due to sudden increase in velocity when an incoming stream impinged upon a stream normal to it; 4, loss due to surface friction; and 5, loss at final discharge from the air-gap channel. (This last loss is $\frac{v^2\,o}{2\,g}$, and requires no further discussion). The expressions for the losses are given here; the means for separating them in the experiments are given in the complete paper.

1. Loss within the radial vent duct. The pressure drop in a vent duct had been determined in previous tests and could be represented by the equation

$$\frac{P}{\gamma} = C\,i\,\frac{V^2}{2\,g}$$

(Where p = pressure drop, γ = density, V = velocity

at the minimum section of the duct, and g = acceleration of gravity)[5]. As the velocity head at discharge from the vent duct is $\frac{V^2}{2g}$, the loss within the vent duct is evidently

$$(C_i - 1)\frac{V^2}{2g} \tag{1}$$

2. Loss accompanying the turning of a right angle. The expression just given accounts for the pressure drop through the vent duct, provided the air-gap velocity is negligible. Usually, however, the gap velocity is appreciable which causes an additional difference between static pressure at the entrance of the vent duct and the static pressure in the air-gap. This additional pressure drop is due to the abrupt turn which the stream from the vent duct must make when it strikes the air-gap stream. This pressure drop can be represented by $K_L \frac{v^2}{2g}$ (where K_L is a coefficient, depending on the size of the air-gap and v is the velocity in the air-gap just past the vent duct.)

In addition to this loss in pressure there is a loss in velocity head since the velocity in the gap is almost always lower than the velocity issuing from the vent duct. This loss in velocity can be represented by $\left(\frac{V^2}{2g} - \frac{v^2}{2g}\right)$ and is caused by the sudden decrease in velocity when the air from a vent duct mixes with the air in the gap. The total pressure drop from the intake chamber to a point in the air-gap just past the vent duct is then:

$$\frac{p}{\gamma} = (C_i - 1)\frac{V^2}{2g} + K_L\frac{v^2}{2g} + \left(\frac{V^2}{2g} - \frac{v^2}{2g}\right) + \frac{v^2}{2g} \tag{6}$$

The last term represents the velocity head in the gap.

3 and 4. Loss due to sudden increase in gap velocity and duct friction. As a stream from a vent duct impinges upon the stream in the air-gap, the velocity of the gap stream increases suddenly due to the increase in volume. Considerable loss is produced by the eddies accompanying this sudden increase in velocity, and this loss can be represented by $K \frac{v_2^2 - v_1^2}{2g}$. Where v_2 and v_1 are respectively the gap velocities after and before the sudden increase in gap velocity, and K is a coefficient to be determined experimentally. It was found that K could be so chosen as to include the loss due to the duct friction in the gap as well as the loss due to sudden increase in velocity.

5. A list of symbols is given after the final equations.

Combination of loss expressions on the intake side. Let

P = Pressure in the intake chamber.

p_0 = Pressure in the gap at its discharge point. (This was atmospheric pressure in the tests described above or taken as zero for reference.)

v_0 = Gap velocity at the discharge point.

Then by Bernoulli's equation:

$\frac{P_0}{\gamma} = \frac{p_0}{\gamma} + \frac{v_0^2}{2g}$ + sum of losses from intake chamber to discharge point in gap.

or

$$\frac{P}{\gamma} = \frac{p_0}{\gamma} + \frac{v_0^2}{2g} + (C\,i - 1)\frac{V^2}{2g} + \frac{V^2 - v^2}{2g} + \frac{K_L\,v^2}{2g} + K\frac{v_0^2 - v^2}{2g} \tag{8}$$

The accuracy of this expression for pressure drop was checked by testing a large number of intake combinations. Then, using the measured velocities and the above expression for losses, the pressure drop was calculated for each vent duct and this value was checked against the measured pressure drop. Table I shows a tabulation of these values for one test. The agreement is undoubtedly close and, therefore, the equation was taken to be sufficiently accurate.

TABLE I

I. Vent Tube Number	II. Vel. "V" in Vent	III. Total Calc. Pressure	IV. Total Meas. Press.	V. % Difference
3	9480	8.48	8.18	+3.7
5	7280	8.25	8.18	+0.9
6	6070	8.29	8.18	+1.4
7	5090	8.33	8.18	+1.8
8	4100	8.09	8.18	−1.1
9	3400	8.11	8.18	−0.9
10	2650	8.12	8.18	−0.7
11	2300	8.17	8.18	−0.1
12	2140	8.20	8.18	+0.2
13	1860	8.18	8.18	0.0
14	1620	8.17	8.18	−0.1
15	1480	8.15	8.18	−0.4
16	1420	8.15	8.18	−0.4

B. On the discharge side. On the discharge side, the air streams flow from the air-gap through parallel vent ducts out to a common discharge chamber. In these tests they discharged into the atmosphere. The losses of head were divided into four groups: 1, loss within the radial vent ducts; 2, loss accompanying the turning of a right angle; 3, loss due to sudden decrease in velocity arising when some of the fluid discharged through a vent duct; 4, loss due to surface friction. For the particular set-up there was also a small loss in the converging duct leading to the gap channel, but this loss does not appear in the machine, in the parts that are fed from the intakes. There is an entrance loss whose magnitude depends upon the entrance conditions in machines at the end-bell ends. Ap-

proximate data obtained in the turbo-model tests in 1923 permit of evaluation of the latter loss with sufficient accuracy.

1 and 2. Loss within the radial vent, and loss accompanying the turning of a right angle. As for the intake vents, the losses in the radial vents were determined at the time the tests on the turbo model

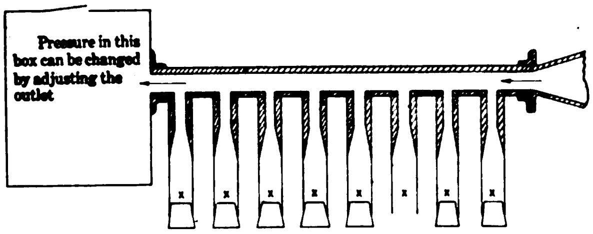


FIG. 7—SCHEMATIC DIAGRAM, SHOWING THE METHOD IN WHICH TESTS WERE MADE FOR EVALUATING LOSS CO-EFFICIENTS ON THE DISCHARGE SIDE

One vent duct was left open. All other vents were closed by rubber stoppers. The pressure in the gap can be changed by adjusting the outlet from the box at the end of the gap so that any combination of velocity and pressure can be obtained. Impact tubes located at points marked "x" give vent duct velocity head if the vent duct is open, or static pressure in the gap if the vent duct is closed by a rubber stopper

were made in 1922 and 1923. They were made with the same apparatus but the direction of flow was reversed. The co-efficient was called C_d, as defined by the equation $\frac{p}{\gamma} = C_d \frac{V^2}{2g}$. The meanings of the symbols are the same as before. It was recognized that the conditions in the machine, or in this model might be different than they were in the small set-up of 1923, because the entrance conditions were different. The loss accompanying the turning of a right angle could not readily be separated from the entrance conditions, and there was little to be gained, if that could have been done without great difficulty. Consequently those two losses were combined, and the new values of the coefficient $C\,d$ takes account of the turning of a right angle, of the entrance loss to the vent duct, and the loss in the vent itself.

In Fig. 8 will be found a plot for one test, No. 3 tube being the only one open. The value of $C\,d$ is not constant, but is dependent upon the gap velocity.

3. Loss due to sudden decrease in velocity. It was shown largely by theory and checked by experiment that when there is a sudden enlargement of cross-section, the loss of head is:

$$\frac{(v_1 - v_2)^{2*}}{2g} \tag{10}$$

v_1 and v_2 are the velocities before and after the enlargement, as given by the volume divided by the cross-sectional area. It may, without much difficulty, be shown that the decrease in velocity in the air-gap to the abstraction of the air through the vent duct, is comparable with the case of sudden enlargement, and probably should be given by the same equation. Equation (**10**) was found to apply with considerable accuracy, except for the case when $v_2 = 0$. Even then the loss considered as part of the total was not great. To check equation (**10**) tests were made in a similar manner to those for the individual tubes, and the gap static pressure on either side of the particular tube was measured.

4. Loss due to surface friction. From the curve in Fig. 8 it will be seen that the friction loss is by no means negligible. It is given by the well-known formula to be found in any standard work on hydraulics:

$$\text{Friction drop} = f \frac{L\ R}{A} \frac{v^2}{2g} \tag{11}$$

Wherein:

f = coefficient of friction
L = Length
R = perimeter of duct
A = Area of cross section of duct
v = velocity
g = acceleration of gravity.

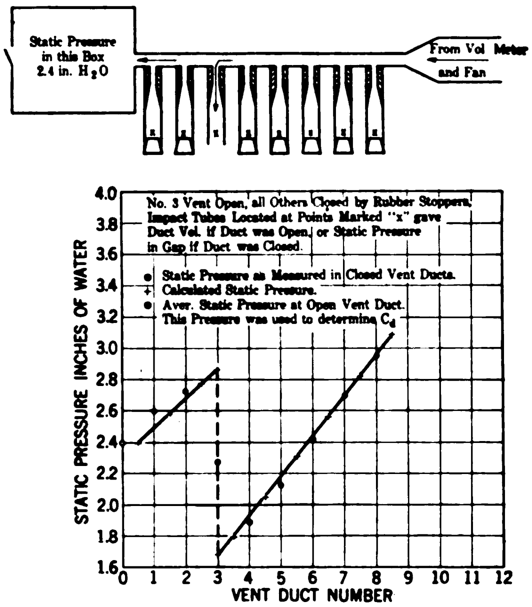


FIG. 8—EXAMPLE OF PLOTTED DATA SHOWING METHOD OF DETERMINING STATIC PRESSURE FOR EVALUATING $C\,d$

If v is in ft. per min., and the density be taken as 0.074 lb. per cu. ft., the friction drop in inches of water is:

$$f \frac{L R}{A} \left(\frac{v}{4030}\right)^2$$

f = about 0.0054

*See Gibson: "Hydraulics and Its Applications." Second edition, pp. 82 and 83. The equation is quite different from what one might at first glance expect:

$$\frac{v_1^2 - v_2^2}{2g}$$

Combination of the equations on the discharge side. Consider the case where the air enters the discharge part of the air-gap from the intake side (that is, not the case where the air enters the air-gap directly from the end-bell—see Fig. 1). Then the static pressure in the gap at that division point between intake and discharge is p_0. The velocity in the gap at that point is v_0. Following the path of a stream of air from that point, to some other point in the gap, the equation by Bernoulli's theorem is:

$$\frac{p_0}{\gamma} + \frac{v_0^2}{2g} = \frac{p}{\gamma} + \frac{v^2}{2g} + \sum \text{losses from the}$$

division point to the point in the gap considered.

$$\frac{p_0}{\gamma} + \frac{v_0^2}{2g} = \frac{v^2}{2g} + C_d \frac{V^2}{2g} + \sum \frac{(v_1 - v_2)^2}{2g} + \sum f \frac{L}{A} \frac{R}{} \frac{v^2}{2g} \qquad (12)$$

Here $\sum \frac{(v_1 - v_2)^2}{2g}$ means the summation of all losses due to sudden decrease in velocity from the division line up to the particular vent duct considered; and $\sum f \frac{L\ R}{A} \frac{v^2}{2g}$ is the summation of friction drops, between the same points, account being taken of the changes in velocity. In equation (**12**) $C\,d\,\frac{V^2}{2g}$ has been written for $\frac{p}{\gamma}$.

When the air enters the gap channel directly, as was the case for the second set-up, or as is the case when the air in a machine enters the gap directly from the end-bell, and the chamber is so large that the velocity head there may be neglected, the static pressure being P, the equation is:

$$\frac{P}{\gamma} = \frac{v^2}{2g} + \frac{p}{\gamma} + \sum \frac{(v_1 - v_2)^2}{2g} + \sum f \frac{L\ R}{A} \frac{v^2}{2g} \qquad (13)$$

This latter equation was used for final checking of the discharge loss coefficients. In Table II the results of one test are summarized.

TABLE II

I Vent Tube Number	II Meas. Static Press.	III Avg. Meas.* Static Press.	IV Avg. Calc. Static Press.	V % Difference
8	7.03			
7		7.32	7.15	2.3
6	7.62			
5		7.84	7.73	1.4
4	8.06			
3		8.20	8.10	1.2
2	8.32			
1			8.25	

*Average of measured pressures on each side of open duct.

Final Equations

The expressions which have been obtained give the pressure drop when the velocities are known. However, equations to be useful to the designer must give velocities for a given pressure drop. To obtain these final expressions, the general method used by Bratt in his 1924 A. I. E. E. paper was followed. The assumption is made that there are an infinite number of vent ducts, each of infinitesimal width, instead of a finite number, each of finite width. This assumption is comparable with the one usually made in polyphase alternating-current machinery; that there is a sine wave distribution of magnetomotive forces and fluxes.

For the intake side the expression for losses could be taken just as it has been given and following the method used by Bratt an equation was obtained which had the same form as Bratt's original equation except that now the constants have been determined experimentally[6].

For the discharge side, the equation for losses as it has been given could be reduced to a differential equation but the solution was too complicated to be practical. It was, therefore, decided to make approximations which would alter the form of equation (**13**), and still be close enough for general application. The assumption was made that there were no gap losses, that $C\,d$ was constant and that its value corresponded to the highest gap velocity. This was the highest value for $C\,d$, so that compensated for having ignored the gap losses. At the division, where the gap velocity is maximum, the assumption is the same as for the actual conditions, since the value of $C\,d$ used corresponds to that point, and the gap losses there are zero. At points where the gap velocity is lower, the assumed value of $C\,d$ is too high, but since then the gap losses are neglected, the static pressure, as calculated by Bernoulli's equation, is high. As the vent duct velocity is dependent upon the quotient of the gap pressure and $C\,d$, and as both are high, the error is quite small.

Summary of Final Equations

Intake	*Discharge*
$v = v_0 \dfrac{\sinh \alpha\,(L_i - x)}{\sinh \alpha\,L_i}$	$v = v_0 \dfrac{\sin \beta\,(L\,d - y)}{\sin \beta\,L\,d}$
$V = \dfrac{a}{S}\,v_0 \dfrac{\cosh \alpha\,(L_i - x)}{\sinh \alpha\,L_i}$	$V = \dfrac{v_0 \cos \beta\,(L\,d - y)}{\sqrt{Cd}\,\sin \beta\,L\,d}$

$$P_i = \gamma \frac{v_0^2}{2g}\left[\frac{1 + K - K_L}{\sinh^2 \alpha\ L_i} + (1 + K) + \cot^2 \beta\,Ld\right]$$

$$P_e = \gamma \frac{v_e^2}{2g}\,(1 + k + \cot^2 \beta\,L_e)$$

Note that to compute the velocities on the discharge side adjacent to the end-bell, the above velocity

6. The derivation of the equations is given in the complete paper.

equations may be used, but y and $L\,d$ are now measured from the end-bell end instead of from the division point, V_e must be substituted for v_0, and the value of $C\,d$ must be used that corresponds to v_e instead of to v_0.

In using the equations it is perhaps a little more convenient to take S as the area of one circle of stator vents at the minimum section, and then $L\,d$, $L\,e$ and $L\,i$ are in number of vents instead of in actual lengths.

In the above equations:

$$\alpha = \frac{S}{a}\sqrt{\frac{1 + K - K_L}{C\,i}} \qquad \beta = \frac{S}{a}\sqrt{\frac{1}{C\,d}}$$

a = Cross sectional area of the air-gap.
$C\,d$ = Discharge coefficient in the radial vent ducts.
$C\,i$ = Intake coefficient in the radial vent ducts.
k = Loss coefficient at entrance to gap, end-bell end.
K = Loss coefficient for sudden increase in velocity.
K_L = Loss coefficient for turning a right angle.
$L\,d$ = Distance from division point to balance point, discharge side.
$L\,e$ = Distance from end-bell to balance point.
$L\,i$ = Distance from division point to balance point, intake side.
$P\,e$ = Pressure in end-bell.
$P\,i$ = Pressure in the intake chamber.
S = Cross sectional area of stator vents at the minimum section per unit length axially.
v_0 = Velocity in gap at division points.
v_e = Velocity in gap at end-bell end.
V = Velocity in stator vents at minimum section.
x = Variable distance from division point, intake side.
y = Variable distance from division point, discharge side.

These equations assume that we know the balance points, *i. e.*, the points in the air-gap when the velocity is zero. These points, which we have called "balance points" are determined by the following conditions,

1. The pressure drop for all paths must be the same.
2. The vent duct velocities at the balance point must be the same when computed for the two parallel circuits which meet at that point.

On account of the transcendental form of the equations, they cannot be solved simultaneously to find the values of $L\,i$ and $L\,d$ (*i. e.*, the balance points). Consequently, a trial and error method must be used for finding them.

The velocities as calculated from these equations were checked against test results for a large number of tests. The results checked against included a large number of tests on the model described in this paper, tests on the model described in the 1924 paper and tests on actual machines. In every case the agreement was found to be satisfactory. Figs. 12, 13 and 14 show the agreement for three of these tests.

CORRESPONDENCE

HIGHWAY LIGHTING

Editor, A. I. E. E. Journal,

I am much interested in your article on Page 24, entitled, "One Genuine Method of Solving The Automobile Headlight Problem."

Ten years' ago, I made a suggestion of scientifically illuminating the highways, which suggestion was much laughed at. It seems to me that most of the light on our highways and even on our boulevards in the city, is wasted by being up in the air. It seems to me that the primary purpose of illuminating a highway, is to illuminate the road itself, and that it does not matter whether or not anything above the road is illuminated.

My suggestion is that along the sides of the highways weather-proof lights, down low like footlights, be installed to thoroughly flood the highway without any light at all coming direct in the eyes of the motorist or even the pedestrian. That is, these lights would be installed low and so shaded that a highway would look like one broad ribbon of light.

If this were done, no head lights at all would be needed on any automobiles and all that would be necessary would be small pilot lights and a tail light, sufficient only to indicate the presence of the car. What do you think of this?

TALIAFERRO MILTON

NEW POWER PROGRAM IN GREAT BRITAIN

The new electrical power program of Great Britain, outlined by the Prime Minister, will be presented to Parliament during the coming session. This electricity bill, if passed, will be of great interest to the country as a whole, and will vitally affect its industries.

The main objects of the bill are the standardization of the frequency, at an estimated cost of £10,000,000; the laying of interconnecting cables between industrial areas; the reduction of the number of generating stations from 584 (at present) to 60; and the lowering of rates for electric current.

NATIONAL POWER BOARD TO DETERMINE POLICY

The plan outlined by the Prime Minister includes the creation of a national power board which will deal with matters of policy. The present electrical commissioners are to continue as technical advisors with particular reference to standardization and unification work now in progress, which, owing to the increased power granted, will be expedited. One result has been a rise in electrical shares on the exchange.

The sites for the new generating stations will, as far as possible, be on rivers and canals. It is estimated that it will take 15 years to develop this project and that ultimately the annual consumption of electricity in the United Kingdom will be raised to at least 500 kilowatt-hours per capita.

The Magnetic Hysteresis Curve

BY HANS LIPPELT[1]

Member, A. I. E. E.

Synopsis.—An analysis of the phenomena of hysteresis is ...nted in the paper which introduces the conception of a reactive ...mponent and a dissipative component of the counteracting force, ...ch appears when magnetizeable material is subjected to a magnetizing force. Using this conception, equations and curves are developed for the hysteresis curve, for the various components and for the hysteresis loss. The loss is shown to depend directly on the dissipative component.

I. Nature of the Problem

1. The purpose of this paper is an analytical study of the fundamental character of magnetic hysteresis with a view to formulating, if possible, reliable mathematical terms in convenient form.

Foremost among the historical works along this line is that by Hopkinson (giving a theory of the magnetic circuit), which was well augmented by Fröhlich as published in the *Elektrotechnische Zeitschrift* of 1881,

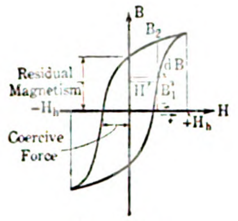


Fig. 1

pages 90 and 139; and a treatise by Professor Kennelly printed in the Transactions of the A. I. E. E. 1891, page 485.

The most familiar representation of magnetic hysteresis is the well-known loop, as shown in Fig. 1, in which the salient features are duly emphasized.

2. *Nature of Forces Involved in the Process of Magnetization.* As will be explained, the process of magnetization of the so-called magnetic metals and alloys seems to involve three forces.

(a). Magnetizing force H, which tends to produce magnetic induction in the material in the direction of H.

(b). Reactive force R, which tends to demagnetize the material, that is, to reduce the induction to zero. It seems to be a force of the nature of internal elastic stress, similar to a reactive tension.

(c). Dissipative force D, which opposes *changes* of magnetic induction. It seems to be a force of the nature of (molecular) friction and tends to maintain the material in the state of magnetization in which it happens to be at the moment.

The first force, H, is of external origin, being produced usually by an electric current.

When the magnetic circuit contains an iron core the total flux per sq. cm. of cross-section is

$$B = H + 4\,\pi\,I = H + \beta \qquad (1)$$

where $\beta = 4\,\pi\,I = B - H$ is called the intrinsic induction in the iron.

To better illustrate the relations, let us assume that a magnetic hysteresis curve $B_1\ B_2$ has been determined by experiment, Fig. 2. Its course is indicated by dotted lines, $B_1\ B_2$. True to definition corresponding curves β_1 and β_2 have been produced by subtracting from the ordinates of $B_1\ B_2$ the corresponding abscissas, H.

3. *Manifestation and Character of Forces R and D.* That the external force H cannot be the only force entering into the process of magnetization may readily be understood from the axiom of physics, according to which any action entails a reaction. H represents the action in this case and two forces, R and D, the reaction. That becomes particularly evident from observations which are common to the well-known experiment of magnetizing iron by an electric current, and which it becomes necessary to again review.

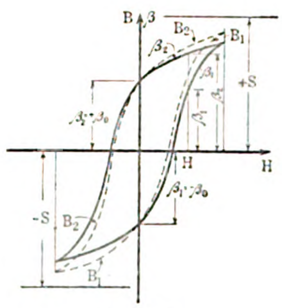


Fig. 2

(a). When an electric current flows through the spool, a magnetic field H is created within its cross-sectional area. This field H acts upon the iron core and causes it to become traversed by a strong magnetic flux β of the same direction as H. The iron will hold that flux as long as the magnetic field H exists. This indicates a tendency of H to produce (impress) induction in the iron in the direction in which it operates.

(b). Now if we interrupt the current, the magnetic field H will disappear and with it most of the magnetism β of the iron. This abatement of magnetism can be explained by the assumption of an internal

1. Thomas E. Murray, Inc., 55 Duane Street, New York City.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

force R, which tends to drive the magnetic flux β out of the iron, as an elastic reaction (tension) would do. Therefore, R is of opposite sign to H.

(c). If we put the current on again, there will reappear both the field H and the magnetism β. With the presence of R conceded under b, we will now have to broaden our conclusion (a) to the extent that the field H causes magnetism to be impressed upon the iron even against the opposing force R. Since the degree of magnetization is the same for the same recurring field H, it is likely that R depends on the degree of magnetization, the latter reaching the steady state, when its sequel, the tension R, has likewise reached its original value. On the other hand, if R were not present, magnetization should be expected to rise to any abnormal value.

(d). If we increase (or decrease) the field H over (or under) the value obtained under c, it will be followed by a strengthening (or weakening) of β. β coming in each case to a steady state when its associate reaction R has adjusted itself to the new value of H. Therefore, R is surely a function of the quantity β

$$R = F(\beta)$$

If no other forces were contingent upon the process, there should be $R = -H$, because in physics the reaction is always equal and opposite to the action. This also fixes the dimension of R to be the same as that of H, namely $C^{-\frac{1}{2}} G^{\frac{1}{2}} S^{-1}$.

It will be shown however, that these two forces R and H do not suffice to explain all the magnetic states, nor any one of them completely. A third force will exhibit itself when existing conditions are scrutinized more thoroughly.

(e). If the flow of current be interrupted altogether, it will be found that also, most of the magnetism has been lost but not all of it. Residual magnetism, either $\beta_2 = +\beta_0$ or $\beta_1 = -\beta_0$ has been retained in the iron, particularly so when the material under test is hardened steel (Figs. 1 and 2).

Consistent with the above reasoning the presence of that residual magnetism β_0 ought to entail a residual reaction R_0. Since the field $H = 0$ (when no current flows), there would now be no force counteracting the reaction R_0 and all the magnetism should disappear from the iron. As it does not disappear, we are compelled to admit the existence of another, a second internal force. We recognize at once one of the characteristics of this new force; namely, it tends to *resist changes* in the magnetic state existing in the iron at the time, inasmuch as the residual magnetism continues to exist in a permanent magnet. The nature of that force, therefore, seems to be that of a friction. It will be designated by the letter D.

When the field H [illegible]'s friction has the special value D_0 and bala[illegible] up against the internal tension R[illegible] Thus

$$D_0 + R_0 = 0$$

and the coincident state of magnetization is expressed by one of the two equations

$$\text{either } \beta_2 = +\beta_0 \text{ or } \beta_1 = -\beta_0$$

as per Fig. 2.

The fact that for any other value of H we observe likewise two values of β (Fig. 2) is proof enough of the magnetic friction D obtaining for all states of magnetization. D manifests itself particularly by the difference between β_1 and β_2 where the changes of β are large as referred to unit changes of H (*e. g.*, where the β curves are steep), and abates where they are small. Hence

$$D = F_1(\Delta\beta)$$

To amplify this reasoning, let us remember that for rapid changes of β (*e. g.*, $\Delta\beta$ = large), the reaction R also changes rapidly. Since H was assumed to change in unit steps only, D must necessarily make up for the rapid changes of R, which in turn conform to rapid changes of β, that is to $\Delta\beta$. This argument is also consistent with the force D being a "resisting" force and for this very reason D is negative, when $\Delta\beta$ is positive and vice versa.

It is obvious that the dimension of D is likewise $C^{-\frac{1}{2}} G^{\frac{1}{2}} S^{-1}$ because only forces of like character can enter into a play of action and reaction.

This force D will after further study reveal itself as the actual cause of hysteresis.

Having conceded three forces H, R and D to govern the process of magnetization, we were able to explain all and any conditions observed to exist in a magnetized material. To do that *all* of these *three forces* were *necessary*, but it is also evident that they are sufficient. The *magnetization* (β), however, when in the steady state depends on the equilibrium of those three forces. That is mathematically expressed in general by

$$H + D + R = 0 \quad (2)$$

and when applied to the ascending branch β_1 by

$$H_1 + D_1 + R_1 = 0 \quad (3)$$

and to the descending branch β_2 by

$$H_2 + D_2 + R_2 = 0 \quad (4)$$

Our problem was outlined in the first paragraph of Section I. It amounts, among others, to finding a formula $\beta = f(H)$, expressing in explicit terms the relation between the field H and the magnetization β. After what was said, this problem resolves itself now into two separate problems, *i. e.*, to determine, primarily the equations for R and D as functions of H; and in conjunction therewith functions expressing R and D in terms of β.

II. Equation of Reactive Force $R = F(\beta)$

4. *Relation of R to β near Saturation.* It is known that the magnetization β of a magnetizable material can rise only to its saturation value S as a limiting value. When magnetization is approaching saturation, it will do so gradually and $\Delta\beta$ is small for large changes of H. Small variation of β, however, entails a negligible

force D and such a state of affairs in connection with equation (2) will be used as a guide for finding a mathematical relation between R and β.

5. *Law of Magnetization near Saturation.* As is well known, the curve of β plotted against the field intensity H as abscissa approaches, for large values of H, an asymptote, which runs parallel to the H-axis at a distance S = maximum value of β, Fig. 3.

That figure confirms the statement made in the foregoing paragraph (4) that β increases only little for large

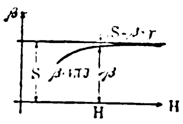


FIG. 3

increments of H. In other words the difference

$$S - \beta = \gamma$$

decreases rather slowly, because $\Delta\beta$ is small and so is the magnetic friction D.

Since the large external action H *must* meet a large internal reaction, it becomes necessary to ascribe a *large* value to the internal magnetic tension R. This quantitative relation becomes very plausible, when comparing the magnetism impressed upon the iron with an elastic medium being heavily compressed in a suitable container. (See Appendix I).

A law that is true in physics for compressed elastic mediums may apply also in our case of magnetism being impressed under similar symptoms upon suitable materials. That law applied will fix the internal reactive tension R as being inversely proportional to the capacity of the material for further magnetization. If $+ S$ is the saturation value and β the amount of magnetism impressed by a positive field $+ H$, the capacity for further magnetization is

$$\gamma = S - \beta$$

(See Fig. 3.) Under our assumption, the reactive component R would be expressed by

$$R_+ = - \frac{K}{S - \beta} = - \frac{K}{\gamma} \qquad (5)$$

where K is a factor of proportionality depending on the units selected for β and R. R_+ has been written to refer it to positive values of H and β.

In formula (5) the constant $-K$ is that reactive tension which exists when $\gamma = 1$.

We had to place the minus sign before the right hand side of formula (5) because R_+ is of a direction opposite to H (and also β), which we had assumed positive.

6. *Applying formula $R_+ = - \dfrac{K}{\gamma}$ to the whole range of magnetization.* This relation (5) applies, strictly speaking only to the range near positive saturation. So long as the contrary is not proven, it is well worth while to try out its alleged validity for the whole range of magnetization and study the effect. Such an initial study of R, without paying attention to D, appears all the more justified, because R is a force depending on the degree of magnetization, while D depends primarily on the quality of the material.

In order to better understand this relation between β and R_+, a curve has been drawn up (Fig. 4) corresponding to formula 5. It proves to be an equilateral hyperbola, whose one axis coincides with the axis of abscissas β, while the other is parallel to the axis of ordinates at a distance equal to $+ S$, *e g.*, the saturation value of β.

For values of β approaching $+ S$, R_+ grows infinitely large and is of negative sign. For smaller values of β the numerical value of R_+ decreases first rapidly then slowly until it attains

$$\text{when } \beta = 0 \text{ a value } R_+ = - \frac{K}{S}$$

According to our curve, Fig. 4, R_- continues to have negative values and does not become zero until

$$\beta = - \infty$$

Returning now for a moment to Fig. 2, we notice that for heavy negative values of field intensity H, the value of β approaches a negative maximum $- S$. Formula 5 and curve Fig. 4, both yield for this value of $\beta = - S$

$$R_+ = - \frac{K}{+ S - (- S)} = - \frac{K}{2 S}$$

while we should expect an infinitely large value for R in conformity with our previous reasoning.

7. *Adapting the law of reactive tension R to negative magnetization.* This discrepancy of the quantitative relation between R and β, which became evident with negative magnetization, may easily be taken care of by

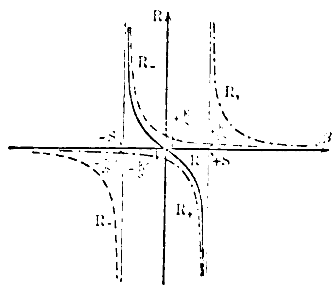


FIG. 4

repeating, for that condition, the application of the law of stressed elastic mediums.

Similar to the process carried out in chapter (5) we write now for strong negative magnetization.

$$R_- = - \frac{K}{(- S) - \beta} = + \frac{K}{S + \beta} \qquad (6)$$

Formula (6) as well as formula (5) represents an equilateral hyperbola (Fig. 4), and in this curve the

same discrepancy as that encountered above is here confronted in reversed form for $\beta = + S$.

8. *Modification of the Law of Inverse Proportionality.* The validity of each individual formula (5) and (6) to the limited zone of magnetization near positive or negative saturation respectively renders both of them unsuitable for general use. The situation is aggravated by the duplicity of value for R when $\beta = 0$, as given above $\left(R_+ = - \dfrac{K}{S} \text{ and } R_- = + \dfrac{K}{S} \right)$.

Even if it were conceded that formula (5) holds for positive magnetization and formula (6) for negative magnetization, the discontinuity and an abrupt change from $- \dfrac{K}{S}$ to $+ \dfrac{K}{S}$ at zero magnetization is not compatible with the behavior of elastic mediums, which had been referred to for comparison (see Appendix I).

However, continuity is a necessary prerequisite and that can readily be obtained by admitting the simultaneous validity of both formulas (5) and (6). Such a step finds its mathematical expression in the following form.

$$R = R_+ + R_- = - \frac{K}{S - \beta} + \frac{K}{S + \beta}$$

or

$$R = - \frac{2 K \beta}{S^2 - \beta^2} \qquad (7)$$

Formula (7) is the sum of the two terms 5 and 6 and so is curve R in Fig. 4 the composite curve of the individual curves R_- and R_+.

The new curve has actually three branches, but the two external ones, which belong to abscissas whose numerical values are larger than S, are at present of no utility. Our present consideration shall be limited to the range between $+ S$ and $- S$.

Of the unknown quantities contained in equations (3) and (4) two may now be considered known, namely

$$R_1 = - \frac{2 K \beta_1}{S^2 - \beta_1^2} \qquad (9)$$

$$R_2 = - \frac{2 K \beta_2}{S^2 - \beta_2^2} \qquad (10)$$

9. *Determination of Constants S and K.* One of these constants, S, depends surely on the magnetic quality of the material under consideration. Experiments have shown that.

Whether and to what extent K depends on the material is still to be proven by tests. Primarily K is a special value of magnetic tension.

From a few coordinated values of β near saturation, the saturation value S itself can be found by extrapolation with sufficient accuracy.

The same test readings of H and β will lend themselves to the determination of the constant K, when recourse is had to formula (7) and $- H$ is substituted for R.

Another method for determining K is explained below in connection with the study of force D.

10. *Conclusions in Regard to reactive Tension R.* We have seen that: (*a*). The reactive component R of the internal counteracting force is a force of the nature of elastic recoil. (*b*). This force R is caused by and is a mathematical function of the magnetic induction β. (*c*). The relation of R to β may be expressed hypothetically by the equation $R = - \dfrac{2 K \beta}{S^2 - \beta^2}$ (*d*). Although the reliability of this equation has been demonstrated by experimental data pertaining to but one material, its plausibility can be enhanced by the agreement of its corollaries with known facts and theories. (See Appendix I).

(*e*.) For values of β near saturation, the equation reduces itself to the form $R = - \dfrac{K}{\gamma}$ (Appendix I).

Under these same limitations Fröhlich's law is reduced to the form $H = \dfrac{K}{\gamma}$. It follows that $R + H = 0$ and that magnetic friction D and hysteresis are negligible near saturation. This conclusion is in harmony with known facts.

(*f*). For small values of β the equation reduces itself to the form $R = - \dfrac{2 K}{S^2} \times \beta$ which makes it very analogous to Hooke's Law for elastic bodies. (Appendix I).

III. Equation of Dissipative Force D

11. *Review and Aspect.* The ultimate object before the author was the establishment of an equation which relates the magnetization β to the field H. Our basic equation (2) harbors the solution of the problem in so far as it ties into a law three magnetic forces which in turn are related to β and H.

The force R proved to be a force having the magnetization β as its cause and being quantitatively related thereto as per equation (7).

The dissipative force D, however, depends on the magnetic quality of the material magnetized. To study the character of this force D and its magnitude necessitates, therefore, a recourse to actual test of suitable materials.

Should we succeed in developing for this force D mathematical terms containing D as a function of H or β, the analytical representation of the magnetic hysteresis curve would then become possible.

(12). *Exploitation of Experimental Data.* For the purpose of investigating to what laws the internal

friction D (*i. e.*, D_1 and D_2) is subject, we employ a hysteresis curve that shows clearly the properties in question. By experiment the writer has determined such a curve for a material known as Hardened Tungsten Steel. The β-curve for this material is shown in Fig. 5.

The method employed was the step-by-step method applied to Hopkinson's Divided Bar, using also a ballistic galvanometer.

The curve is composed of two branches, β_1 and β_2. Only the β_2-branch has been plotted from observed data, because the observed results for the β_1-branch may contain errors of observation. Ascertainment of degree of accuracy is not possible now. The β_1-branch shown is a copy of β_2-branch by virtue of symmetry.

13. *Numerical Values for K and S.* In order now to apply equations (9) and (10) to our curve, the values of S and K ought to be known.

From the curvature of β curve near its highest ordinates (Fig. 5), $S = 16000$ is estimated by graphical extrapolation.

To determine K, curves were plotted first taking K as an arbitrary constant which was later corrected as will be explained. For plotting these curves equations (9) and (10), $R = -\dfrac{2K\beta}{S^2 - \beta^2}$, were made use of. By their aid $+R$ could be plotted as a function of β (similar to Fig. 4). However, it was found more useful to plot $-R$ as a function of H. The hysteresis curve, Fig. 5, gives values of H corresponding to different values of β and by use of these values, taken from the hysteresis curve, it was possible to plot $-R$ as a function of H.

The curves for $-R_1$ and $-R_2$ so plotted are shown in Fig. 5. This Fig. 5, however, shows the final corrected curves which were not obtained until the correct value of K had been determined.

As already mentioned, K was first given an arbitrary value and the curves for $-R_1$ and $-R_2$ were plotted against H. An inspection of these original curves showed that for large values of H they approached the straight line $H_{ordinate} = H_{abscissa}$. Knowing this it was possible to plot the curves to their true scale as shown in Fig. 5. Also the true value of K could be determined and it was found to be $K = 0.5682 \times 10^6$ for the sample tested.

14. *Curves for D_1 and D_2 as depending on Field H. Permanent Magnets.* As $-R = (H + D)$ it is possible to get values of D from the $-R$ curves in Fig. 5. This was done and curves for D_1 and D_2 as functions of H were accordingly plotted in Fig. 5. $(-R - H = D)$.

Observe that the ordinates of D_1 are negative, while those of D_2 are positive.

Of special interest is the maximum value, which—referring to curve D_1—occurs for

$$H_1 = \text{approximately } +36\, C^{-1/2} G^{1/2} S^{-1}$$
$$D_1 = \text{approximately } -70\, C^{-1/2} G^{1/2} S^{-1}$$

Furthermore for

$$H_1 = 0 \text{ we have } \begin{cases} D_1 = -61.5\, C^{-1/2} G^{1/2} S^{-1} \\ \beta_1 = -9230\, C^{-1/2} G^{1/2} S^{-1} \\ +R_1 = +61.5\, C^{-1/2} G^{1/2} S^{-1} \end{cases}$$

When no external field H exists the two internal forces D_1 and R_1 (also D_2 and R_2) are numerically equal, but of opposite sign and therefore balance one another.

If we now go along curve β_1 (Fig. 5) from value -9230 units, where $H = 0$ to -8000, which represents a decrease in the magnetic flux, we get for this lower state of magnetization

$$R_1 = +47.4\, C^{-1/2} G^{1/2} S^{-1}$$
$$D_1 = -68.4\, C^{-1/2} G^{1/2} S^{-1}$$
$$H_1 = +21.\ \ C^{-1/2} G^{1/2} S^{-1}$$

This means for this decrease in flux the internal friction D_1 has increased and is stronger than the internal tension R_1, which has decreased. Therefore,

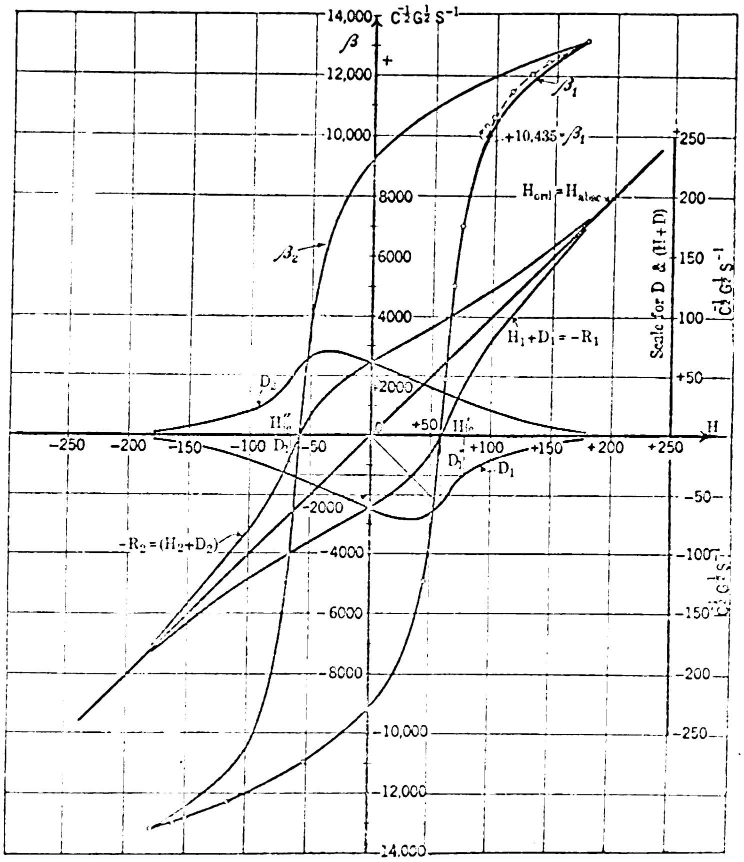


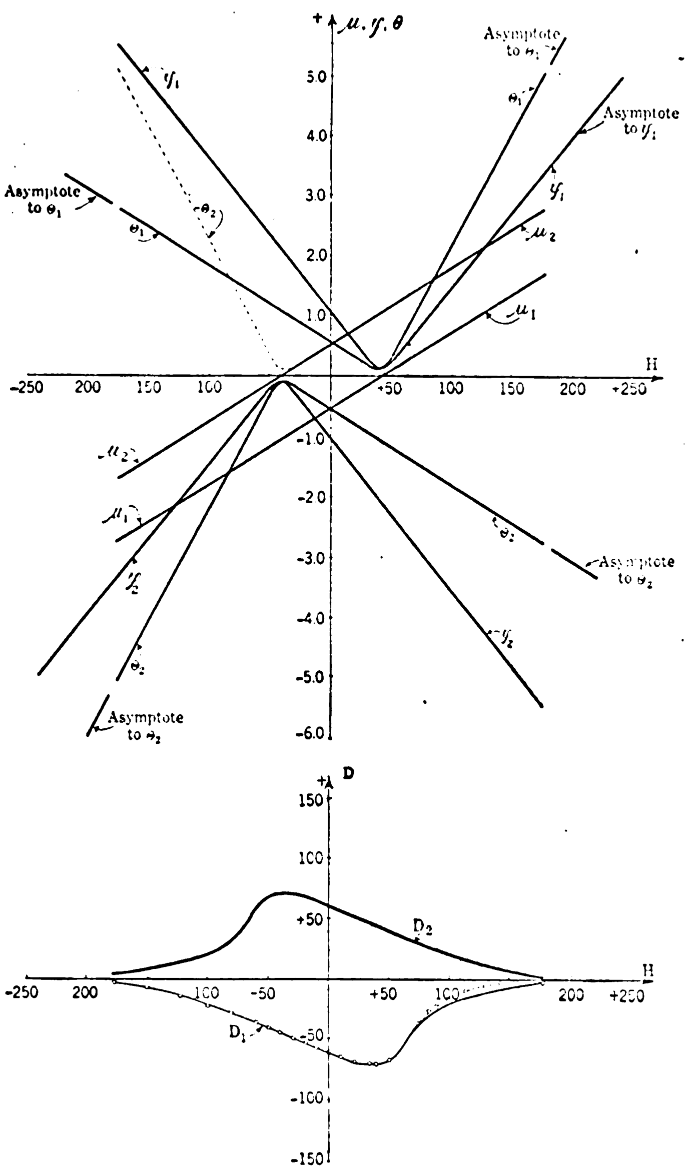
FIG. 5

without the addition of $H_1 = +21$ to force R_1, the magnetism within the iron could not diminish. This fact explains the phenomenon of permanent magnets. We may put it in this way.

"In permanent magnets magnetic friction and reactive tension are equal. For diminishing flux the fric-

tion increases, while the tension decreases. Therefore, the flux *cannot* decrease as a result of the reactive tension."

Also for other small and increasing values of H_1 the magnetic friction is both increasing and greater than the reactive magnetic tension, being smaller and diminishing. Such conditions will obtain until D_1



Figs. 6-7

reaches its maximum value. After that, both D_1 and R_1 are decreasing, and, as a sequel, the magnetization β_1 of the steel does rapidly decline.

For $\beta = 0$, we have $\begin{cases} -D_1 = +H_1 = \text{approx.} + 59 = \text{the coercive force} \\ R_1 = 0. \end{cases}$

For this condition magnetic friction and field intensity counteract and cancel one another, while the magnetic tension is zero.

For further rising field strength the magnetization β_1 increases rapidly at reversed (positive) values, owing to a rapid receding of D_1. The increase in flux, however, will soon cause R_1 to rise and the increments in magnetization, as referred to constant increments in field intensity, become smaller and smaller the more we approach the highest value of β_1. At the same time the magnetic friction D_1 converges towards the limit zero, while the reactive magnetic tension R_1 is striving towards an infinitely large value.

15. *Mathematical Relation of D and H.* After having analyzed in a general way the curves plotted from observed data, the problem remains to find mathematical terms, expressing the intrinsic and mutual relations of all the forces involved and of the flux.

As regards the D curves discussed above it was possible to get a mathematical relation between D and H. The method of deriving this relation is given in Appendix II. It was found that the graphical curves D_1 and D_2 are closely satisfied by the following equations.

$$D_1 = -\frac{A}{\cosh \theta_1} \tag{11}$$

with

$$\left.\begin{aligned} \theta_1 &= u_1 + \varphi_1 \\ u_1 &= + c\,(H_1 - f) \\ \varphi_1 &= + q\sqrt{p + u_1^2} \end{aligned}\right\} \tag{12}$$

and

$$D_2 = +\frac{A}{\cosh \theta_2} \tag{13}$$

with

$$\left.\begin{aligned} \theta_2 &= u_2 + \varphi_2 \\ u_2 &= + c\,(H_2 + f) \\ \varphi_2 &= - q\sqrt{p + u_2^2} \end{aligned}\right\} \tag{14}$$

For the sample tested the constants are as follows $A = 70.061\ C^{-1/2}\ G^{1/2}\ S^{-1}$; $f = 42$; $c = 0.012515$; $p = 0.003255$; $q = 2$

In connection with these equations the respective curves have been computed and drawn up in Figs. 6 and 7. Fig. 6 shows the graphs for u_1, φ_1, θ_1 and u_2, φ_2, θ_2, while in Fig. 7 a copy is given of the D_1 and D_2 curves as plotted from *observed* results.

In curve D_1 a few small circles indicate such points of D_1 curve as have been computed by formula (11).

IV. Magnetic Flux

16. *Relation of β to R.* By solving equations (9) and (10) for β_1 and β_2 respectively, we get in general

$$\beta = + \frac{K}{R} - \frac{1}{R}\sqrt{K^2 + R^2 \times S^2} \tag{15}$$

Values for β_1 and β_2 have likewise been computed. Between observed and computed values of β_1 and β_2 an agreement of even better degree than for D_1 (Fig. 7) is apparent in Fig. 5. And such better agreement is due to the fact that quantity $R = -(H + D)$ enters into formula (15). If D were not quite correct, the error would not manifest itself any more, than D partakes in the sum $R = -(H + D)$.

Deviation between observed and computed values is indicated for the β_1 branch only by a dotted line Fig. 5).

However, for $H_1 = +93.4$ the *observed* value $\beta_1 = +10435$ has been plotted and it falls very close to the computed (dotted) line. The above formulas may, therefore, be considered as being correct to satisfy any reasonable demands.

The term on the right hand side of formula (15) permits of a nice transformation. Move the product $R^2 S^2$ outside the square root and write:

$$\beta = S\left[\frac{K}{S\,R} - \sqrt{\left(\frac{K}{S \times R}\right)^2 + 1}\right]$$

By applying now the following substitution

$$\frac{K}{SR} = \sinh\psi \text{ or } \psi = \sinh^{-1}\frac{K}{SR} \qquad (16)$$

our formula will turn into

$$\beta = \pm S\left[\sinh\psi - \cosh\psi\right] = \mp S \times e^{-\psi} = \mp S\frac{1}{e^{\mp\psi}} \qquad (17)$$

For the exponential form we have

$e = 2.7188$ the base of hyperbolic logarithms
ψ = a positive hyperbolic angle
$-$ sign applies when R is positive (β = negative)
$+$ sign applies when R is negative (β = positive)

These relations are represented graphically by full line curve in Fig. 4.

By substituting in formula (15) for R the term $-(H + D)$, with D as per equations (11) and (13), β may be expressed in terms of H:

$$\beta = +\frac{K}{-\left(H + \dfrac{\mp A}{\cosh\theta}\right)} - \frac{1}{-\left(H + \dfrac{\mp A}{\cosh\theta}\right)} \times \sqrt{K^2 + \left(H + \frac{\mp A}{\cosh\theta}\right)^2 \times S^2} \qquad (18)$$

and this is the equation of the Hysteresis Curve.

V. Energy Loss and Other Relations

17. *Loss of Energy.* This problem of the hysteresis curve would not be completely answered without stating the so-called hysteresis loss.

As known, this loss in ergs is computed by (Fig. 1)

$$L = \frac{V}{4\pi}\overset{-H_h}{\underset{-H_h}{\mp\!\!\int}} H\,dB = 2\frac{V}{4\pi}\int_0^{-B_h}(H_1 - H_2)\,dB \;(C^2 G S^{-2}) \qquad (19)$$

whereby V is the volume of the magnetized material in cubic-centimeters and $\overset{-H_h}{\underset{-H_h}{\mp\!\!\int}}$ indicates that we have to integrate between the limits from $-H_h$ to $+H_h$ and back to $-H_h$. H_h is the highest field intensity attained.

Observing now equation (1) our integral dissolves into

$$L = \frac{V}{4\pi}\overset{-H_h}{\underset{-H_h}{\mp\!\!\int}} H\,dH + \frac{V}{4\pi}\overset{-H_h}{\underset{-H_h}{\mp\!\!\int}} H\,d\beta$$

The value of the first of those two integrals is nil, leaving for the loss

$$L = \frac{V}{4\pi}\overset{-H_h}{\underset{-H_h}{\mp\!\!\int}} H\,d\beta = \frac{V}{4\pi} \times I \qquad (20)$$

$I = \overset{-H_h}{\underset{-H_h}{\mp\!\!\int}} H\,d\beta$ represents the area within the loop $\beta_1\,\beta_2$ of Fig. 2.

Designating the highest value that β attains by β_h and by further transformation we get

$$I = -2\left\{\int_{\beta_1=0}^{\beta_1=\beta_h}\beta_1\,dH_1 - \int_{\beta_2=0}^{\beta_2=\beta_h}\beta_2\,dH_2\right\} \qquad (21)$$

The following equations (15), (9), (10), (3), (4), made use of in the order named, will permit to express these integrals in terms of H, and eventually yield the loss thus:

$$L = -\frac{V}{2\pi}\Bigg\{+\int_{+H_0}^{+H}\left(-\frac{K\cosh\theta_1}{H_1\cosh\theta_1 - A} + \frac{1}{H_1\cosh\theta_1 - A}\times\sqrt{K^2\cosh^2\theta_1 + (H_1\cosh\theta_1 - A)^2 S^2}\right)d\,H_1$$

$$-\int_{-H_0}^{+H_h}\left(-\frac{K\cosh\theta_2}{H_2\cosh\theta_2 + A} + \frac{1}{H_2\cosh\theta_2 + A}\times\sqrt{K^2\cosh^2\theta_2 + (H_2\cosh\theta_2 + A)^2 \times S^2}\right)d\,H_2\Bigg\} \qquad (22)$$

with θ_1 and θ_2 as per equations (12) and (14) and $H = +H_0$ when $\beta_1 = 0$ $H = -H_0$ when $\beta_2 = 0$. highest value attained by H is H_h.

Similarly

$$I = -2\int_0^{\beta h}\beta\,(-\,d\,D_1 + d\,D_2) = -\,2\int_0^{\beta h}\beta\,d\,(-D_1 + D_2) \qquad (24)$$

and the loss

$$L = -\frac{V}{4\pi}2\int_0^{\beta h}\beta\,d(-D_1 + D_2) = -\frac{V}{2\pi}\int_0^{\beta h}\beta d(-D_1 + D_2) \qquad (25)$$

also

$$L = +2\frac{V}{4\pi}\int_0^{\beta h}(-\,D_1 + D_2)\,d\beta \qquad (23)$$

The solution of this latter integral requires D_1 and D_2 or $(-\,D_1 + D_2)$ as a function of β. That will be accomplished in the next chapter.

But it may be remarked here that the differential

of energy loss, according to formula (28), reveals itself as the product of the magnetic friction times the change in the flux, to wit:—"friction times magnetic current." Formula (28) in this form $\frac{d\,L}{d\,t} = \frac{V}{2\,\pi}$ $(-D_1 + D_2)\frac{\partial\beta}{\partial t}$ expresses the "Hysteresis Power

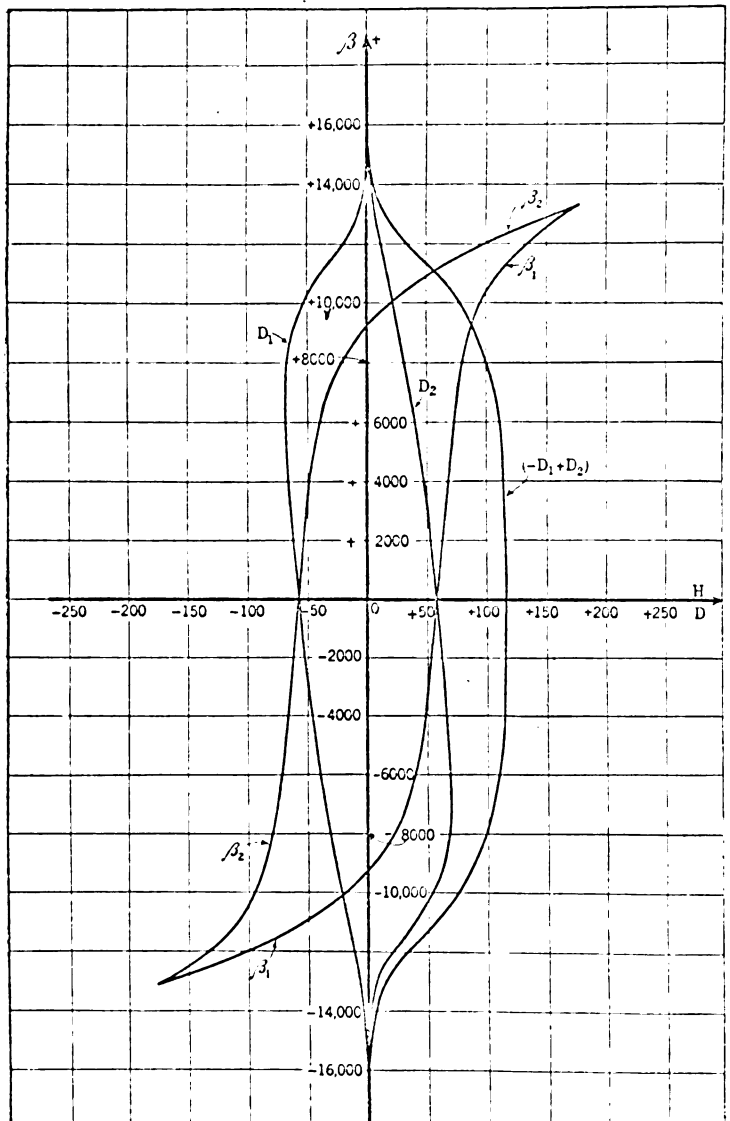


FIG. 8—MAGNETIC HYSTERESIS CURV :

Loss" as being proportional to the product "Force of Friction times Magnetic Current."

12. *Magnetic Friction D as a function of induced flux β.* Fig. 8 shows the curves of magnetic friction D_1 and D_2 over the induced flux β as abscissas.

These curves D_1 and D_2 were derived by transposing the ordinates D_1 and D_2 from their H abscissas to such β abscissas as are coordinated to the H abscissas.

No matter between what limits the magnetic cycle occurs, for $H = \pm\infty$ the values of D_1 and D_2 are zero and those of β_1 and β_2 are $\pm S$.

Consequently our two curves D_1 and D_2 must have zero points for the abscissas $+S$ and $-S$. This enables us to consider D_1 and D_2 as two half waves of two combined sine and cosine series with higher harmonics.

Referring now to curve D_1 particularly, its equation has been determined on that basis, using a method developed and described by Prof. Runge,[2] namely

$$D_1 = 10^{-3} \times S \sum \left(b_n \sin n\frac{\pi}{2}\frac{\beta_1}{S} + a_n \cos n\frac{\pi}{2}\frac{\beta_1}{S}\right) \tag{29}$$

and

$$D_2 = 10^{-5}\,S \sum \left(b_n \sin n\frac{\pi}{2}\frac{\beta_2}{S} - a_n \cos n\frac{\pi}{2}\frac{\beta_2}{S}\right) \tag{30}$$

with

n =	1	3	5	7	9	11	13	15
b_n =	+0.612	+0.606	−0.2185	−0.702	+0.0976	−0.030	+0.0219	−0.0202
a_n =	−3.89	+0.014	+0.345	−0.195	−0.0528	+0.020	−0.015	−0.004

19. *The Dissipated Energy (Numerical).* By virtue of equations (28), (29) and (30), we have for the loss

$$L = \frac{V}{2\,\pi}\int_0^{\beta_h}(-D_1 + D_2)\,d\beta \tag{31}$$

In forming the difference $(-D_1 + D_2)$ all sine members disappear and we get

$$\frac{L}{V} = -10^{-3} \times \frac{2}{\pi^2}S^2 \times \lambda = -194100 \text{ ergs per cu. cm.} \tag{32}$$

wherein

$$\lambda = \left[\sum \frac{\text{const}}{n}\sin n\frac{\pi}{2}\frac{\beta}{S}\right]_0^{\beta_h} = 3.7423 \tag{33}$$

$$\beta_h = \text{approx. } 13183;\ S = 16000$$

$$n = 1, 2, 3 \ldots\ldots 15$$

The only dimensional quantity on the right side of formula (32) is S^2 whose dimension in the $C\,G\,S$— system is $(C^{-1/2}\,G^{1/2}\,S^{-1})^2 = C^{-1}\,G\,S^{-2}$ = ergrs. per cu. cm., what it ought to be. In that way we get a confirmation that our theory and results are right.

According to the well-known Steinmetz formula, the hysteresis loss is computed by

$$\eta \times B_{max}^{1.6} \text{ in ergs per cu. cm.} \tag{34}$$

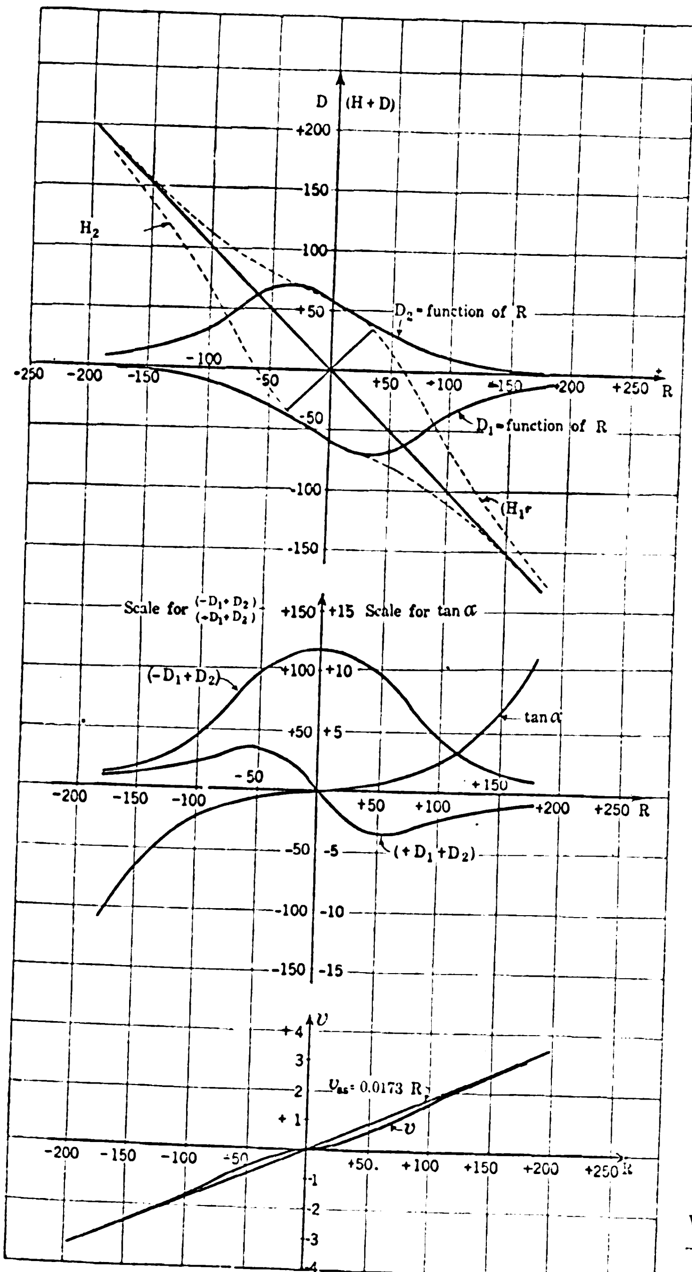
2. See *Electrotechnische Zeitschrift*, 1905, p. 247. C. Runge, "*Theorie & Praxis der Reihen*" Goshen at Leipsig, Germany.

which, when compared with our results, will ultimately net $\left(\text{neglecting } \frac{H_h}{S} = 0.011\right)$:—

$$\eta = 0.04862$$

and

$$\lambda = \frac{1000\,\eta \times \pi^2}{2}\left(\frac{\beta_h}{S}\right)^{1.6} \times S^{-2/5} \qquad (36)$$



FIGS. 9–10–11

Further experiments should show to what extent this formula is correct.

Appendix III contains formulas which give the energy loss in explicit terms of the leading quantities.

20. *Magnetic Friction D as Function of Magnetic Tension.* Fig. 9 shows curves. For formulas see Appendix III.

21. *Loss of Energy in Terms of Flux β and Tension R.* Formulas and computations will be found in Appendix III. Pertinent curves are illustrated below Figs. 9, 10, 11.

VI. ALTERNATING CURRENT EXCITATION

23. *Sine Current.* In the case where an alternating current is used to furnish the magnetomotive force, the intensity of the magnetic field will be expressed by

$$H = H_h \times \sin\frac{2\,\pi}{T}\,t = \text{const} \times I_0 \sin\frac{2\,\pi}{T}\,t \qquad (37)$$

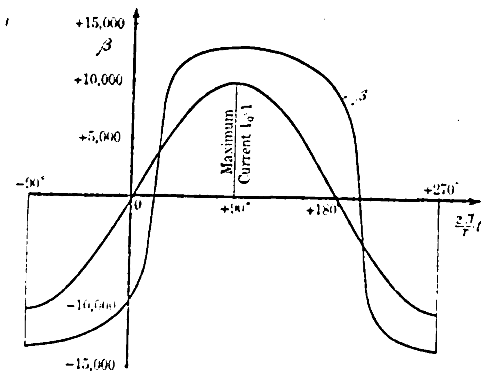


FIG. 12

while the curve for β contains higher harmonics as per Fig. 12 (for the sample tested).

$$\beta = S \times \sum c_n \sin\left(\frac{2\,\pi}{T}\,t + \omega_n\right) \qquad (39)$$

with

n =	1	3	5	7	9	11
C_n =	+0.9482	+0.2324	+0.1212	+0.07891	+0.05684	+0.09989
ω_n =	−8°26′	−61°7′	−106°28.4′	−151°48.6′	+163°3.6′	−102°23.6′

24. *Sine Voltage.* For the case of a sine voltage

$$E = E_0 \sin\frac{2\,\pi}{T}\,t$$

being applied to the windings around the magnetic material, the magnetic flux β and field H are illustrated in Fig. 13.

$$\beta = S \times \sum C_n \sin\left(\frac{2\,\pi}{T}\,t + \Omega_n\right) \qquad (41)$$

with

n =	1	3	5	7	9	11
C_n =	+0.8314	$+\frac{2.868}{1000}$	$+\frac{0.6956}{1000}$	$+\frac{0.069}{1000}$	$+\frac{0.08924}{1000}$	$+\frac{0.5953}{1000}$
Ω_n =	−90°14.8′	+82°35′	+60°37.9′	+94°56′	+176°0′	−161°38.4′

and

$$H = 177 \sum h_n \sin\left(\frac{2\,\pi}{T}\,t + \nu_n\right) \qquad (42)$$

with

n =	1	3	5	7	9	11
h_n =	+0.7559	−0.2592	−0.0629	−0.00624	−0.00806	−0.00538
ν_n =	−64°13.7′	+82°35′	+60°37.9′	+94°56′	+176°0′	−161°38.4′

VII. Applying the Theory

To show the ability of the new theory we shall now apply it to the well-known theory of Hopkinson's Magnetic Circuit, in conjunction with Professor Kennelly's paper on Reluctivity (TRANSACTIONS of the A. I. E. E. 1891, page 485.)

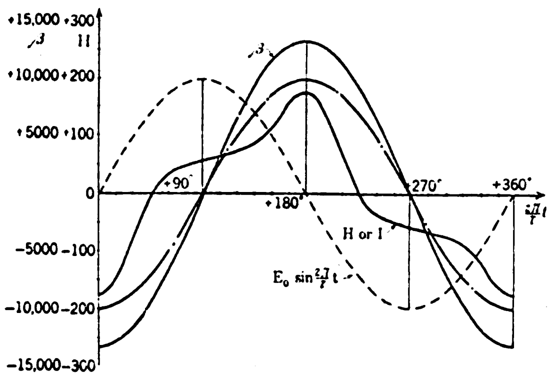


FIG. 13

In said paper (Figs. 4 and 5) the rectilinear characteristic of the metallic reluctivity $\rho = \dfrac{1}{4\pi\kappa}$ when plotted against H is particularly stressed.

With the results of our theory conceded, calling for internal reactive forces R and D, *only that part* of H which is equal $-R$ remains available for magnetization proper. If ρ be therefore related to $-R$, instead of H, we get for the metallic reluctivity

$$\rho = \frac{1}{4\pi\kappa} = \frac{-R}{\beta} = \frac{-R}{\mp S} e^{\phi}$$

use $-S$ when R = positive
use $+S$ when R = negative

and for the apparent reluctivity

$$r = \frac{1}{\mu} = \frac{\rho}{1+\rho}$$

both of which are illustrated in Fig. 14 at two different scales for our sample of hardened Tungsten Steel.

We note particularly that for large values of $R-$ (which differ only slightly from corresponding values of H) ρ is very nearly a straight line whose asymptote runs through the origin of the system at an inclination

$\tan \tau = \dfrac{1}{S}$, which in our case $\dfrac{1}{16000} = 0.0000625.$

It is of the same order as the gradient of right hand end of curve for "Glass Hard Pianoforte Steel, Ewing 1890," given in Fig. 5 of Professor Kennelly's paper. The straight lines (substitutes for curves) in said Fig. 5 do, however, not run through origin, because those curves are plotted against H, which includes the component opposing D.

Even diamagnetism may be explained now, by reversing in above formula for ρ the sign of R. That is permissible from the mathematical standpoint and conceivable from the physical standpoint so long as β in Fig. 4 remains between the limits $+S$ and $-S$. Reversal of sign of R takes place automatically when $\beta > S$, but such a condition cannot be reconciled with our definition of S as a maximum value of β.

Notations and Symbols Used in This Paper

B Induction or flux density
H Magnetizing force; also spatial induction
β Intrinsic induction (*i. e.*, $B - H$)
S Saturation value, that is the limiting value of β
γ Capacity for further induction (*i. e.*, $S - \beta$)
R Reactive component of internal force, opposing magnetization in either direction.
D Dissipative component of the internal force, opposing all changes of induction β.
M Maximum value of $(-D_1 + D_2)$
Subscript$_1$ indicates appertainment to ascending branch of hysteresis loop
Subscript$_2$ indicates appertainment to descending branch of hysteresis loop
Subscript$_h$ indicates highest vaule attained

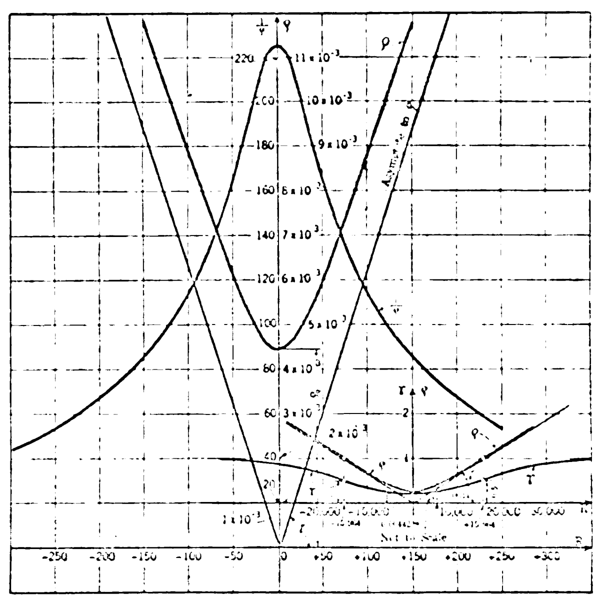


FIG. 14

Subscript$_0$ indicates that a related quantity has zero value
θ = $u + \varphi$, a hyperbolic angle
α = a circular angle
v = a hyperbolic angle

The unit for quantities B, H, β, S, γ, R, D, M in the $C\,G\,S-$ system is $C^{-1/2}\,G^{1/2}\,S^{-1}$ that is the Gauss = Number of lines of force per square centimeter.
L = Energy Loss in ergs ($C^2\,G\,S^{-2}$).
1.356×10^7 ergs = 1 ft-lb.

For illustration of leading symbols see Figs. 1 to 4.

Steady-State Stability in Transmission Systems
Calculation by Means of Equivalent Circuits or Circle Diagrams

BY EDITH CLARKE[1]

Associate, A. I. E. E.

Synopsis.—*The maximum load on a proposed transmission system must be within the steady-state power limit of the system for stability of operation. Two methods of calculating steady state stability are given in detail and illustrated by examples. (1) The given transmission system is replaced by a simple equivalent system, then the steady-state power limit of this equivalent system is determined graphically. (2) By means of a circle diagram the system is tested for stability with the maximum proposed load on the system.*

All formulas from published references necessary for the calculations are included and all calculations are given in full so that similar studies can readily be made by an engineer who has not previously made a study of the subject of stability.

THE object of this paper is to give two methods of determining the stability of operation of a proposed transmission system under steady-state conditions. The calculations will be given in detail so that the engineer who has not previously made a study of the subject will have no difficulty in applying the tests for stability to his system. The first method is by means of an equivalent circuit and the second by means of a circle diagram. Both methods are based on theorems which are exact, but in order to fit the transmission system to the theorems certain assumptions must be made. The results will therefore be approximate to the extent to which the assumptions approximate actual conditions.

Formerly when a transmission system was proposed, it was customary to make the line calculations for voltage regulation and losses for the maximum load conditions, and to select the generators, transformers and synchronous condensers to fit these conditions. There was nothing in such calculations to indicate that the system would be stable, but fortunately the length of line and maximum load have been such that cases of instability have been rare. At the present time when the tendency is for longer lines and greater loads, it is necessary to consider the question of stability both for steady state and transient conditions. Steady-state stability only will be considered in this paper.

In steady-state stability the assumption is made that the load comes on in infinitesimal amounts so that the transient caused by one increment is over before the next increment is added. The criterion of steady-state stability is this: Assuming that the system is operating satisfactorily under the assumed load conditions, will it continue to operate satisfactorily if an increment of synchronous load is added and all excitations remain constant? When load is added there is an increase in current and a drop in voltage before there is any change in excitation. The voltage regulators then increase the excitations and normal voltage is obtained. If the load on the system is *just* the amount which can be transmitted at excitations which correspond to normal voltage, any increase in synchronous load will cause instability because the voltage must drop before the voltage regulators can increase the excitations and at the given excitations no more power can be transmitted. Therefore, when the voltage starts to drop it will continue to drop, for there is no voltage at which the load can be transmitted with those excitations.

When a generator and motor are on the same bus, at no-load, neglecting no-load losses, their induced voltages are in phase. Keeping the excitations on motor and generator constant as the motor is gradually loaded, the phase displacement between the excitation voltages of motor and generator increases with load until the machines fall out of step. The load at which the machines fall out of step is the maximum load and the angle is the maximum power angle. This angle and the power corresponding to it can be calculated. Power corresponding to an angle greater than the maximum power angle can also be calculated although it cannot be delivered.

In the simple transmission system consisting of a synchronous generator supplying power to a synchronous motor over a line having resistance and reactance, but no appreciable capacitance or leakance, the maximum power that can be transmitted over the system, and the angle between the generator and motor excitation voltages corresponding to maximum power, are not difficult to calculate. This simple system will be stable under a proposed load if the phase displacement between the synchronous generator and synchronous motor excitation voltages corresponding to the proposed load is less than the phase displacement which corresponds to maximum power on the shaft of the motor. When a transmission system consisting of generators, lines with distributed constants, and the usual station load can be replaced by the simple transmission system, the maximum power that can be transmitted over the system is easily calculated. In studying steady-state stability by means of equivalent circuits an attempt is made to replace the complicated transmission system by the equivalent simple system.

1. Central Station Engineering Dept., General Electric Co.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926. Complete copies available upon request.

Equivalent Line

Dr. E. A. Kennelly[2] has shown that a line with distributed constants can be replaced by either an equivalent π or T line in which the constants are lumped. The π line consists of a line with a shunt at each end and the T line of a line with a shunt at the center. The nominal π is formed by placing the total impedance, Z, of the actual line in the line or architrave of the π and one-half the admittance, Y, in each shunt or pillar. The nominal T is formed by placing one-half the total impedance of the actual line in each arm of the T and the total admittance in the shunt or staff. The nominal π and T lines are not exact equivalents of the actual line, but by applying correcting factors to them the equivalent π and T lines are obtained which are exact equivalents of the actual line.

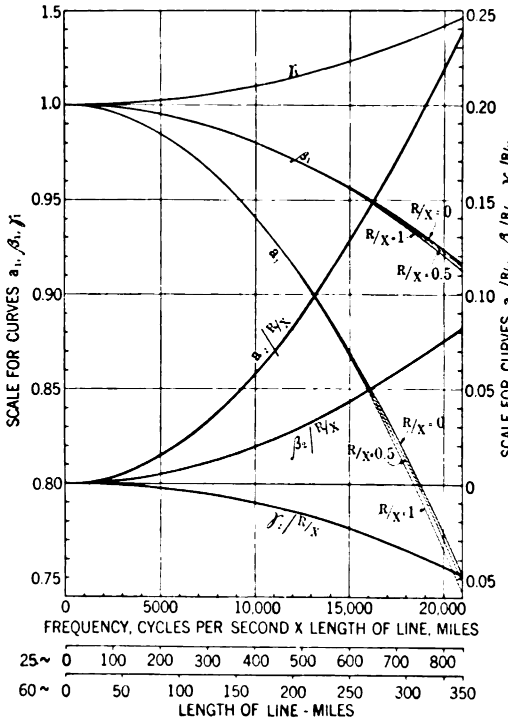


Fig. 1—Complex Hyperbolic Functions

$$\cosh \sqrt{Z\,Y} = 1 + \frac{Z\,Y}{2} + \ldots = a_1 + j\,a_2$$

$$\frac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}} = 1 + \frac{Z\,Y}{2} + \ldots = \beta_1 + \beta_2$$

$$\frac{\tanh \sqrt{Z\,Y/2}}{\sqrt{Z\,Y/2}} = \gamma_1 + j\,\gamma_2$$

Correcting Factors for Converting the Nominal π or T Line Into the Equivalent π or T. The correcting factors which must be applied to convert the nominal π or T into the equivalent π or T are $\dfrac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}}$ to be applied to the architrave of the π and the staff of the T and $\dfrac{\tanh (\sqrt{Z\,Y/2})}{\sqrt{Z\,Y/2}}$ to be applied to the pillars of the π and the arms of the T.

2. "Application of Hyperbolic Functions to Electric Engineering Problems."

Fig. 1 gives the real and imaginary parts of these correcting factors. For convenience the real and imaginary parts of cosh $\sqrt{Z\,Y}$ are also given.

Power at a Point Within the Equivalent π. The π-line viewed from either end is an exact equivalent of the line with distributed constants but the current and voltage at any point in the architrave of the π do not correspond to current and voltage on the actual line. Let the π-line in Fig. 2 be the equivalent π of the line $A\,B$ with distributed constants. Although the current at d is the same as the current at B, the current at c has no counterpart in the actual line. The power at d is the same as the power at B, but the power at c is the power at d plus the power lost in shunt Z_4. When the power is known at b and c it can be calculated at a and d.

Synchronous Impedance

It is understood that the synchronous impedance of a synchronous generator or motor is not constant. However, given the characteristics of the machine and the conditions of operation, it is possible to find an *equivalent* synchronous impedance which may be considered constant for the case under consideration. In the work which follows constant synchronous impedance refers to this equivalent synchronous impedance.

For the synchronous condenser it is necessary to find an equivalent excitation as well as an equivalent synchronous impedance. This is discussed at greater length in Appendix E.

Equivalent Generator

If a system consist of a synchronous generator and synchronous motor, both of constant synchronous impedance, connected by a line with a shunt at the generator end, this system can be replaced for all points beyond the shunt by a system unchanged beyond the shunt, but having a new generator whose impedance is the impedance of the generator and shunt in parallel and whose excitation voltage

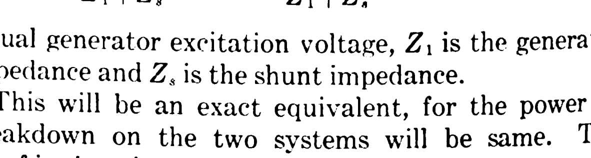


Fig. 2—A. Line $A\,B$ with Distributed constants
B. Equivalent π = Line

$$E_1' = E_1 \frac{Z_1\,Z_s}{Z_1 + Z_s} \div Z_1 = E_1 \frac{Z_s}{Z_1 + Z_s},$$ where E_1 is the actual generator excitation voltage, Z_1 is the generator impedance and Z_s is the shunt impedance.

This will be an exact equivalent, for the power at breakdown on the two systems will be same. The proof is given in Appendix C (b).

Equivalent Motor

If a system consist of a synchronous generator and synchronous motor, both of constant synchronous

impedance, connected by a line with a shunt at the motor end this system can be replaced for all points in front of the shunt by a system unchanged up to the shunt, but having a new motor whose impedance is the impedance of the motor and shunt in parallel and whose excitation voltage $E_2' = E_2 \dfrac{Z_2 Z_s}{Z_2 + Z_s} / Z_2$ $= E_2 \dfrac{Z_s}{Z_2 + Z_s}$, where E_2 is the actual motor excitation voltage, Z_2 is the motor impedance and Z_s is the shunt impedance; but power on the fictitious system corresponding to breakdown power on the actual system occurs when the phase displacement between the generator and equivalent motor excitation voltages is the total impedance angle of the fictitious system plus the angle, $2(\theta_2 - \theta_2')$, where θ_2 is the impedance angle of the actual motor and θ_2' is the impedance angle of the equivalent motor. The proof is given in Appendix C (*b*).

Equivalent System and Voltage Regulators

If a system consists of a synchronous generator and synchronous motor, both of constant synchronous impedance, connected by a line with a shunt at each end, voltage being maintained at the ends of the line, this system can be replaced for all points of the line by a system consisting of the same line without shunts, a generator whose impedance is the impedance of the actual generator and shunt at the generator end in parallel and a motor whose impedance is the impedance of the actual motor and shunt at the motor end in parallel; but power on the fictitious system corresponding to breakdown power on the actual system occurs when the phase displacement between equivalent motor and generator excitation voltages is the total impedance angle of the fictitious system plus $2(\theta_2 - \theta_2')$ where θ_2 is the impedance angle of the actual motor and θ_2' the impedance angle of the equivalent motor. The proof is given in Appendix D.

When $2(\theta_2 - \theta_2') = 0$ deg., the fictitious system becomes an equivalent system, for the power at breakdown on the two systems will be the same. When resistance is neglected in the motor and motor end shunt $2(\theta_2 - \theta_2') = 0$ deg. or 360 deg.

Since no limitation is placed on the shunt impedances in the proofs given in the appendix, in addition to representing the capacitance in the line, they may represent reactors, resistance load or any other dead load.

Equivalent Circuit Method

Graphical Solution. When the actual system has been replaced by the equivalent simple system, the maximum power which can be transmitted may be obtained graphically.

Let Fig. 3A represent the simple equivalent system, where

$Z_5 = r + jx =$ the impedance of the equivalent line.

$Z_1 = r_1 + jx_1 =$ the actual generator impedance.

$Z_1' = r_1' + jx_1 =$ the equivalent generator impedance formed by taking the shunts at the generator end of the line in parallel with the generator impedance.

$Z_2 = r_2 + jx_2 =$ the actual motor impedance.

$Z_2' = r_2' + jx_2' =$ the equivalent motor impedance formed by taking the shunts at the motor end of the line in parallel with the motor impedance.

E_1 = excitation voltage of the actual generator.

E_2 = excitation voltage of the actual motor.

E_1' = excitation voltage of the equivalent generator $= E_1 \dfrac{Z_1'}{Z_1}$

E_2' = excitation voltage of the equivalent motor $= E_2 \dfrac{Z_2'}{Z_2}$

E_A = terminal voltage at the generator end of the line.

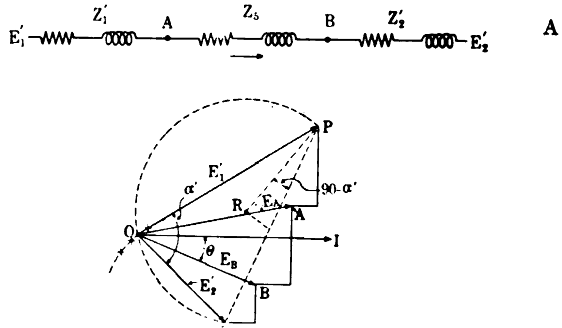


FIG. 3—A. EQUIVALENT TRANSMISSION SYSTEM
B. GRAPHICAL DETERMINATION OF MAXIMUM POWER OVER THE EQUIVALENT TRANSMISSION SYSTEM

E_B = terminal voltage at the receiver end of the line.

$Z_t = (r + jx + r_1' + jx_1' + r_2' + jx_2') = R_t + jX_t$
$= z_t\, e^{j\theta t}$
= total impedance of the equivalent system.

$\theta_t = \tan^{-1} \dfrac{X_t}{R_t}$ = total impedance angle.

$\theta_2 = \tan^{-1} \dfrac{x_2}{r_2}$ = impedance angle of the actual motor.

$\theta_2' = \tan^{-1} \dfrac{x_2'}{r_2'}$ impedance angle of the equivalent motor.

Calculate $\alpha' = \theta_t + 2(\theta_2 - \theta_2')$

Since there are no shunts in the equivalent or fictitious system the same current will flow in all parts of the circuit. Taking current as standard phase, lay off

$QBAP = I(r_2' + jx_2') + I(r + jx) + I(r_1' + jx_1')$

to any convenient scale. Fig. 3B. The value of this scale will be determined when the construction has been completed and the position of point O determined.

There are two conditions which determined the position of point O.

1. $\alpha' = \theta_t + 2(\theta_2 - \theta_2')$

2. The ratio between the magnitudes of E_A and E_B or between E_1' and E_2' is known. For a regulated line E_A and E_B are given, and for a line without voltage regulators E_1' and E_2' can be calculated from the known values E_1 and E_2.

Consider the case of the regulated line: To satisfy the first condition join P and Q and at P drawn PR making an angle, $(90° - \alpha')$ with PQ. With R, the intersection of PR with the perpendicular bisector of PQ, as a center and RP as radius describe arc PQ. If point O lies on this arc, the first condition will be satisfied. To satisfy the second condition, find a series of points whose distances from A and B are in the ratio E_A/E_B and draw a curve through them. O will lie on the intersection of this curve with the arc PQ.

The scale of the vector diagram is determined, for $OB = E_B$. All voltage drops are now given in terms of E_B. E_B is known, therefore all voltage drops are known and the current can be calculated. The power factor angle, θ, can be measured.

Maximum Power at $B = E_B \,.\, I \,.\, \cos\theta$.

The impedances, voltages and currents may be expressed in ohms, volts and amperes respectively or in per cent, as is most convenient.

Algebraic Solution—Resistance Neglected. When resistance is neglected and equal voltages are maintained at the ends of the line a simple formula can be derived for the power delivered.

If

X_1' = the equivalent generator reactance.
X_2' = the equivalent motor reactance.
X = the equivalent line reactance.
V_A = V_B = magnitude of line terminal voltages, E_A and E_B.

$$P_{max} = \frac{V_B^2\sqrt{\left(X_1' + \frac{X}{2}\right)\left(X_2' + \frac{X}{2}\right)}}{\left(\frac{X}{2}\right)^2 + \left(X_1' + \frac{X}{2}\right)\left(X_2' + \frac{X}{2}\right)} \qquad (1)^*$$

When V_B is in volts to neutral, and reactances are in ohms, power will be in watts per phase. If voltages and reactances are in per cent, power will be in per cent (20% = 0.20).

When V_B = 100 per cent and the motor and generator have the same impedance $(X_1' = X_2')$, equation (1) becomes

$$P_{max} = \frac{X_1' + \frac{X}{2}}{\left(\frac{X}{2}\right)^2 + \left(X_1' + \frac{X}{2}\right)^2} \qquad (2)$$

*This equation was first developed by C. A. Nickle.

When $X = O$, which is the case for a motor and generator on the same bus,

$$P_{max} = \frac{1}{X_1'} \qquad (3)$$

When $X_1' = X_2' = O$, which is the case for infinite busses at the ends of the line,

$$P_{max} = \frac{1}{X} \qquad (4)$$

Application of the Fictitious or Equivalent System to Steady State Stability Problems

1. *Effect of Capacitance in the Line.* If resistance is neglected and generator and motor of equal impedances are assumed, equation (2) may be used to calculate maximum power over the line with and without capacitance. Without capacitance, X_1' will be the actual generator impedance. Capacitance in the line

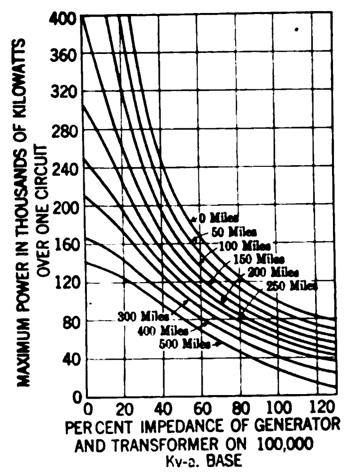


Fig. 5—Maximum Synchronous Load Delivered over 220-Kv., 60 Cycle, Transmission Lines of Various Lengths

When resistance is neglected. Synchronous generators and motors assumed to have equal synchronous impedances. (Transformer impedance included in generator impedance)

will reduce X, since X is multiplied by the correcting factor β which is less than unity, but it will increase X_1', for when the negative reactances of the shunts of the equivalent π-line are combined in parallel with the positive reactances of the machines, the equivalent reactances are greater than the actual machine reactances. The effect of capacitance will be to increase or decrease the maximum power depending upon whether the change in X or in X_1' has the greater influence.

Curves for Estimating Maximum Power

The curves in Fig. 5 were calculated for 60 cycles and various lengths of line, assuming reactance of 0.813 mhos per mile and capacity susceptance of 5.22×10^{-6} mhos per mile, 220 kv. was maintained at each end of the line, resistance was neglected in the line and in the generators and motors which were assumed of equal synchronous impedances. These curves can be used as a first approximation.

2. *Reactor Across the Generator Terminals.* If a reactor is placed across the generator terminals the effect is opposite to the effect produced by the capacity shunt. The reactor reduces the equivalent generator impedance so that more power can be transmitted over the system. It must be remembered that the excitation on the generator is increased by the use of a reactor, but when full field is not being used on the generator, a reactor increases the power that can be transmitted by the same amount that a generator of the same rating would do. Since reactors are cheaper than generators, a reactor of the size that would put full excitation on the generator can be used to advantage to increase the stability of the system.

3. *Power Limits of a Long Line.*

a. Limit of the line alone.
b. Limit of the line and transformers.
c. Limit of the line transformers and generator.
d. Limit of the system with various kinds of load.
 1. Synchronous motors.
 2. Lights and synchronous motors.
 3. Lights, induction motors, synchronous motors and synchronous condensers.
 4. Same as (3) but with a generator supplying local load.

A line with generator and transformers will be selected then the maximum power will be obtained for the specified conditions.

Given:

A three phase, 60 cycle, 250 mile line.

Line constants: r = 0.151 ohms per mile
x = 0.813 ohms per mile
y = 5.22 micro-mhos per mile
Leakance = O.

Step-up transformers: 270,000 kv-a. total
2 per cent resistance
12 per cent reactance
13,200—220,000 volts.

Step-down transformers: 240,000 kv-a. total,
2 per cent resistance
12 per cent reactance
210,000-13,200 volts

Generators: 270,000 kv-a. total
0.9 power factor, 13,200 volts
100 per cent synchronous impedance.

Voltage regulators will maintain 220 kv. and 200 kv. at the generator and receiver ends respectively on the low sides of the transformers (assuming a one-to-one ratio of transformation). The magnetizing current in the transformers will be neglected.

From equation (**7**) Appendix C (*a*).

$$P_{max} = \frac{V_1 V_2}{z}\left(1 - \frac{V_2}{V_1}\cos\theta\right),$$ where V_1 and V_2 are terminal voltages at the generator and receiver ends respectively, Z is total impedance, and θ is total impedance angle.

When V_1 and V_2 are in volts to neutral and Z is in ohms, power will be in watts per phase. If voltages and impedances are in per cent, power will be in per cent (20 per cent = 0.20).

When V_1 and V_2 are bus voltages, Z the total impedance between the buses and θ the total impedance angle, P_{max} will be the maximum power that can be exchanged between the buses.

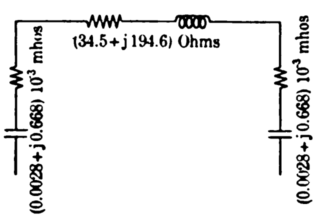


FIG. 6—EQUIVALENT π OF THE TRANSMISSION LINE ALONE

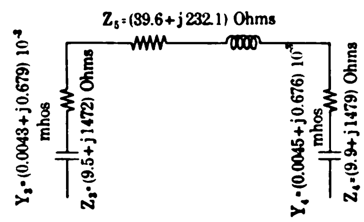


FIG. 9—EQUIVALENT π OF THE LINE AND TRANSFORMERS

When V_1 and V_2 are excitation voltages of synchronous generator and synchronous motor respectively, Z the total impedance between them and θ the total impedance angle, P_{max} will be the synchronizing power between the two machines.

Fig. 6 gives the equivalent π of the line alone. Fig. 9 gives the equivalent π of the line and transformers.

The maximum power which can be transmitted over the line alone and over the line with transformers may be obtained by subtracting the power lost in the receiver shunt from the total power which can be exchanged between the buses.

(a) The limit of the line alone = 187,000 kw.

(b) The limit of the line with transformers = 158,500 kv.

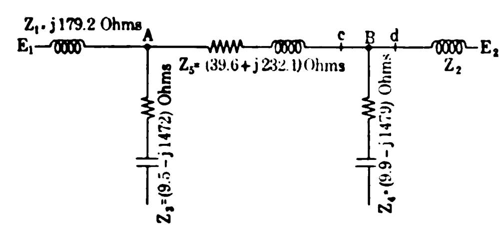


FIG. 11—EQUIVALENT π OF THE LINE AND TRANSFORMERS

With synchronous generator and motor. Impedances are in ohms referred to the high side.

(c) Limit of the line, transformers and generator is obtained by assuming a motor of zero impedance or an infinite bus at the receiver end.

Fig. 11 represents the line with end shunts and a motor and generator each of constant synchronous impedance. The power at *d*, that is the power de-

livered to the load, will be the power at c minus the power lost in Z_4. Fig. 12 gives the equivalent circuit with the impedances in per cent on a 100,000 kv-a. base. 100 per cent voltage = 200 kv. The shunt Z_3 has been combined in parallel with the generator impedance. The shunt Z_3 has not been combined with the motor impedance.

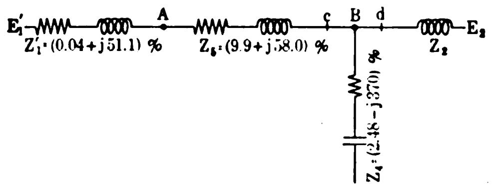


FIG. 12—EQUIVALENT CIRCUIT OF LINE, TRANSFORMERS, GENERATOR AND MOTOR

Impedances are in per cent on a 100,000-kv-a. base. 100 per cent voltage = 200 kv.

The voltages and impedances in per cent from Fig. 12 are

E_A = 110 per cent, E_B = 100 per cent,

$Z_1' = (0.04 + j\,51.1)$ per cent, $Z_2' = O$

$Z_5 = (9.9 + j\,58.0)$ per cent,

$Z_5 + Z_1' + Z_2' = (9.9 + j\,109.1)$ per cent $= Z_t$

α' = maximum power angle $= \theta_t + 2\,(\theta_2 - \theta_2') = \theta_t$

$$= \tan^{-1}\frac{109.1}{9.94} = 84.7 \text{ deg.}$$

Making the graphical construction as described above, Fig. 13 is obtained. From Fig. 13

$$\text{Since } O\,B = 100 \text{ per cent Voltage, } I = \frac{\overline{B\,P}}{\overline{O\,B}} \Big/_{st}$$

$$= \frac{1.845}{1.095} = 1.685 = 168.5 \text{ per cent current.}$$

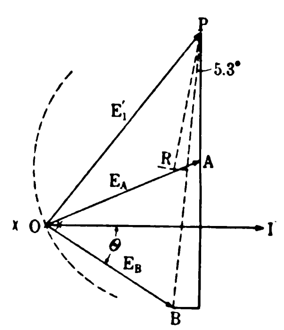


FIG. 13—GRAPHICAL DETERMINATION OF MAXIMUM POWER WITH AN INFINITE BUS AT THE RECEIVER END

Power factor at B = 0.84 lead.

Power at c = 1 × 1.685 × 0.84 = 1.415

= 141.5 per cent on 100,000 kv-a. base

= 141,500 kw.

Power lost in shunt Z_4 = 180 kw.

Limit of the line, transformers and generators = 141,300 kw.

d. Limit of the system with various kinds of load.

1. Synchronous motor load of total capacity 170,000 kv-a., 85 per cent synchronous impedance.

Z_2 = motor impedance on 100,000 kv-a. base = 50 per cent

$$Z_2' = \frac{Z_2\,Z_4}{Z_2 + Z_4} = \text{impedance of equivalent motor}$$

$= (0.07 + j\,57.8)$ per cent

Fig. 14 gives the equivalent circuit.

Z_t = total impedance = $(10.0 + j\,166.9)$ per cent.

θ_t = total impedance angle = 86.6 deg.

θ_2 = impedance angle of actual motor = 90 deg.

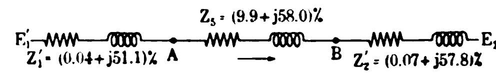


FIG. 14—EQUIVALENT CIRCUIT FOR SYNCHRONOUS MOTOR LOAD

θ_2' = impedance angle of equivalent motor = 89.9 deg.

$2\,(\theta_2 - \theta_2')$ = 0.2 deg.

$\alpha' = \theta_t + 2\,(\theta_2 - \theta_2') = 86.7$ deg.

Using the equivalent circuit given in Fig 14 and. making the graphical construction as described above, Fig. 15 is obtained.

Since $O\,B$ = 100 per cent voltage, I = 112.5 per cent current and

Power factor at B = 0.943 lead.

Power at c = 1 × 1.125 × 0.943 = 1.06

= 106,000 kw.

Power lost in shunt Z_4 = 180 kw.

Maximum power that can be delivered to the load = 106,000 kw.

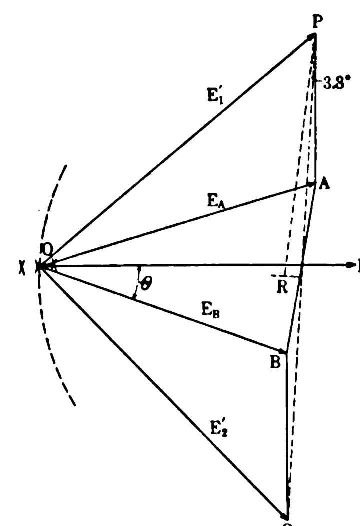


FIG. 15—GRAPHICAL DETERMINATION OF MAXIMUM POWER FOR A SYNCHRONOUS MOTOR LOAD

2. Resistance load of 30,000 kw., synchronous motors of total capacity 170,000 kv-a. with 85 per cent synchronous impedance.

R = resistance of the resistance load shunt.

= 1333 ohms.

= 333.3 per cent on 100,000 kv-a.; base, 200 kv.

Z_4' = impedance of Z_4 and R in parallel = $(184 - j\,165)$ per cent

Z_2 = impedance of actual motor = 50 per cent

$Z_2' = \dfrac{Z_2 Z_4'}{Z_2 + Z_4'}$ = impedance of equivalent motor $= (9.8 + j\,56.1)$ per cent

Z_t = total impedance of equivalent circuit = $(19.74 + j\,165.2)$ per cent

θ_t = 83.2 deg. = total impedance angle.

$\alpha' = \theta_t + 2(\theta_2 - \theta_2') = 83.2\text{deg.} + 2\,(90 - 80.1\text{deg.}) = 103.0$ deg.

The graphical construction is given in Fig. 16.

Since $O\,B$ = 100 per cent

I = 138.5 per cent and power factor at B = 0.90 lead

Power at $c = 1 \times 1.385 \times 0.90 = 1.248$ = 124,800 kw.

Power lost in the line shunt Z_4 = 180 kw.

Maximum power that can be delivered to the load = 124,600 kw.

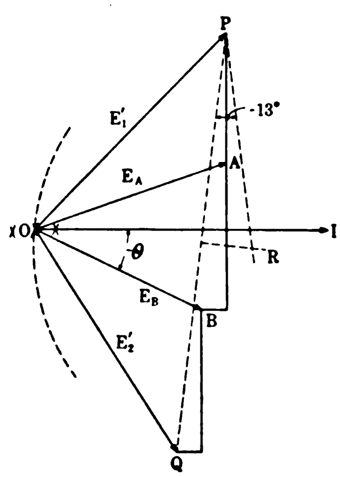


FIG. 16—GRAPHICAL DETERMINATION OF MAXIMUM POWER FOR A LOAD PARTLY RESISTANCE AND PARTLY SYNCHRONOUS

3. Lights, induction motors, synchronous motors and synchronous condensers.

4. Same as (3) but with generator supplying local load.

As voltage drops on an induction motor load, the power required by the load remains practically constant and the power factor becomes less lagging. A lightly loaded synchronous motor has the same characteristics. The induction motor load therefore, may be replaced by an approximately equivalent synchronous motor.

A method of treating the synchronous condenser in the equivalent circuit is given in Appendix E.

Examples of type (3) can be solved by the equivalent circuit method but the solution with the circle diagram is more satisfactory than the solution by the equivalent circuit method available at present. An example of type (4) is solved by the circle diagram method. See example (3) following. It is hoped that systems more complicated than the one considered here as well as examples of types (3) and (4), will eventually be completely represented by equivalent circuits.

CIRCLE DIAGRAM METHOD

The test for stability by this method is to assume a slight increase in load and to determine if by a drop in receiver voltage this new load can be carried with the excitations corresponding to the original load.

When a system is operating at normal voltage ana a load is added there is an increase in current at the receiver end and a drop in voltage. The power given to the additional load comes from the change in phase displacement between the sending and receiving end equipment. Due to the drop in voltage at the load, the original load does not require the same power it required at normal voltage if it is the average station load. The kw. and kv-a. taken by the original load changes with voltage. If voltage slightly less than normal is assumed at the receiver end and the kw. and kv-a. corresponding to the original load at this voltage plus a small load increment can be transmitted over the line with the given generator excitation, the system is stable, for the small increment is the contribution to the additional load made by the change in phase displacement of the system. For the limit of stability this increment approaches zero.

The method of obtaining the general circuit constants of a transmission system, and the construction of the power circle diagram from these constants has been described by Mr. R. D. Evans and Mr. H. K. Sels in a paper[4] before the Institute.

GENERAL CIRCUIT CONSTANTS

The same line, transformers and generator used to illustrate the equivalent circuit method will be used for the circle diagram.

The constants of the line alone are:

$$A = D = \cosh \sqrt{Y\,Z} = a_1 + j\,a_2 = 0.8700 + j\,0.0236$$

$$B = Z\frac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}} = Z\,(\beta_1 + j\,\beta_2) = 34.52 + j\,194.6$$

$$C = Y\frac{\sinh \sqrt{Z\,Y}}{\sqrt{Z\,Y}} = Y\,(\beta_1 + j\,\beta_2)$$

$$= (-\,0.0104 + j\,1.248)\,10^{-3}$$

(a_1, a_2, β_1 and β_2 obtained from Fig. 1.)

The circuit constants of the line and the step-up and step-down transformers, neglecting magnetizing current, are calculated from *Item* (g) of the Evans and Sels paper.[5] To include magnetizing current *Item* (j) should be used instead of (g).

$A_0 = A + C\,Z_s = 0.8431 + j\,0.0279$

$B_0 = B + A\,(Z_s + Z_r) + C\,Z_s\,Z_r = 39.6 + j\,232.1$

$C_0 = C = (-\,0.0104 + j\,1.248)\,10^{-3}$

$D_0 = A + C\,Z_s = 0.8424 + j\,0.0280$

Z_s and Z_r are the transformer impedances at the sending and receiving ends respectively.

4. Power Limitation of Transmission Systems, TRANSACTIONS of the A. I. E. E., Vol. 43, 1924, page 33.

It is of interest to note that these constants can be obtained from the equivalent π including the line and transformer or the equivalent π can be obtained from these constants. See Appendix F.

The circuit constants including the generator as well as the line and transformers are

$$A_{00} = A_0 + Z_1 C_0 = 0.6193 + j\,0.0260$$
$$B_{00} = Z_1 D_0 + B_0 = 34.59 + j\,383.1$$

Where A_0, B_0, C_0 and D_0 refer to the circuit constants of the line and transformers and Z_1 is the generator impedance.

Construction of the Circle Diagram

$$(P_R + l\,E_R^2)^2 + (Q_R + m\,E_R^2)^2 = n^2\,E_R^2\,E_s^2 *$$

is the equation of the Receiver Power Circle Diagram in volt-amperes. If the question is expressed in kilovolt amperes and divided by E_R^4 it becomes

$$\left(\frac{P_R}{E_R^2} + l\,10^3\right)^2 + \left(\frac{Q_R}{E_r^2} + m\,10^3\right)^2 = \left(n\,10^3\,\frac{E_s}{E_r}\right)^2$$

This is a circle for receiver power in terms of the receiver voltage and the ratio between the sending and receiving voltages. The center of the circle is at the point $-\,l\,10^3,\ -\,m\,10^3$.

If

$$A_0 = a_1 + j\,a_2$$

and

$$B_0 = R_0 + j\,X_0$$

$$l\,\dagger = \frac{a_1 R_0 + a_2 X_0}{R_0^2 + X_0^2}$$

$$m = \frac{a_1 X_0 - a_2 R_0}{R_0^2 + X_0^2}$$

$$n = \frac{1}{\sqrt{R_0^2 + X_0^2}}$$

Two circle diagrams will be drawn; one for the line and transformers and the other for the line, transformers and generator. Since they are both for power at the receiver end in terms or receiver end voltage, they will be drawn on the same chart. The ratio of the voltage on the low side of the transformer at the generator end to the voltage on the low side at the receiver end for normal operation has been assumed 220/200 = 1.1. One circle with $E_s/E_r = 1.1$ will be drawn in the diagram for the line and transformers. A series of circles with the ratio of the excitation voltage of the generator to the receiver voltage having various values will be drawn for the line, transformers and generator.

The problems already solved by means of the equivalent circuit will now be solved by the circle diagram.

b. The power limit of the line and transformers at the specified voltages is obtained from the dotted circle at the point where the tangent to the circle is vertical. At this point $kw_r/kv_r^2 = 3.95$, and $kw_r = 3.95 \times (200)^2 = 158{,}000$ kw.

c. The power limit of the generator, line and transformers is obtained from the dotted curve at the point where the tangent to the solid circle is vertical. At this point $kw_r/kv_r^2 = 3.53$, and $kw_r = 3.54 \times (200)^2 = 141{,}200$ kw.

The limit of the system with various kinds of load can not be determined directly by means of the circle diagram. A certain load must be assumed and then the system tested for stability with this load. If the system is stable, a larger load should be assumed, but if unstable, a test should be made with a smaller load. If this process is continued until a load is obtained for which the system is stable, but for which there is no margin, this will be the maximum power of the system.

To Test for Stability on the Circle Diagrams

Calculate kw_r/kv_r^2 for the given load at normal voltage and find the corresponding point on the dotted circle. The ratio of generator excitation voltage to receiver voltage is read from the solid circle cutting the dotted circle at this point, and the generator excitation voltage calculated. Assume a receiver voltage slightly less than normal and calculate the active and reactive power of the load corresponding to this voltage, assuming constants excitations. Divide the active and reactive power in kilovolt amperes by the square of the assumed receiver voltage in kilovolts and locate the point on the diagram. Read E_1/E_r at this point and calculate E_1, the generator excitation voltage. If this value of E_1 is equal to or less than the excitation voltage calculated at normal voltage the system is stable. It is sometimes more satisfactory to select a receiver voltage slightly above normal as well as one below normal, then when the corresponding calculated generator excitation voltages are both higher than the excitation voltage corresponding to normal receiver voltage, the assumed load is the power limit.

1. Given: 170,000 kv-a. synchronous motor, 85 per cent synchronous impedance.

It has been shown by the equivalent circuit method that 106,000 kw. is the maximum power that can be delivered to this motor. Testing by means of the circle diagram, Fig. 17, for a load of 106,000 kw., point A, located on the dotted circle for $kw_r/kv_r^2 = 2.65$, gives the generator excitation voltage from the solid circle passing through A as 242 kv. at normal receiver voltage. Point A' corresponds to 98 per cent receiver voltage and A'' to 102 per cent receiver voltage. The corresponding generator excitation voltage in each case is just about 242 kv. which indicates that 106,000 kw. is very near the limit of stability.

2. Given: Resistance load of 30,000 kw., and the synchronous motor of example 1.

The power delivered to a resistance load varies as the square of the voltage. The power delivered to a shaft load is practically independent of voltage. Points

*Equation (28) A. I. E. E. Transactions, Vol. 43, page 36.

†Circle Diagrams for Transmission Systems, R. D. Evans and H. K. Sels, *Electric Journal*, December 1921.

B, B' and B'' on the circle diagram give the generator excitation voltages corresponding to receiver voltages of 100 per cent, 98 per cent and 102 per cent respectively for a load of 120,000 kw., and points C, C' and C'' the corresponding values for a load of 130,000 kw. The system is stable at 120,000 kw. but unstable at 130,000 kw.

3. Given: Total load of 180,000 kw. of which one-third is resistance load, one-third induction motor load and one-third synchronous motor load. The induction motors have an average power factor of 0.7 lag at normal voltage. The synchronous motors have 100 per cent synchronous impedance, are 75 per cent loaded and are operated at unity power factor. A 100,000 kv-a. synchronous condenser is placed at the load. The generators at the receiver end of the line, having total capacity of 100,000 kv-a. and synchronous impedance of 100 per cent, supply 45,000 kw. to the load and part of the reactive kv-a. needed for voltage regulation. Is the system stable?

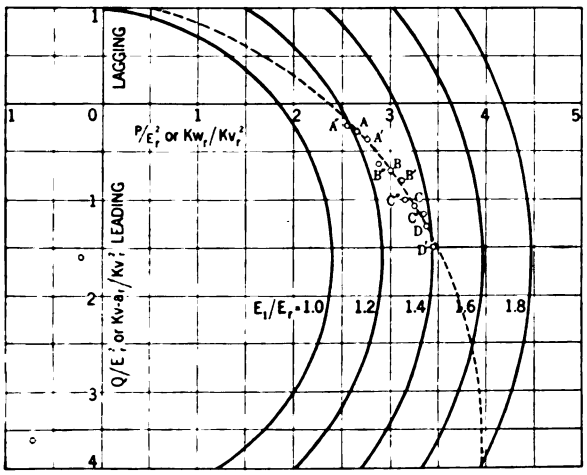


FIG. 17—CIRCLE DIAGRAM FOR THE TRANSMISSION SYSTEM

100 Per Cent Receiver Voltage

E_r = 200 kv. = 100 per cent receiver voltage.

P_r = 135,000 kw. = total power over the line.

$\dfrac{P_r}{E_r^2} = \dfrac{\text{kw}_r}{\text{kv}_r^2} = 3.375$, determines location of point D on dotted circle, Fig. 17.

$\dfrac{Q_r}{E_r^2}$ = 1.28 read at point D, Fig. 17.

Q_r = 51,200 kv-a. = total reactive power over the line.

E_1/E_r = 1.385, obtained from solid circle passing through D.

E_1 = 277 kv. = excitation voltage of generator at sending end.

98% Receiver Voltage.

E_r = 196 kv. = 98 per cent voltage

P_r = 132,600 kw.
Q_r = 57,270 kv-a.
active and reactive power of the original load at 98 per cent receiver voltage and constant excitations.

$\dfrac{P_r + Q_r}{E_r^2} = 3.45 + j\,1.49$, determines location of point D'

E_1/E_r = 1.41, obtained from solid circle passing through D'.

E_1 = 276 kv., excitation voltage of generator at the sending end.

Since E_1, the calculated generator excitation voltage, at 98 per cent receiver voltage is less than E_1 at 100 per cent receiver voltage for the same receiver load, the system is stable. These calculations do not indicate the load which can be added with stability maintained. They merely indicate that the system is stable under the assumed load conditions.

In the examples which have been considered a single generating station supplies power over one circuit to a single receiving station. In more complicated systems where it may be necessary to cut and try, the circle diagram can be used to advantage for the various parts of the system.

ACKNOWLEDGMENT

The idea of combining the shunts at the ends of the line with the synchronous apparatus is due to Mr. C. A. Nickle who proved that "neglecting resistance, a line with synchronous apparatus and reactance or capacitance shunts may be replaced by a line and equivalent synchronous apparatus with no shunts."

The writer wishes gratefully to acknowledge her indebtedness to Messrs. H. H. Dewey and R. E. Doherty for their encouragement and suggestions which have broadened the scope of this study, and to Mr. Nickle for his suggestions in the development of certain phases of the subject.

PURER IRON PRODUCED ELECTRICALLY

Pig iron is now the basic form from which all types of iron and steel are made but it may become obsolete and the direct manufacture of malleable iron and steel from ore may follow the invention of a special electric furnace of commercial size that has been built in the great Hagfors, Stockholm, Sweden, ironworks where iron ore and coal mixed and fused have been made to produce pure iron containing only two per cent of carbon, and steel that can be worked in the usual manner.

The new process is continuous and fusion ceases only temporarily when the furnace is tapped, while the absence of gases and slag produces a superior product.

The United States leads the world in the number of electric steel furnaces in use, and with the discovery of a process of making iron and steel directly from ore would give a tremendous impetus to the use of the electrical smelting furnace.

Studies of Transmission Stability

BY R. D. EVANS* and C. F. WAGNER*
Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*Stability may be defined as the capacity of a power system to remain in equilibrium under steady load conditions, and its ability to regain a state of equilibrium after a disturbance has taken place. The lack of stability first manifested itself in the cases of overloaded machines and high impedance tie lines. The transmission of large blocks of power over long distances has presented the problem in a new form. Attention was directed to this problem in a group of papers before the Institute at the Midwinter Convention of 1924.*

These papers gave a general discussion of the stability problem and pointed out the necessity of considering the limitations imposed not only by the line alone but by the transformers, rotating machines and load. Extensive and pertinent discussions followed which emphasized the importance of the limitations imposed on power transmission by stability conditions.

The papers and discussions at the 1924 Midwinter Convention established a method for the determination of power limits under steady load conditions assuming fixed excitation. The limit so determined is due to the inherent characteristics of machines and does not take into account the possibility of changes in excitation due to the action of voltage regulators. The possibility of exceeding the "inherent stability limits" by the operation of the voltage regulators and exciters was pointed out. This condition of "artificial stability" was not at that time believed to be attainable. It was recognized that under the actual operating conditions on a transmission system instability would occur because of short circuits or other disturbances at a point considerably below the maximum static limit.

Subsequently extensive studies of stability conditions were made to determine the feasibility and economics of a number of large transmission projects. These studies emphasized the necessity of determining the maximum permissible load under the most severe operating conditions which obviously arise at the time of system disturbances, such as switching operations or flashovers with the attendant switching.

Transmission stability has been the subject of a number of articles in the technical press and of papers before the Institute, the principal ones of which are listed in the bibliography. C. L. Fortescue's paper before the Seattle Convention in September 1925 serves as an introduction to the present paper, presenting in a qualitative manner results of recent investigations whereas this paper presents methods for the quantitative determination of system oscillations.

During the early part of 1926 extensive stability tests including switching operations and single phase faults to ground were conducted on the system of the Pacific Gas and Electric Company. These tests will be described in a companion paper by Roy Wilkins.†

The present paper first deals with the principal elements entering into the stability problem, such as the action of generators and exciters during disturbances, effect of dissymmetry produced by single-phase short circuits, simplification of the load end network and methods for combining these various factors in the determination of the electromechanical oscillations of the system following major disturbances. Results of calculations by these methods are compared with the results of tests on the system of the Pacific Gas and Electric Company. The paper concludes with a discussion of various methods of improving stability.

Introduction

FUTURE power developments in this country and in Canada will involve the transmission of larger blocks of power over greater distances than hitherto have been realized in actual practise. Attention is being directed to the possibilities of hydroelectric developments located remote from load centers. In order to compete on an economical basis with high efficiency steam plants located near load centers, it is necessary to transmit large amounts of power per circuit. However, electrical considerations show that the power limits per line closely approach the limits determined by economical considerations. For these reasons the stability of transmission systems is particularly important.

The present investigation of the stability problem has for its object the determination of power limits for a transmission system under the various conditions that arise in actual operation. The results which may be expected of such an investigation include (1) the determination of the proper basis of design of machines and control apparatus for future power developments involving long transmission lines, (2) the development of methods of analysis and testing equipment to determine the performance of existing systems, (3) the improvement of operating methods with a view of reducing the effects of disturbances. This should follow naturally as a result of the better understanding of what takes place during and following a disturbance.

Stability may be defined as the capacity of a power system to remain in equilibrium under steady load conditions and its ability to regain a state of equilibrium after a disturbance has taken place. The first part of this definition is referred to as "static stability" and the second part as "transient stability." It should be noted that after a disturbance the system will not necessarily seek the original state of equilibrium.

The maintenance of stability on a transmission system is obviously of the utmost importance since a line deficient in stability is inoperative. Normal loads on a system must, of course, lie well below the static limit. The importance of transient limits depends largely upon the importance attached to the interruption in power supply over the transmission line. If switching out of a section of line for inspection or repair at times of heavy load would always lead to loss of synchronism, the operating conditions would be intolerable. If the increases in load, which normally take place on a sys-

*Both of the Westinghouse Electric & Mfg. Company.

†"Practical Aspects of System Stability" JOURNAL of A. I. E. E. Feb. 1926.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, Feb. 8-11, 1926. Complete copies available upon request.

tem, would result in loss of synchronism, the operating conditions would also be intolerable. If any kind of a fault on a transmission system would always lead to loss of synchronism, the operating conditions would be unsatisfactory. It is recognized that stability cannot be maintained under all abnormal conditions, but the layout should be such as to prevent loss of stability under the more frequently occurring conditions, such as the addition of a reasonable block of load, normal switching operations, and the majority of single-phase, line-to-ground faults. The decision as to the standard of service is important, and, in our opinion, nothing less than that suggested above will be tolerable for the super power transmission systems which have been contemplated.

Reference should be made to the paper by C. L. Fortescue, presented at the Seattle Convention in 1925, which gives a general discussion of static stability and presents a picture of the phenomena taking place during transients. Mr. Fortescue's paper serves as an introduction to the present paper, the former presenting in a qualitative manner results of recent investigations whereas the latter presents methods for the quantitative determination of system oscillations.

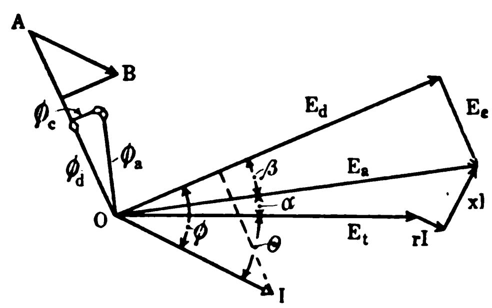


FIG. 1—GENERATOR VECTOR DIAGRAM

METHOD OF CALCULATION OF SYSTEM DISTURBANCES

System disturbances set up oscillations which are essentially the same phenomena regardless of the method of initiation. Consequently, the same general methods of calculation may be applied to of all them. The performance of a system during and following a disturbance will involve the following problems; generator and exciter characteristics, simplification of the load-end network, inertia effect of rotating machines, governor characteristics, dissymmetry due to single-phase short circuits, and methods of combination of electrical and mechanical oscillations into one final result.

GENERATOR CHARACTERISTICS

The effect of generator characteristics during transients can be analyzed conveniently by the Blondel two-reaction method in which the flux is resolved into two components, a direct component in phase with the field poles and linking the field windings and a cross component in quadrature with the field poles. Referring to Fig. 1, I is the armature current, E_t terminal voltage and E_a internal voltage. The latter voltage is resolved into two components, E_d and E_c, which are produced by rotation of the direct component and cross component of flux respectively. During transients, these components, which have associated with them different windings, have different decrements. In salient pole machines test results indicate that the cross component of flux can be assumed to vary instantly to its new value and the variation in direct component of flux can be calculated at any instant by the following formula

$$\frac{d\,E_d}{d\,t} = \frac{10^8}{n\,N\,C_1}\,(e_x - i\,r).$$

where

e_x = exciter voltage at any instant.
$i\,r$ = voltage drop in the field at any instant.
n = turns per pole of field winding.
N = number of poles.
C_1 = flux per pole per generator terminal volt.

The construction of large turbo generators is such as to produce a damping action which prevents rapid change in cross component of flux. In this case, it is sufficiently accurate to assume that the total internal voltage E_a is fixed in phase position relative to the field structure during transients, and that the total component varies in proportion to the direct component.

EXCITATION SYSTEMS

Excitation systems serve to supply the m. m. f. required in synchronous machines to produce the direct component of voltage of such value as to maintain any desired terminal voltage. With hand-operated systems, the excitation remains constant during the transient unless changed by the operator, but with automatic regulators changes in excitation normally take place. Automatic voltage regulators are of two principal types, the vibrating or Tirrill type and the rheostatic type.

The vibrating regulator functions by cutting a block of resistance "in" or "out" of the exciter field circuit at such a rate as to maintain the proper mean value of exciter voltage to supply the required field current for the main machine. The rate of change of exciter voltage for the transient conditions as the contacts open and close can be calculated by the following formula:

$$\frac{d\,e}{d\,t} = \frac{k}{N\;n}\,(e - i\,r)$$

where

N = number of poles.
n = number of turns per pole.
ϕ = flux per pole.
e = $k\,\phi$.
k = voltage produced by rotation of unit flux.

The quantity in parenthesis represents the difference between the terminal voltage and the $i\,r$ drop in the field winding of the exciter, and represents the voltage which must be supplied by the inductive drop in the field winding. This equation expresses the relation

between the rate of change in terminal voltage of the exciter with time as a function of e and i, and enables one by a step-by-step method to determine the exciter voltage as a function of time.

With the rheostatic type of regulator, the exciter voltage remains constant, but the resistance in the main field of the alternator is automatically varied by means of a motor-operated face plate rheostat controlled by the regulator. It may be noted that with this type of regulator the operation occurs in the field circuit of the main machine, whereas with the vibrating type, the operation occurs in the field circuit of the exciter. With the vibrating regulator there is a time lag in the building up of the voltage across the machine terminals due to the time constants of the exciter field, whereas with the rheostatic regulator, a certain amount of time is required for the movement of the motor-operated rheostat.

The Load End Network

A transmission line will usually deliver power to a load end system of considerable extent and having other sources of power. Frequently this "load end network" will have connected to it much greater capacity than the output of the transmission line. The load end network constitutes a problem in stability studies, because rigid analytical methods are frequently impractical on account of the complexity of the network, and because it is difficult to find a network that is equivalent to the actual network, at the same time being sufficiently simple to be handled analytically.

The load end network includes synchronous generators and condensers in addition to the load the principal components of which are synchronous motor, synchronous converter, induction motor and lighting load. E. J. Amberg has given the following segregation of load on a particular system, which segregation appears to be quite typical:

TABLE III

Typical Segregation of Peak Load

Type	Percentage
Induction motor..............	60
Synchronous motor............	10
Synchronous converter.........	10
Lighting.....................	—20

The various types of load have different characteristics. With synchronous and induction motors, the true power demand may be assumed to remain constant with variation in voltage, whereas the lighting and synchronous converter load will vary as the square of the voltage. The reactive power varies greatly with the type of load and in the curves of Fig. 7 are shown the variations of reactive power with variation in terminal voltage.

It is impractical to consider a multitude of individual loads, and it becomes necessary, therefore, to use some such composite load characteristic as shown in Fig. 8. An approximation of the load characteristics that is very convenient is the assumption of a constant impedance shunt load. The variations in load voltage usually are not great because it is maintained by the local generators and synchronous condensers. It is this fact which permits the relatively crude approximation of constant impedance load to give satisfactory results for the majority of cases.

The load characteristic is also affected by changes in system frequency. Quite definite information on this point is available from actual operating experience. J. P. Jollyman* has stated that a reduction in frequency from 60 to 59 cycles will reduce the real power demand by 3.5 per cent.

The method to be employed for analyzing load end networks from the standpoint of stability is dependent chiefly upon the number of synchronous machines. In case the load end network involves one synchronous machine and induction motor and lighting load the network may be replaced by a single synchronous machine with a shunt admittance branch to represent the non-synchronous load. In case there are two or more synchronous machines which would carry proportional loads at times of disturbances, they may be handled in a similar manner. In many cases, the assumption that the voltages of all load end synchronous machines are in phase represents a crude approximation. A quite accurate assumption for such a case is to assume that a constant angular relation between the various synchronous machines is maintained. By this method the synchronous machines are compelled to operate as a unit instead of permitting them to make small movements with respect to each other. On very large receiving systems, disturbances on the transmission system are likely to have relatively little effect on individual machines and it becomes permissible to represent an extensive transmission network with many sources of voltage by a single equivalent network with a single machine and a single shunt admittance to represent non-synchronous load. For very large receiving networks the inertia may be considered infi-

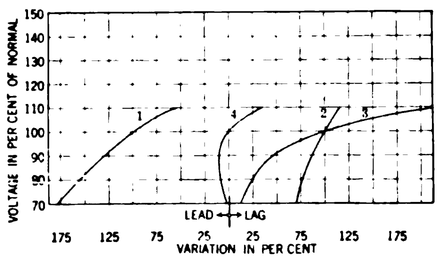


Fig. 7—Variation of Reactive Kv-a. with Voltage

1. Synchronous motor—75 per cent load, 85 per cent p. f. lead (at normal voltage)
2. Induction motor, 75 per cent load, 79 per cent p. f. lag (average at normal voltage)
3. Transformer exciting kv-a.
4. Synchronous converter (reactive kv-a. in per cent of machine rating)

*Stored Mechanical Energy in Transmission Systems, A. I. E. E. Journal, Sept. 1925.

nite or if desired corrections may be introduced in the inertia of the supply end generator.

Mechanical System Data. The stored mechanical energy in the synchronous rotating machinery is important in determining the period of system oscillations and the rate of change of angular positions of rotors, and hence internal voltage in response to changes in input or output. Because of their inertia, the rotors cannot change phase position immediately. During the first instant of a disturbance the redistribution of power can be calculated with the internal voltages in the same position as at the instant immediately preceding a disturbance. Before the beginning of the transient the input and output are equal, the rotor being in equilibrium, but with the redistribution of power the equilibrium is disturbed and the rotors accelerate or decelerate, the rate being determined by the following equation:

$$a = \frac{180\,f}{E}\,\Delta P \qquad (6)$$

where

α = acceleration in electrical degrees per sec. per sec.

f = system frequency.

E = stored mechanical energy at synchronous speed in kilowatt seconds.

ΔP = difference between input and output in kw.

By assuming sufficiently small time intervals and assuming the acceleration constant during the interval, or by assuming larger intervals and correcting for average acceleration, the rotor movements can be traced by a step-by-step method of calculation throughout the period of disturbance.

The stored energy is dependent upon the total mass, the distribution of this mass, and speed. The following table indicates the stored energy in kilowatt-seconds per kilowatt output for a large number of different units of each type of machine.

TABLE IV

STORED ENERGY OF MACHINES

1. Water Wheel Generators. Average of units ranging from 1500 to 35,000 kw. = 2.40 kw.-sec. per kw. From an examination of a small amount of data the flywheel effects of the waterwheels appear to be in the neighborhood of 10 per cent to 20 per cent of the generator flywheel effects.

2. Steam Turbine Generator Units. Average of units ranging from 1500 to 35,000 kw. Generators = 5.32, turbines = 5.65. Total = 10.97 kw.-sec. per kw.

3. Rotary Converters (Railway & Edison). Average of units ranging from 750 to 3250 kw. = 2.10 kw.-sec. per kw.

4. Synchronous Condensers. Average of units ranging from 1000 to 40,000 kv-a. = 1.48 kw.-sec. per kv-a.

The synchronous machinery, and to a lesser extent, the eddies in synchronous machinery, tend to cushion any sudden changes in phase position and voltage. This induction generator effect differs from the synchronous effect in that it is responsive to speed changes rather than angular space changes. However, the effect is small and may be neglected.

Governor Characteristics

The time constants of governors are also important in their effect upon system stability during certain types of disturbances. The acceleration or deceleration of the rotor determining the phase position of the internal voltage depends upon the difference between generator input and output, the input being regulated by the governor. In present day practise, the governor is a device which functions on speed. This point is important as large angular displacements might take place before the governing device begins to function.

In general, however, since governors react only after the speed change and since these changes are extremely small during switching operations, the variations in gate opening can be neglected for these conditions. The action of the governor during single-phase short circuits will depend upon the change in output and the resulting speed change occasioned thereby. For relatively small changes of the order of 25 per cent of rated load, consideration of the "dead time" and the relatively slow traversing rate of about six seconds would justify neglecting any change in gate position due to governor action. In general, one must look into the individual case and determine whether or not the effect of governors can be neglected. If their effect must be taken into account, it will be found convenient in the analysis to plot the variation in speed of machines and in gate opening as functions of time. These curves enable one to determine the interaction between rotor velocity and gate opening throughout the transient condition.

Single-Phase Short Circuits

The calculation of single-phase, short-circuit currents on a transmission network is complicated, because the currents and voltages in the different phases are unsymmetrical. Each phase is inductively coupled with the other phases in transmission lines, transformers and rotating machines. In addition, rotating machines, including synchronous generators, motors and condensers, and also induction motors, provide a distinct phase-balancing action, tending to restore symmetry in voltage and current. Because of the fact that no suitable method had previously been published, the authors found it necessary to develop a method for the solution of the single-phase, short-circuit problem. This method is essentially a combination of two well-known methods of network solutions; namely, phase sequence components, and general circuit constants. In the phase sequence method developed by C. L. Fortescue,* the voltages and currents of a three-phase grounded system are resolved into three components, namely, the positive sequence, the negative sequence, and the zero sequence. This results in an important simplification for the case we are considering of balanced polyphase systems, as the different sequences do not react one upon another. For normal balanced loads, only positive sequence voltages and currents are

*Trans. A. I. E. E., Vol. XXXVII, p. 1027.

present. In case of a line-to-line fault, only the positive and negative sequence components are present; while in the case of a fault to ground, all three components are present. Synchronous machines generate only positive sequence e. m. fs. and the negative and zero sequence voltages appearing at machine terminals are due to the voltage drops produced by negative and zero sequence currents, respectively. Since polyphase synchronous machines generate only positive sequence voltages, it follows that machine decrements involve only positive sequence voltages and currents, and the constants of the machines and the network to which they are connected. In other words, it is possible to compute the decrements for single-phase short circuit by the methods applicable to three-phase short-circuits if the positive sequence voltages and currents of the various machines are considered.

The most convenient methods for handling transmission networks employ the general circuit constants developed by Evans and Sels. In this connection, it may be pointed out that the recent revision of the book "Electrical Characteristics of Transmission Lines" by William Nesbit gives a very complete series of tables of the general circuit constants for transmission lines covering the commercial ranges of conductors and spacings for lines from 50 to 300 miles in length. The method of general circuit constants was originally developed for the solution of balanced three-phase systems where only positive sequence components of currents and voltages are present. The method, however, can readily be extended for negative and zero sequence components.

It can be shown that the effect upon the positive sequence voltage and current of a wire-to-wire or wire-to-ground fault can be accurately represented by replacing the fault by a symmetrical impedance to ground. For a line-to-ground fault this impedance per phase will be equivalent to the sum of the negative and zero sequence impedances as measured at the point of fault, and for the wire-to-wire fault the equivalent impedance is equal to the negative sequence impedance as measured at the point of fault.

Combination of Factors

The various individual factors entering into the problem of stability have been discussed in the previous section. These factors are combined in a step-by-step method to obtain the magnitude of system oscillations. Reference should be made to the complete paper for a more detailed description of the method. The results of the calculations are plotted in the form of angle time, voltage time, and power time diagrams from which a very good estimate of the stability of operation can be obtained.

Application of Methods to Various Types of System Disturbances

The methods of calculating system oscillations described in the preceding Section will now be discussed with respect to their application to the various types of system disturbances. The principal conditions which may give rise to important disturbances on a power system are as follows:

1. Sudden increases in load.
2. Switching operations.
3. Faults.

For a general discussion of the phenomena accompanying these various types of disturbances, reference should be made to the paper by Mr. Fortescue.

Sudden Increases in Load

The supply of power from long-distance transmission lines is usually supplemented by local steam or hydroelectric power plants. In ordinary operation, sudden increases in load do not occur except in the case of the loss of a load end generator as the result of a breaker operation. For this condition, however, the load is taken up largely by the retardation of the parallel units which initially tend to contribute power in inverse proportion to their connecting impedances. The increased demand for power will require a new position of equilibrium and before reaching it, the system on account of mechanical inertia will tend to overshoot and go out of step if the transient limit is too low. If the system withstands the first overswing, both ends of the system will usually stay in step and slow down simultaneously. The increased load will cause a reduction in system frequency and in machine voltages which will bring the governors and voltage regulators into action, tending to restore the system to normal.

Switching Operations

The switching operation most likely to be important from the standpoint of stability of a transmission system is the opening of a section of line under load. The switching out of a section of line will cause the system to seek a new position of equilibrium, and the system in moving to this new point will overswing to such an extent as to produce instability if the transient limits are too low. If the system does not pull out of step on the first overswing, it is unlikely to do so later because sufficient time will usually be available for regulators to increase the excitation of the machines.

Faults

From the standpoint of maintaining stability, faults produce most severe conditions occurring in ordinary operating experience.

Three different types of faults may occur; namely three-phase, single-phase line-to-line, and the single-phase line-to-ground. High-voltage transmission systems are normally designed with neutral grounded and with relatively large clearances between conductors. There is a distinct tendency to employ single circuit tower lines and horizontal spacing of conductors on account of ice conditions. Greater attention is being given to substation layout in order to minimize the possibility of three-phase and single-phase line-to-line

faults. These considerations indicate that the occurrence of any type of fault other than the single-phase line-to-ground is relatively remote. Data on some of the high-voltage transmission circuits indicate that over 90 per cent of the faults that have occurred were from line to ground. In view of these facts, it appears that the layout should be such as to provide a reasonable margin of stability in the case of single-phase line-to-ground faults, but that it is not essential in the case of three-phase and single-phase line-to-line faults.

A fault on a transmission line will normally give rise to three circuit conditions; namely, the original condition before the fault, the condition during the fault, and the condition after the fault is cleared; and in addition another intermediate step if more than one breaker is required to clear the fault. The time interval between these changes in circuit conditions is insufficient for the system to readjust itself, consequently the changes may occur at such times as to augment the magnitude of the system oscillation. The description of the way in which the opening of a breaker to clear a line-to-neutral fault may give rise to very large system oscillations, is given in the paper by Mr. Fortescue previously referred to.

Studies of faults should not be limited to the high-voltage lines alone, but should include the distribution system and also the low-voltage bus at generating stations or at substations.

Static and Artificial Stability

In previous papers on transmission stability the subject of static stability has received most consideration. The published methods for determining the static stability limits have employed the assumption of constant field current in synchronous machines. It is to be noted that the limits so calculated are dependent only upon inherent characteristics of the machines and the other parts of the system. E. B. Shand pointed out the theoretical possibility of maintaining a condition of "artificial" stability in which the inherent static limits could be exceeded by operation of regulators and exciters. It was then generally believed and at that time not contradicted that the speed of commercial regulators and exciters was insufficient to permit the attainment of artificial stability on actual power systems. Adequate methods of transient analysis were not then available, and only by means of transient analysis or tests as on a miniature system, is it possible to prove that artificial stability may be obtained on commercial systems. Artificial stability may be defined as the condition of stable operation of power systems which is attainable only through the operation of the automatic voltage regulators and exciters. The time available for the functioning of this apparatus is dependent upon the rate of change of rotor position and the time constants of machines. The natural period of mechanical oscillation of a power system under light load conditions is of the order of a second or less, but in the vicinity of the static limit the natural period becomes longer. At the static limit the time constants of machines become the controlling factors in determining rotor movements. On this account sufficient time may be available for important changes in excitation as a result of the operation of voltage regulators.

Artificial stability can best be considered as a series of periodic transients and for this reason will be investigated by the methods of transient analysis. Calculations were made to show the possibility of obtaining a condition of artificial stability on systems equipped with commercial apparatus by considering the simple case of a generator and motor connected through a reactance tie. A load in excess of the static limit at normal terminal voltage and with constant excitation was assumed. The angle between rotors was arbitrarily increased by a small amount and calculations were made of the resulting oscillation taking into account the transients in machine fluxes and the effects of

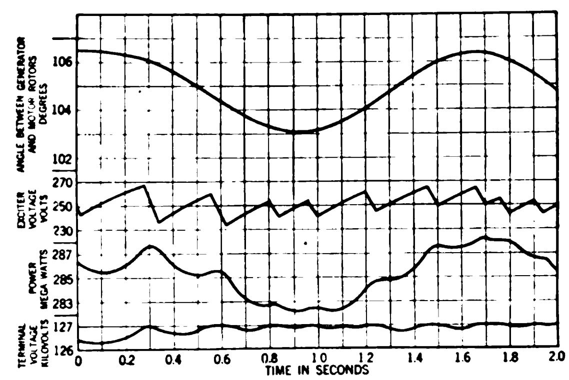


Fig. 13—The Effect of the Excitation System in Maintaining Artificial Stability

exciters and regulators and also the mechanical movements of rotors. The results of the calculations are given in Fig. 13 which indicates the possibility of securing artificial stability by the use of commercial regulators and exciters. The significant thing to note is the fact that the mechanical oscillation was so slow that the voltage regulator had time to open and close several times during an oscillation.

Analysis of Stability Tests

Cooperative stability tests were made during the early part of 1925 on the transmission system of the Pacific Gas & Electric Company as described in a companion paper by Mr. Roy Wilkins. Such tests furnish accurate information as to the operation of a system at times of disturbances and are valuable for planning future expansion. In addition, these tests which were the first of their kind, afford an opportunity to check methods of calculations and to analyze test results on an actual transmission system.

These tests are described in detail in the companion paper by Mr. Wilkins. The present discussion will be restricted to the comparison of test results and calcula-

tions. Two representative tests, one a switching operation and the other a single-phase fault, were selected for analysis.

Switching Operation

The layout of the part of the Pacific Gas & Electric Co. system involved in these tests is indicated in Fig. 14. One transmission line was operated at "110 kv." and the other at 220 kv. In test No. 12, the one selected for analysis, a switching operation was performed by opening the high voltage breaker in the 220-kv. line at the Pit River No. 1 powerhouse, transferring all of the load to the 110-kv. line. A relatively severe switching disturbance is produced in this manner as the load on the 110 kv. line is increased to over 300 per cent of the initial value.

The application of the methods of calculation previously described to the particular problem will now be discussed. The load end network consists of the 110-kv. and lower voltage distribution system, connected loads and local generators and the synchronous condensers at the Vaca-Dixon substation. This type of network may be considered as involving two sources of e. m. f. having a fixed angular relation, and a shunt impedance load and may be analyzed by the use of one of the equivalent "load end networks." The supply end network involves three power plants in parallel, Pit River No. 1, Hat Creek No. 1 and No. 2. Since Hat Creek No. 1 and No. 2 are very close together and their electrical and mechanical characteristics are similar they can be considered as one unit but due to the difference in impedance and inertia effects the Hat Creek plants cannot be combined in this manner with the Pit River No. 1 plant. This necessitates a set-up consisting of two salient pole machines at the supply end and a single equivalent machine at the load end with a shunt impedance branch representing non-synchronous load. The solution is then obtained by the step-by-step method, assuming constant gate opening for the supply end, constant direct component of voltage at the supply end generator, and constant internal voltage at the load end machines.

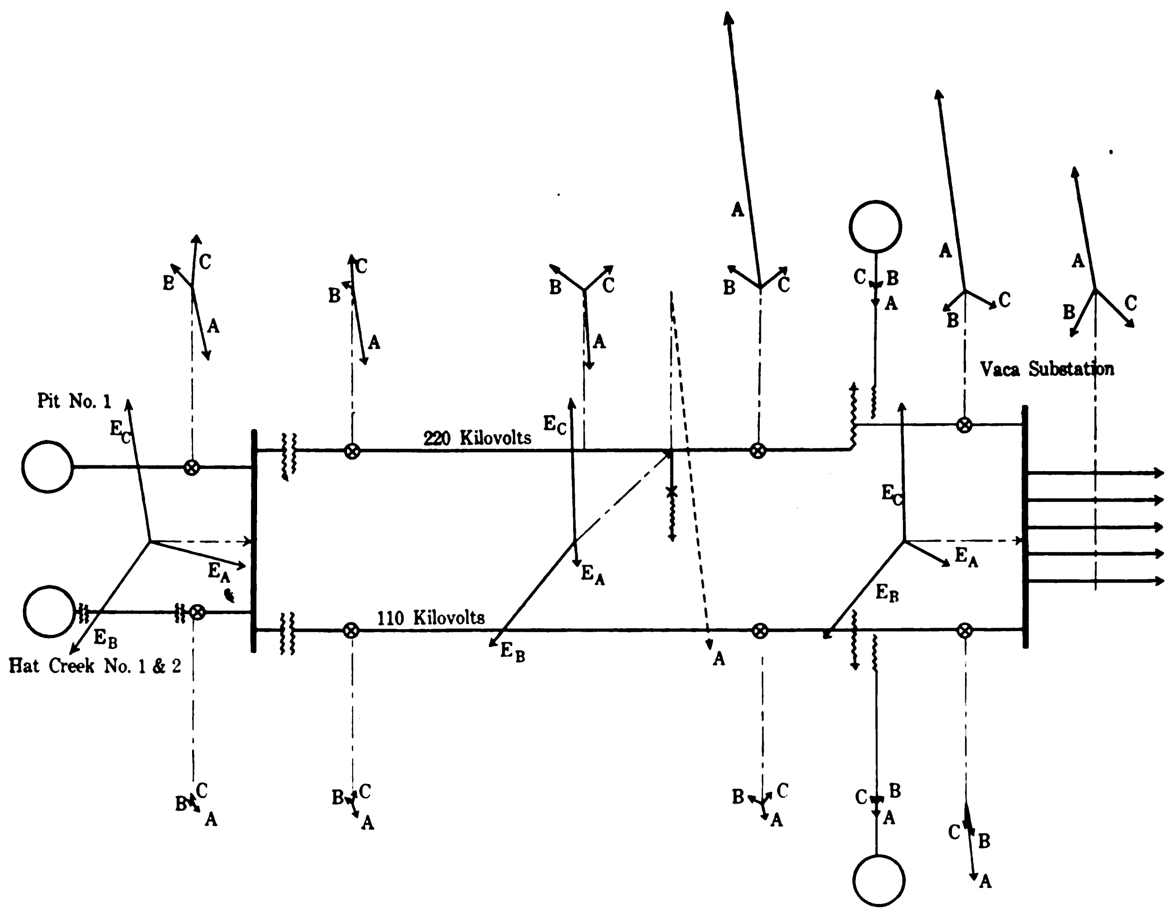


Fig. 14—Voltage and Current Distribution on Transmission System of Pacific Gas & Electric Company

With a single-phase fault to ground on 220-kv. line near Vaca substation—calculated. Voltage 30,000 volts per in.; current, 500 amperes per in., 110-kv. base

Results of the calculations of the switching operation are shown by a number of curves of power, voltage and angle plotted as functions of time from the beginning of the disturbance. In the curves of Fig. 15 are shown the calculated and observed values of power measured at Pit River No. 1. Similar curves for the generator voltage at Pit River No. 1 and the 110-kv. bus voltage at Vaca are given in Fig. 16. Fig. 17 shows the in-

stantaneous observed and calculated angles between the rotor of the Pit generator and the voltage of the 110-kv. bus at Vaca.

It will be noted that the curves show good agreement between calculated and observed values as to general magnitude and trend. It should be explained at this time that the breaker did not open the circuit completely at the beginning of the switching disturbance. This accounts for the time displacement of about 0.2 seconds in the observed results and also for the fact that the observed oscillation is of somewhat smaller magnitude.

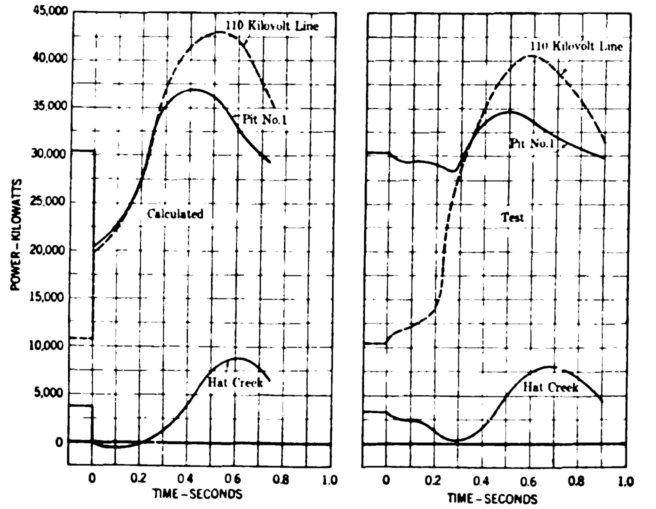


FIG. 15—COMPARISON OF TESTS AND CALCULATIONS OF POWER-OPENING ONE LINE

SINGLE-PHASE FAULT TO GROUND

The system layout for the single-phase fault to ground was the same as for the switching test previously described. The fault was applied to the 220-kv. line two towers from the Vaca-Dixon substation.

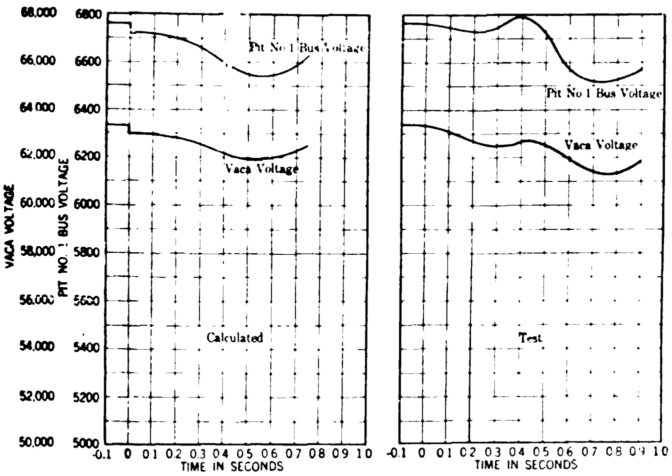


FIG. 16—COMPARISON OF TESTS AND CALCULATIONS FOR VARIATIONS IN VOLTAGE OF PIT NO. 1 BUS AND VACA 110-KV. BUS-OPENING ONE LINE

An analysis was made to determine the initial distribution of currents and voltages over the entire system by the methods outlined in Appendix II. The simplified network identical to that used for the calculations of switching operation was used with the "equivalent symmetrical network" connected at the point of short circuit. The conditions of tests were unusual in that the closely coupled transmission lines were operating at different voltages.

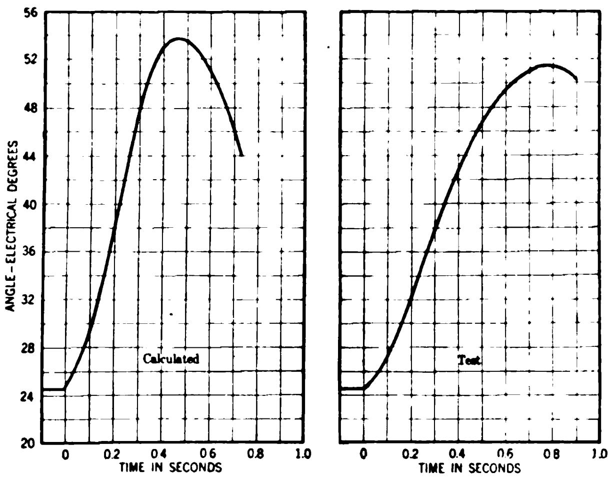


FIG. 17—COMPARISON OF TESTS AND CALCULATIONS OF ANGLE BETWEEN VACA BUS VOLTAGE AND ROTOR OF PIT NO. 1 GENERATOR,—OPENING ONE LINE

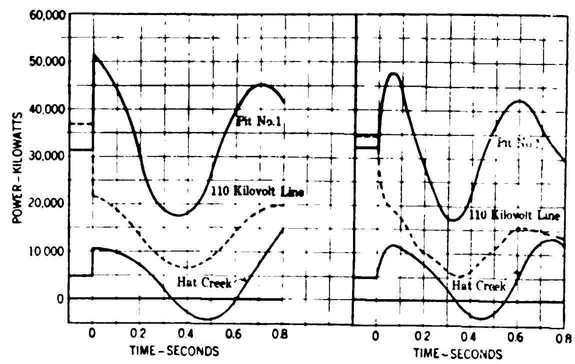


FIG. 18—COMPARISON OF TESTS AND CALCULATIONS OF POWER—CLOSING ONE LINE

Tests were also made and the transients recorded when the same breaker was closed. The results of tests and calculations of power variations for this condition are shown in Fig. 18. In this case the effect of the non-simultaneous action of the different poles does not enter, and a very close check is obtained.

TABLE V

COMPARISON OF MEASURED AND CALCULATED INSTANTANEOUS SYMMETRICAL VOLTAGES AND CURRENTS FOR FAULT TO GROUND AT VACA-DIXON SUBSTATION

	Measured	Calculated
1. Residual current in circuit breaker at Vaca	1020	1130
2. Voltage, *A* phase at Vaca	60000	59300
3. Residual voltage, 110-kv. bus at Vaca	14200	13300
4. Residual current in 220-kv. line at Pit. No. 1	140	138
5. Current, *B* phase, 220-kv. line at Pit No. 1	235	280
6. Current, *A* phase, Pit No. 1 generator*	2780	4150
7. Voltage, *A* phase, Pit No. 1 generator	4840	4996
8. Current *A* phase, 110-kv. line low side at Pit No. 1	1070	1030

*Discrepancy unexplained.

The results of calculations are shown in Fig. 14 which gives the vector distribution of the currents and voltages at different points in the system. In this figure, all the vectors are given on a common voltage basis of 110 kv., and to obtain the actual values of current and voltages in any particular part of the circuit it is necessary to take into consideration the transformer ratios and phase shifts due to the star-delta transformations. The diagram assumes the normal direction of power flow from the Pit end toward the load. The fault actually occurred on Phase *B* but, for convenience in calculation, it was assumed to occur on Phase *A*. It will be noted that at the time of fault the negative phase sequence current supplied from the condensers at Vaca are greater than the positive sequence components. The pronounced distortion of the current vectors is due largely to the low value of the transmitted load at the time of the tests.

In Table V is given the comparison of calculated voltages and currents with the corresponding quantities observed during the tests. The calculated values are based on the instantaneous symmetrical value of short circuit current and the test results are based on the values during the fourth cycle after the application of the fault. The close agreement considering the factors involved serves as a sufficient check upon the general method.

Methods of Increasing Stability

The most evident method of increasing the stability limit of a transmission system for a given voltage is to decrease the series impedance. This may be accomplished by the use of:

1. Additional circuits.
2. Lower frequency.
3. Percy Thomas split conductor.
4. Lower transformer impedance.

Another important general method for increasing the power stability of a transmission system is to employ measures to maintain or increase terminal voltages. This may be accomplished by the use of the following methods:

1. Machines of special characteristics.
2. Compensated machines.
3. High speed excitation.
4. Intermediate condenser stations.
5. Shunt reactors.
6. Additional tie lines at the receiver end of the system.

The layout of a transmission system may be modified so as to limit the magnitude of short-circuit currents. This can be accomplished by the use of reactors or transformers, and the avoidance of the bussing arrangements ordinarily employed. This method is open to the objection that it is not sufficiently flexible to meet the requirements of changing operating conditions.

Preliminary investigations of governor characteristics also indicate that certain modifications would be quite effective in maintaining system stability.

These general methods for increasing stability together with a certain amount of supporting test data are discussed in more detail in the unabridged paper.

The authors wish to take this opportunity to express their appreciation of the cooperation and assistance of the engineers of the Pacific Gas & Electric Company—especially Messrs. J. P. Jollyman and Roy Wilkins—in affording opportunity of investigating stability conditions on a large, high-voltage power system. In addition, they also wish to acknowledge the assistance of their associates, particularly Mr. S. B. Griscom, who has made important contributions to the methods presented.

Conclusions

Stability is an important limitation in the transmission of large amounts of power per circuit over long distances. Provision for securing stability should be made for both steady state and the more frequently occurring abnormal conditions. The limiting condition, as indicated by these studies, is the single-phase fault to ground, followed by the disconnection of the faulty section of line. Normal switching operations, except in a few special cases, will not give rise to severe system disturbances. Under emergency conditions in which a large proportion of the lines are out of service, the system may approach the limit of static stability.

The static limit of systems operating without voltage regulators is determined by the inherent characteristics of the machines and lines. With voltage regulators, a condition of artificial stability may be obtained on commercial systems and the machines tend to operate on a constant voltage rather than a constant excitation characteristic.

Methods have been presented for the analysis of stability for the various conditions that arise in system operation. The principal new features are the treatment of machine characteristics, the simplification of load end networks, and the handling of single-phase faults.

Increase in the power or stability limits may be obtained by the use of a number of methods discussed in the paper. Of particular importance are high-speed excitation and machines of special design capable of delivering a relatively large increase in lagging kv-a. with drop in voltage. Mention should also be made of special governor control.

The underlying requirement for securing stability of a system delivering a large amount of power, is one of obtaining good regulation of line and terminal equipment. Improved stability conditions may be obtained by methods providing good regulation, either inherently as by compensated machines, or automatically by high-speed excitation systems.

The use of intermediate condenser stations permits the transmission of the largest amount of power per circuit. The effectiveness of this scheme may be con-

siderably increased by the use of specially designed condensers or compensated condensers, or by high-speed excitation.

Stability is important not only for high-voltage long-distance transmission, but also for low-voltages and interconnections where relatively large amounts of power are handled per circuit.

The method of operating a power system, including setting of relays and circuit breakers, sequence of switching operations, governor adjustments, etc., has an important bearing on stability. An analysis of these factors as they affect stability should lead to the selection of the operating method which would minimize system disturbances.

Heaviside's Proof of His Expansion Theorem

BY M. S. VALLARTA[1]

Associate, A. I. E. E.

Synopsis.—*Heaviside's proof of his celebrated Expansion Theorem, found scattered in his "Electrical Papers," is reconstructed. It is based upon his so-called "conjugate theorem," also discovered independently by Routh, which establishes a relation between any two normal modes of oscillation of a dynamical system. Heaviside's argument applies to systems having finite number of degrees of freedom and no repeated or null roots of the determinantal equation of the system. The relation between Heaviside's, Carson's and Wagner's proofs is also pointed out.*

* * * * *

LET an arbitrary electric network be given and suppose a unit constant voltage is impressed at a certain instant. Then the determination of the d-c. transient and of the steady state which follows consists in finding an integral of a linear differential equation of the nth order, with constant coefficients and satisfying n initial conditions. By ordinary methods the determination of the arbitrary integration constants using the initial conditions is, as a rule, extremely laborious, except perhaps in the simplest type of circuits; therefore, a formula giving directly the transient current, without requiring the determination of integration constants, would mean a considerable advance in circuit theory. If further it is realized that when the d-c. transient and the corresponding steady state are both known, the behavior of the network under all common types of impressed voltages is also known[2], the importance of such a formula becomes at once evident.

In his celebrated Expansion Theorem, Oliver Heaviside gave just such a formula. In accordance with his somewhat eccentric habits of thought, he merely wrote down his final result on page 127 of the second volume of his "Electromagnetic Theory," without giving a proof, even without the slightest hint to his previous investigations leading to this result. This seems to have eventually given rise to the impression that Heaviside did not prove his Expansion Theorem, but rather found it in some obscure fashion, peculiar to him, by considerations which might not be of the nature of a logical proof. Thus J. R. Carson in his latest paper on circuit theory[3] writes that "the Expansion Theorem was stated by Heaviside without proof; how he arrived at it will probably always remain a matter of conjecture," while K. W. Wagner[4] writes, "Heaviside gibt die Formel ohne Beweis, ja selbst, ohne einen solchen anzudeuten" (Heaviside gives the formula without proof; what is more, without giving an indication of one) and exactly the same view is expressed in a recent paper by L. Casper[5]. Now, although no proof of the Expansion Theorem, and even no indication of such, is given in the "Electromagnetic Theory," numerous scattered investigations which might lead up to this remarkable formula are found in Heaviside's "Electrical Papers" and also in many of his published writings; therefore, the possibility that he might have given a proof of his Expansion Theorem was recognized by some writers, among them V. Bush[6], L. F. Woodruff[7] and the present author[8]. It was not until quite recently, however, that a reconstruction of Heaviside's own proof of his Expansion Theorem was possible.

The first to examine Heaviside's investigations leading to the Expansion Theorem and recognize their interest, extreme generality and correctness, was T. J. Bromwich[9], who, in an exhaustive paper published in 1916, but read in 1914, not only gave an independent

1. Massachusetts Institute of Technology, Cambridge, Mass.

2. J. R. Carson, *Theory of the Transient Oscillation of Electrical Networks, etc.* TRANSACTIONS A. I. E. E., p. 346, 1919.

3. "Electric Circuit Theory and Operational Calculus." *Bell System Technical Journal*, Vol. IV, p. 685, Oct. 1925; See p. 713.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

4. "Über eine Formel von Heaviside zur Berechnung von Einschaltvorgänge," *Archiv für Elektrotechnik*, Vol. 4, p. 159, 1916.

5. "Zur Formel von Heaviside für Einschaltvorgänge," *Archiv für Elektrotechnik*, Vol. 15, p. 95, 1925.

6. "Heaviside's Operational Calculus," Mimeographed notes for use of students at Massachusetts Institute of Technology, p. 37, July, 1925.

7. "Principles of Electric Power Transmission and Distribution," p. 237, footnote, Wiley, New York, 1925.

8. "Notes on Heaviside's Operational Method," Mimeographed notes for use of students at Massachusetts Institute of Technology, p. 17, March, 1923.

9. "Normal Coordinates in Dynamical Systems," *Proceedings of the London Mathematical Society*, Vol. 15, p. 401, 1916. See pp. 415-420.

derivation of the Expansion Theorem, similar to Wagner's[10], but also showed with extreme clearness the connection between Heaviside's argument and those methods of derivation which, like Bromwich's and Wagner's make use of contour integrals to solve the dynamical equations.

Heaviside's derivation of his Expansion Theorem is based on the so-called "conjugate theorem" which we now proceed to establish. The conjugate theorem was probably first discovered by Routh[11], but Heaviside was undoubtedly unaware of Routh's results, his methods are completely independent and, further, his results are easier to state than those of Routh.

Consider an electric network of n degrees of freedom (n currents required to specify the circuit completely at any one instant). It is well known that such a network is the exact analogue of a dynamical system of n degrees of freedom in which the forces of reaction are proportional to the displacements from equilibrium or zero configuration (*i. e.*, elastic forces of Hooke type) and the forces of resistance are proportional to the velocities. In this electromechanical analogy, inductance is equivalent to coefficient of inertia, the reciprocal of capacity to the elastic coefficient and resistance to the coefficient of dissipation or frictional coefficient; electromotive force corresponds to applied force, current to velocity and charge to displacement. This fact has been already utilized in the analysis of circuit problems by mechanical models and conversely by Doherty and many others.

The equations of motion of a dynamical system of the type specified above are well known to be[12]:

$$\left.\begin{array}{l}
\left(C_{11}\dfrac{d^2}{d\,t^2} + B_{11}\dfrac{d}{d\,t} + A_{11} \right) x_1 + \;.\;.\;.\;. \\
\qquad + \left(C_{1n}\dfrac{d^2}{d\,t^2} + B_{1n}\dfrac{d}{d\,t} + A_{1n} \right) x_n = F_1 \\
\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;. \\
\left(C_{n1}\dfrac{d^2}{d\,t^2} + B_{n1}\dfrac{d}{d\,t} + A_{n1} \right) X_1 + \;.\;.\;. \\
\qquad + \left(C_{nn}\dfrac{d^2}{d\,t^2} + B_{nn}\dfrac{d}{d\,t} + A_{nn} \right) x_n = F_n
\end{array}\right\} \qquad (1)$$

In this system of linear differential equations, $C_{\kappa\kappa}$, $B_{\kappa\kappa}$ and $A_{\kappa\kappa}$ are the coefficients of inertia, dissipation and elasticity of the kth branch, x_κ the displacement of the kth branch and $C_{\kappa j}$, $B_{\kappa j}$, $A_{\kappa j}$ the coefficients of inertia, dissipation and elasticity between the kth and the jth branches. $F_1, F_2 \;.\;.\;.\;.\; F_n$ are the external forces acting on the corresponding branches.

Equations (**1**) form the starting point of Heaviside's argument[13]. On account of the precise analogy between the electric network and the mechanical system, it is immaterial whether use is made of electrical or mechanical entities and it is permissible to change from the network to the mechanical system if only the right equivalents are used. Let Q be the rate at which energy is dissipated in the system, due to the presence of frictional forces in it, U the potential energy of the elastic forces and T the kinetic energy. The power transferred to the system by the applied forces is $\sum_{k=1}^{n} F_\kappa\,\dot{x}_\kappa$ ($\dot{x}_\kappa = d\,x_\kappa/d\,t$), so the conservation of energy gives,

$$\sum_{k=1}^{n} F_\kappa\,\dot{x}_\kappa = Q + \dot{U} + \dot{T} \qquad (2)$$

which says that the power delivered by the applied forces is equal to the energy dissipated, plus the rate of increase of the kinetic energy of the system, plus the rate of increase of the stored elastic energy. Q, U and T are defined in terms of the variables $x_1 \;.\;.\;.\;.\; x_n$ which determine the state of the system at a given instant by the expressions,

$$\left.\begin{array}{lll}
2\,T = \sum_{i,j=1}^{n} C_{ij}\,\dot{x}_i\,\dot{x}_j & & (C_{ij} = C_{ji}) \\
Q \;\;= \sum_{i,j=1}^{n} B_{ij}\,\dot{x}_i\,\dot{x}_j & & (B_{ij} = B_{ji}) \\
2\,U = \sum_{i,j=1}^{n} A_{ij}\,x_i\,x_j & & (A_{ij} = A_{ji})
\end{array}\right\} \qquad (3)$$

The symmetrical conditions imposed on the coefficients $A_{ij} = A_{ji}$, $B_{ij} = B_{ji}$, $C_{ij} = C_{ji}$ mean that there are no forces of gyrostatic origin, also no forces not derivable from a potential-energy function. Such relations are also assumed to be satisfied in the corresponding electric network, thus excluding thermionic devices, etc.

It is well known that the reduced system of differential equations obtained from equations (**1**) *i. e.*, the system obtained by putting all the impressed forces equal to zero, admits an exponential solution of the type $x_\kappa = X_\kappa\,e^{pt}$, X_κ and p being real, imaginary or complex constants to be determined. Such solutions are called the *normal* solutions. The substitution $x_\kappa = X_\kappa\,e^{pt}$ transforms (**1**) from a system of linear differential equations with constant coefficients, with time as independent variable, to a system of algebraic equations with p as unknown. It is further known that the condition that the system in question have a solution is that the determinant of the coefficients shall vanish. This determinant is defined by

10. Wagner's proof of the Heaviside theorem appeared as a part of his paper already quoted (l. c. footnote 4) on March 21, 1916. Bromwich's paper was read on March 12, 1914, received April 22, 1916, published in 1916.

11. "Rigid Dynamics," Vol. 2, Articles 383, 384; 1892.

12. For a full discussion of these equations and their derivation see for example Whittaker's "Analytical Dynamics," p. 177, Cambridge, 1917.

13. "Electrical Papers," Vol. 2, p. 202. First published in his paper "On the Self-Induction of Wires," Parts 3 and 4, Philosophical Magazine, Vol. 22, pp. 332-352 and pp. 419-442, October and November, 1886; see p. 335 and p. 426.

$$D(p) = \begin{vmatrix} A_{11}+B_{11}\,p+C_{11}\,p^2 \;\ldots\; A_{1n}+B_{1n}\,p+C_{1n}\,p^2 \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ A_{n1}+B_{n1}\,p+C_{n1}\,p^2 \;\ldots\; A_{nn}+B_{nn}\,p+C_{nn}\,p^2 \end{vmatrix} \quad (4)$$

$D(p) = 0$ is then known as the determinantal equation of the system. If p_κ is a root of $D(p) = 0$, p_κ also satisfies the original equations (1). For each root $p = p_\kappa$ of the determinantal equation, suppose we find a solution, $l_1, l_2, l_3 \ldots l_n$ for the equations,

$$\left.\begin{array}{l} (A_{11} + B_{11}\,p_\kappa + C_{11}\,p_\kappa^2)\,l_1 + \ldots \\ \quad + (A_{1n} + B_{1n}\,p_\kappa + C_{1n}\,p_\kappa^2)\,l_n = 0 \\ \cdots\cdots\cdots\cdots \\ (A_{n1} + B_{n1}\,p_\kappa + C_{n1}\,p_\kappa^2)\,l_1 + \ldots \\ \quad + (A_{nn} + B_{nn}\,p_\kappa + C_{nn}\,p_\kappa^2) = 0 \end{array}\right\} \quad (5)$$

If then the initial displacements u_κ and the initial velocities v_κ are adjusted so that,

$$\left.\begin{array}{l} \dfrac{u_1}{l_1} = \dfrac{u_2}{l_2} = \ldots = \dfrac{u_n}{l_n} = A \\[2ex] \dfrac{v_1}{l_1} = \dfrac{v_2}{l_2} = \ldots = \dfrac{v_n}{l_n} = A\,p_\kappa \end{array}\right\} \quad (6)$$

a possible solution of the system (1) is given by,

$$x_1 = A\,l_1\,e^{pKt}\; x_2 = A\,l_2\,e^{pKt}\; x_n = A\,l_n\,e^{pKt} \quad (7)$$

that is, by placing,

$$X_1 = A\,l_1, \quad X_2 = A\,l_2 \quad X_n = A\,l_n \quad (8)$$

The constant A therefore fixes the amplitude of the displacement. Further, on account of the linearity of the equations, $x_r = \sum_\kappa A\,l_\kappa\,e^{pKt}$ is also a solution, the summation being over the roots of $D(p) = 0$. But it is by no means evident that the $2\,n$ equations (6), which determine the amplitude of the normal solutions, are themselves algebraically capable of solution; in fact examples can be given where the normal solutions are not algebraically independent. The most direct proof that the constants A can be found is to express them in terms of the initial values of displacements and velocities. This is done by the Heaviside-Routh conjugate theorem.

Coming back now to Heaviside's argument, suppose that all the impressed forces vanish, so that no energy can be transferred to the system, while the stored energy, due to the elastic connections of the system, is dissipated irreversibly through frictional forces. Let p_1 and p_2 be any two different roots of $D(p) = 0$, satisfying equations (1), so that $x_1 = X_1\,e^{p_1t}$, $x_2 = X_2\,e^{p_2t}$ are solutions of (1). Let further Q_1, U_1, T_1 be the dissipation, kinetic and potential-energy functions corresponding to the normal solution p_1 *i. e.*, to $x_1 = X_1\,e^{p_1t} \ldots\ldots x_n = X_n\,e^{p_1t}$. Then the conservation of energy gives,

$$Q_1 + \dot{U}_1 + \dot{T}_1 = 0 \quad (9)$$

but since,

$$\dot{U}_1 = \frac{1}{2}\,p_1 \sum A_{ij}\,x_i\,x_j + \frac{1}{2}\,p_1 \sum A_{ij}\,x_i\,x_j = 2\,p_1\,U_1 \quad (10)$$

and, likewise,

$$\dot{T}_1 = 2\,p_1\,T_1 \quad (11)$$

therefore,

$$Q_1 + 2\,p_1\,(U_1 + T_1) = 0 \quad (12)$$

In the same way, let Q_2, T_2, U_2 be the dissipation, kinetic and potential-energy functions corresponding to the normal solution p_2, *i. e.*, to $x_1' = X_1\,e^{p_2t} \ldots\; x_n' = X_n\,e^{p_2t}$. We have, precisely as above,

$$Q_2 + 2\,p_2\,(U_2 + T_2) = 0 \quad (13)$$

Now, since p_1 is a root of the determinantal equation, and p_2 is also a root of the determinantal equation, therefore $x_1, x_2 \ldots x_n$ and $x_1', x_2', \ldots\ldots x_n'$ are both solutions of the original system of equations (1). If now, following a nomenclature suggested by Bromwich, we define the relative kinetic energy, the relative potential energy and the relative dissipation of the two normal modes of oscillation p_1, p_2, by means of the expressions

$$\left.\begin{array}{l} \dfrac{1}{2}\,Q_{12} = \sum\limits_{i,j=1}^{n} B_{ij}\,\dot{x}_i\,\dot{x}_j' \\ U_{12} = \sum\limits_{i,j=1}^{n} A_{ij}\,x_i\,x_j' \\ T_{12} = \sum\limits_{i,j=1}^{n} C_{ij}\,\dot{x}_i\,\dot{x}_j' \end{array}\right\} \quad (14)$$

we find again from the conservation of energy that

$$\frac{1}{2}\,Q_{12}+p_2\,U_{12}+p_1\,T_{12}=0,\; \frac{1}{2}\,Q_{12}+p_1\,U_{12}+p_2\,T_{12}=0 \quad (15)$$

whence, by subtraction

$$(p_1 - p_2)\,(U_{12} - T_{12}) = 0 \quad (16)$$

and therefore, $U_{12} = T_{12}$, which is the so-called conjugate theorem. It says in words that the relative kinetic energy of two normal solutions (two normal modes of motion) is equal to the relative potential energy of these two normal solutions. It is to be noted quite carefully that the above reasoning holds only for the case of different roots, $p_1 \neq p_2$.

Heaviside also shows that the conjugate theorem holds for the electromagnetic system expressed by Maxwell's equations. It is to be observed in this connection that the equations (1) which correspond, as already explained, to the electric network, are consistent with the Maxwell circuital laws provided only that the displacement current is negligible compared to the conduction current[14], therefore any argument based on these equations applies to the dynamical system under consideration, but not conversely. The proof is quite simple, but will not be given here[15].

Now let T_{r0}, U_{r0}, be the relative kinetic energy of the normal mode corresponding to the root p_r with respect to the *initial* velocities and displacements, T_{rr}, U_{rr}, the kinetic energy of the normal mode under consideration with respect to itself. T_{r0}, U_{r0}, T_{rr}, U_{rr}, are defined by the expressions,

14. See for example M. Abraham, "Theorie der Elektrizität," Vol. 1, pp. 227-260, Leipzig. 1920.

15. Heaviside, "Electrical Papers," Vol. 2, p. 203-204.

$$\left.\begin{array}{ll} T_{r0} = \sum\limits_{i,j=1}^{n} C_{ij}\, p_r\, l_i\, v_j & T_{rr} = \sum\limits_{i,j=1}^{n} C_{ij}\,(p_r\, l_i)\,(p_r\, l_j) \\ U_{r0} = \sum\limits_{i,j=1}^{n} B_{ij}\, l_i\, u_j & U_{rr} = \sum\limits_{i,j=1}^{n} B_{ij}\, l_i\, l_j \end{array}\right\} \quad (17)$$

whence it follows that $U_{rr} = 2\,U$, $T_{rr} = 2\,T$ (cf. equations (3)). Now if coefficients $B_K = A\, l_K$ are found as outlined above, so that,

$$\left.\begin{array}{l} U_{r0} = \sum\limits_{k=1}^{n} B_K\, U_{Kr} \\ T_{r0} = \sum\limits_{k=1}^{n} B_K\, T_{Kr} \end{array}\right\} \quad (18)$$

then

$$B_r = \frac{U_{r0} - T_{r0}}{U_{rr} - T_{rr}} \text{ and } A = \frac{T_{10} - U_{10}}{T_{11} - U_{11}} \quad (19)$$

because, by the conjugate theorem, all the differences $U_{rs} - T_{rs}$ vanish.[16]

Let us now suppose that all the applied forces save one, F_1, are zero. On account of the linearity of the equations, this is just as general as inserting forces $F_1, F_2, \ldots F_n$ in each one of the n branches. Let F be an exponential, real, imaginary or complex function of time. Then, for any x,

$$x_K = \frac{F_1}{Z\,(p)} \quad (20)$$

$Z\,(p)$ being a function of p obtained from equations (1) by elimination of all the x's except the one desired. It is in general given by the ratio of two determinants. Now,

$$F_1 \frac{d\, x_K}{d\, p} - x_K \frac{d\, F_1}{d\, p} = - x_K^2 \frac{d}{d\, p} \frac{F_1}{x_K} = - x_K^2 \frac{d\, Z}{d\, p} \quad (21)$$

and, by the conjugate theorem,

$$2\,(T - U) = x_K^2 \frac{d\, Z}{d\, p} \quad (22)$$

Heaviside[17] now directs his attention to the electric network corresponding to the mechanical system so far considered and reasons in terms of voltage and current instead of force and velocity or displacement. It has been already shown that the internal connections of the system, *i. e.*, the coefficients A, B, C, determine how the variables chosen to fix the system should vary in order that the resultant system be normal and that the amplitude of the normal modes of oscillation is in turn determined by the conjugate theorem. The actual current and the actual voltage are then represented by sums of normal solutions (cf. equations (7) and (8))

$$V_K = \sum_j A_j\, u_j\, e^{p_j t} \qquad I_K = \sum_j A_j\, w_j\, e^{p_j} \quad (23)$$

the summations being over the roots of the determinantal equation $Z\,(p) = 0$. The coefficients are, as stated, determined by the conjugate theorem.

In order to find the current due to a constant applied voltage, Heaviside makes use of the following argument: Suppose that instead of inserting a constant voltage e, a condenser of capacity C is inserted in the circuit at the same point; by allowing C to increase indefinitely the effect of a constant applied voltage is obtained. This is an essential point, as it reduces the problem on hand to a subsidence problem, with no external forces. Therefore, the current can still be obtained as a sum of normal solutions. For suppose that the condenser C is inserted in the network at a given point and at a certain instant, there being no current and no voltage in any of its branches at that instant. The problem is then to find the subsidence to equilibrium of a system under its own internal stored energy. The conjugate theorem therefore holds. Let the algebraic function expressing the relation between a voltage F_K in branch K and the current I_K in the same branch be $Z\,(p)$ (see Equation (20)); suppose now that the condenser C is inserted in the same branch K and let the corresponding function be $Z_1\,(p)$. Remove the voltage F_K, charge the condenser and switch it on branch K. We have now the subsidence problem, to be solved through the same process as before, by making use of the known properties of normal functions and the conjugate theorem.

Let w_j, u_j, be the normal mode of oscillation of current and of corresponding voltage in the branch under consideration where the condenser is inserted. Since the current is equal to the rate of decrease of charge in the condenser, therefore

$$w_j = - C\, \dot{u}_j = - C\, p_j\, u_j \quad (24)$$

because u_j is a normal coordinate. Initially, that is, at the instant the condenser is switched on its initial voltage V is $V = \sum_j A_j\, u_j$ and $\sum A_j\, w_j = 0$, as there is no current[18]. The electric (potential) energy stored in the condenser is $\frac{1}{2}\, C\, V\, u_j$, so by the conjugate theorem

$$C\, V\, u_j = 2\,(U - T)\, A_j \quad (25)$$

U, T being the electric and magnetic energies of the normal mode. But we have also, by the conjugate theorem

$$2\,(U - T) = - w_j^2 \left.\frac{d\, Z_1}{d\, p}\right|_{p = p_j} \quad (26)$$

Therefore by (25) and (26)

$$A_j = - \frac{C\, V\, u_j}{w_j^2 \left.\dfrac{d\, Z_1}{d\, p}\right|_{p = p_j}} \quad (27)$$

16. See Heaviside's "Electrical Papers," Vol. 1, p. 523, or "The Electrician," November 27, 1885, p. 46; also Routh, l. c. footnote (11).

17. Electrical Papers, Vol. 2, p. 372; see also his paper "On Resistance and Conductance Operators, etc," in Philosophical Magazine, Vol. 24, pp. 479-502, 1887. See p. 501.

18. The initial current is zero because A_{ij}, B_{ij}, C_{ij} are all finite.

Now substitute u_j from (24) in (27), the result is

$$w_j A_j = V \left(p_j \frac{d Z_1}{d p} \bigg|_{p = p_j} \right)^{-1} \quad (28)$$

and substituting in the second of (23):

$$I_K = \sum_j \frac{V e^{p_j t}}{p_j \, d Z_1 / d p \, \big| \, p = p_j} \quad (29)$$

which is the subsidence current. Now to get the effect of a constant applied voltage, let C be increased indefinitely, keeping V constant. This is the same as though the circuit were connected to a source of infinite energy. Now the structure of $Z_1(p)$ may be readily seen to be such that

$$\lim_{C \to \infty} Z_1(p) = Z(p) \quad (30)$$

and when C increases indefinitely one root of $Z_1(p) = 0$ approaches zero, because the condenser in the branch K introduces in the determinantal equation a term which varies inversely with C. It follows that when C increases indefinitely

$$p_j \frac{d Z_1}{d p} \bigg|_{p = p_j} = p_j \frac{d Z}{d p} \bigg|_{p = p_j} \text{ for all roots except } p = 0,$$

and for $p = 0$ (31)

$$\lim_{C \to \infty} \left(p \frac{d Z}{d p} \right)_{p = 0} = Z(0) \quad (32)$$

therefore, finally

$$I_K = \frac{V}{Z(0)} + \sum_j \frac{V e^{p_j t}}{p_j \dfrac{d Z}{d p} \bigg|_{p = p_j}} \quad (33)$$

which is the Heaviside Expansion Formula.

Two points are to be noted in connection with Heaviside's derivation. The first is that his method of reasoning applies only to the case where the determinantal equation has no null and no repeated roots, otherwise, the conjugate theorem breaks down and therefore also the expansion theorem. The second is that the proof as it stands applies only to a system with finite number of degrees of freedom.

Heaviside also gave another alternative proof of his Expansion Formula, the essential point of which is the splitting of the quotient $F_{rs}(p)/D(p)$, where $F_{rs}(p)$ is the cofactor of the element containing the coefficients A_{rs}, B_{rs}, C_{rs} in the determinant $D(p)$, into a sum of partial fractions.[19] This is also the essential point in Carson's first proof[20].

Heaviside has also tried to generalize his proof so as to apply to a system of infinite number of degrees of freedom, but his argument, while quite convincing from a physical standpoint, is not mathematical. It may be formulated analytically, but the proof of the theorem for infinite roots leads to formidable difficulties, some of which have already been examined by Bromwich[21] (l. c. footnote 9). The relation between the conjugate theorem and Wagner's method of attack has been fully treated by Bromwich and will not be taken up here.

It is almost certain that few have realized the extraordinary completeness and generality of some of Heaviside's investigations. It is in the hope of calling attention to the unexplored parts of his work, also as an effort to secure a better appreciation of his labors, that this paper has been written.

19. "Electrical Papers," Vol. 2, p. 226, where the footnote supersedes the text.

20. "On a General Expansion Theorem, etc.," *Physical Review*, Vol. 10, p. 217, 1917, also l. c. footnote (3).

21. Wagner's proof is not applicable to infinite roots as it stands, because Cauchy's residual theorem, on which his proof is based, does not apply to infinite number of poles without special investigation of the behavior of the function under the integral sign.

INSULATION IN USED MACHINES

The standards of the American Institute of Electrical Engineers and other similar rules or specifications prescribe a definite high-potential test for new electric generators and motors. Much can be said for and against subjecting insulation to a higher stress than it ever will be called upon to stand in actual operation, but at any rate the specified overpotential is a perfectly definite guide for the maker and the user of a machine. However, when it comes to a machine already in use the situation becomes quite indefinite. A used machine may be subjected to a high-potential test either as a part of periodic inspection or on special occasions—for example, after repairs to the winding or a change in connections.

Since even the best known insulation deteriorates with time, it would hardly seem rational to subject a used machine to a high-potential test of the same severity as a new machine. At the same time, when a machine is performing an important duty the operating engineer prefers to know of an impending failure in advance rather than to wait until the machine actually breaks down at an inopportune moment. To test it "destructively" is to invite such a failure, but apparently there are no reliable non-destructive physical tests to indicate the condition of insulation. Measurement of insulation resistance is not always indicative, and even a high-potential direct-current test with a kenotron may give a false assurance, since the dielectric loss is absent.

This question of dielectric tests on used machines is of considerable importance to public service companies and to users of large electric motors in various industries. With it is closely connected the problem of finding a non-destructive physical test indicative of an incipient deterioration or of the state of preservation of the insulation. The time is ripe to engage in thoroughgoing research in this direction.—*Electrical World.*

ILLUMINATION ITEMS

By the Committee on Production and Application of Light

A NEW LIGHTING ORGANIZATION IN FRANCE

A society for the improvement of illumination (Societe pour le Perfectionnement de l'Eclairage) has been organized in France by some of the leading central stations, electrical manufacturers, contractors, dealers, and others interested in the development of the electrical industry. It has its headquarters in Paris. The object of the organization is clearly set forth in a circular which, freely translated, reads as follows:

"Considerable work has been done this past year in different countries to promote the development and improvement of illumination in all fields; public lighting, industrial, commercial and residential.

"Innumerable commercial and industrial enterprises utilize electric light very poorly because no rational study has been made of the best conditions of installation. The luminous sources produce glare and harm vision, in place of lighting properly the objects or the spaces which it is intended to illuminate. It is often the same in the case of public lighting. In lighting the home, people ordinarily limit themselves to using or copying old devices without seeking to make the best of the many advantages which the use of electricity offers.

"The Society for the Improvement of Lighting (S. P. E.) proposes to collect, centralize, distribute and popularize information relative to lighting practise; to develop illuminating engineers; to conduct a campaign in favor of better lighting; to explain and to show by meetings, publications and experiments, the principles on which rational installations must be made; to study, on behalf of those who desire it, the arrangements which should be made in individual cases to obtain the maximum useful effect.

"This Society seeks no commercial profit and sells no apparatus of any kind. It places itself at the disposal of all who have need of advice or information on lighting subjects. Its advice or its information is given always gratuitously. Therefore no one need hesitate to consult it, because it has been created and organized for the purpose of popularizing better lighting."

The first six booklets which have been prepared by this organization in its campaign for better lighting present in a very forceful way, the advantages of good illumination and the need of avoiding glare. They are quite different in appearance and style than the popular advertising material here. Many lighting men in this country will follow with interest the work which the new society is doing to carry the message of good lighting to the people of France.

It is indicated that in 1925 the total amount of new financing by American public utilities, excluding steam railroads, exceeded $1,750,000,000. This figure compares with $1,500,000,000 in 1924.

LIGHTING INSTALLATIONS SHOULD BE DESIGNED FOR SUBNORMAL EYES

Intensities of illumination are generally far from adequate for perfect or "normal" eyes. To increase the intensity to the high level most suitable and economically desirable for workers with normal vision is such a formidable task that little thought has been given to that necessary for the best efficiency of workers whose vision is subnormal. Apparently it has been assumed that subnormal eyes are in an insignificant minority. However, the truth seems to be that the majority of workers' eyes are not perfect. Evidence to this effect has been accumulating of late through systematic eye examination. Furthermore, it has been found that, for seeing equally well, if possible at all with defective eyes requires a greater intensity of illumination than for normal eyes. Correcting refractive errors by means of glasses is, to some extent, equivalent to increasing the intensity of illumination; but there is enough evidence to indicate that average eyes, even if corrected by means of glasses, require more light than normal eyes to attain equal facility in seeing.

Many statistics of eye examination have been published, among the most recent being those obtained by the United States Public Health Service in two New York post offices. These are sufficient to illustrate the great prevalence of eye defects. The eyes of two thousand, five hundred employees were examined with the following results: Normal or no defects, 17.1 per cent; one refractive error or more, 73.7 per cent; one inflammatory condition or more, 14.5 per cent; one muscular unbalance or more 25.6 per cent; using glasses, 35.6 per cent. These percentages are startling, but approximately the same results have been obtained in other investigations, and a glance at the bespectacled contingent to any gathering is enough to convince one of their accuracy.

It is not surprising to those who have reached the "bifocal" stage in life that the percentage of near-sightedness and other eye defects increases as the average age of a group of workers increases. The percentage of normal eyes decreases rapidly beyond the age of forty years. In lighting practise, this means that a relatively higher intensity of illumination should be supplied in those industries where skilled labor is important, because, in general and up to a certain point, skill is acquired with age. Thus it is seen that the prevalence of defective eyes over perfect or "normal" ones makes it necessary in the practise of lighting that special consideration be accorded to them.—*Electrical World.*

The night aviator flies from Jacksonville to Miami trusting mainly to his compass save for the 70-mile stretch from Palm Beach to Miami, which is lighted. At a meeting in Fort Pierce, plans were initiated to the end that the entire 390-mile route shall become a glorious White Way.

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Cleveland Has Very Successful and Well Attended Meeting

From every point of view the Regional Meeting held in Cleveland, March 18-19, was an outstanding success. An attendance of 430, intense interest in the technical papers and in the addresses by prominent men, and enjoyment of the other features distinguished this meeting. The members of the convention committee deserve the greatest praise for their efforts in planning and managing the affair.

Papers on Sectionalized Electric Drive

Sectionalized electrical drive, particularly as applied in paper mills, was the subject of the first two technical sessions which were held on Thursday, March 18, in the Hotel Cleveland, the convention headquarters. Three papers on this topic were presented and there followed a very complete discussion in which a large number of paper-mill executives and engineers took part. The discussion brought out the fact that sectional drive of paper mills is generally desirable for new mills. There were some questions as to the economic advantages of replacing mechanical drive in old mills of certain classes with electrical drive. Also there was doubt in the minds of some of the paper-mill men of the necessity for such refinements of speed regulation as those described in the papers but it was admitted that in-so-far as a better quality of paper could be produced the refinements would be justified. The three papers were: *Electrification of Paper-Making Machines*, by S. A. Staege, Westinghouse Electric & Mfg. Co.; *The Development of the Sectional Paper-Machine Drive*, by H. W. Rogers, General Electric Co., and *Sectional Paper-Machine Drive*, by R. N. Norris.

Those taking part in the discussion were: T. D. Montgomery, L. W. W. Morrow, F. C. Bowler, N. D. Paine, H. L. Sanborn, J. F. Rhodes, R. T. Kintzing, E. B. Bearce, E. B. Wright, R. S. White, C. A. Farrell, Tom Harvey, R. S. Lowry, J. H. Crossley, A. O. Spierling, H. C. Busser, W. W. Spratt, S. A. Staege, H. W. Rogers, and R. N. Norris.

Dinner, with Address by Newton G. Baker

On Thursday evening the convention dinner was held in the Hotel Cleveland. Music and a number of entertainers made this an enjoyable occasion. After the dinner A. G. Pierce, Vice-President of the Middle-Eastern District, A. I. E. E., introduced the toastmaster, C. P. Cooper, President, Ohio Bell Telephone Company, who in turn presented Mayor Marshall of Cleveland who welcomed the members in the name of the City. F. L. Hutchinson, National Secretary, A. I. E. E., responded for the Institute in a short address in which he outlined the Institute's purposes and activities. The Honorable Newton G. Baker, former Secretary of War, then gave an inspiring address on some of the major problems of American civilization. Farley Osgood, Past-President, A. I. E. E. responded for the Institute members.

Domestic Electric Refrigeration

On March 17 two addresses on electric refrigeration were given. The first of these was by C. F. Kettering, President, General Motors Research Corporation, and its title was *Some Scientific Phases of Refrigeration*. Mr. Kettering explained in a most interesting way the principles of refrigeration and their applications, as well as the requirements for producing and marketing household refrigerators. A number of interesting demonstrations helped to explain Mr. Kettering's points.

G. E. Miller, Cleveland Electric Illuminating Company, spoke on *Domestic Refrigeration from the Central-Station Point of View*. In an illustrated address he described the possibilities of the domestic refrigerator as a load builder and its value as a central-station load.

Farley Osgood, consulting engineer and Past-President of the Institute, was the last speaker on Friday afternoon. He took as his subject *Engineering and Humanity*, telling of the responsibilities and opportunities for service by the engineer in solving city, state and national problems.

On Friday at noon a luncheon was given by Vice-president Pierce to the Branch Counselors of the Middle Eastern District and a few other guests. A committee on Student Activities of the District was organized consisting of all the Branch Counselors within the District and the Vice-President and Secretary of the District. Prof. H. B. Dates of the Case School of Applied Science Branch was elected Chairman.

Visit to Nela Park

On Friday evening a trip was made to Nela Park, the laboratory and plant of the National Lamp Works of the General Electric Company. At the Park short addresses were made by R. W. Shenton of the National Lamp Works, on *Nela Park, Its Organization and Objectives*, and by Ward Harrison, National Lamp Works, on *Recent Developments in Illumination*. Following these addresses there were demonstrations of illumination for industry, automobiles and the home, and then visits were made to the laboratories and historical museums.

A number of other trips were made on Saturday morning by small groups and individuals to various places of engineering and civic interest.

The able general committee which planned this convention was as follows: A. G. Pierce, Vice-President of Middle Eastern District; A. M. MacCutcheon, General Chairman; C. S. Ripley, Secretary; L. D. Bale, Transportation; H. B. Dates, Program; C. L. Downs, Reception; H. L. Grant, Publicity; G. A. Kositzky, Finance; A. M. Lloyd, Registration; E. H. Martindale, Attendance; C. N. Rakestraw, Dinner, and I. H. Van Horn, Trips. A large number of committee members worked faithfully and effectively under these men, resulting in a most successful and enjoyable meeting to all who attended.

Regional Meeting of Great Lakes District at Madison May 6-7

A two-day Regional Meeting will be held by the Great Lakes District of the Institute in Madison, Wisconsin, on May 6 and 7, with headquarters at the Hotel Loraine. An interesting program has been arranged featuring the following topics:

Rural Electrification
Developments in High-Tension Underground Cables
Cooperative Research Relations Between the Colleges and the Industries
Performance of Radio Receiving Circuits.

On Thursday evening, May 6th, a dinner will be given at which President Glenn Frank of the University of Wisconsin will give the address.

A luncheon meeting for the Counselors of the Student Branches of the District has been scheduled for Thursday noon. Thursday afternoon will be devoted to inspection trips to points of interest such as the hydroelectric plant at Prairie du Sac, the Forest Products Laboratory, the University, the Capitol, and the industries of Madison. Several excellent golf courses will be open to members attending the meeting.

The meeting and program committee consists of the following: Chairman, Edward Bennett; J. B. Bailey, A. G. Dewars, H. R. Huntley, L. E. A. Kelso, Carl Lee and R. G. Walter.

The chairmen of the various local committees are as follows: C. M. Jansky, Publicity and Attendance; John R. Price, Hotel and Dinner; L. J. Peters, Registration and Reception; R. G. Walter, Finance; C. B. Hayden, Entertainment and Trips.

Madison is easily reached by automobile by any one of several routes. Detailed information concerning condition of roads may be obtained by addressing Mr. J. C. Bitterman, Madison Association of Commerce, Madison, Wisconsin.

PROGRAM OF MADISON MEETING

THURSDAY MORNING

9:00 A. M. Registration.
9:45 A. M. Technical Session: R. G. Walter, Chairman.

Rural Electrification, by Grover C. Neff, Wisconsin River Power Company.

Important Features of a Successful Plan for Rural Electrification, by George G. Post, Milwaukee Electric Railway & Light Company.

These papers will be discussed by R. A. Stewart, University of Minnesota; Eugene Holcomb, Consumers Power Company; C. B. Hayden, Railroad Commission of Wisconsin; R. A. Duffee, University of Wisconsin; and E. H. Lehman, University of Illinois.

THURSDAY NOON, 12:30 P. M.

Luncheon meeting of Branch Counselors.

THURSDAY AFTERNOON

Inspection Trips and Golf.

THURSDAY EVENING

Regional dinner at the Hotel Loraine. Address by President Glenn Frank, of the University of Wisconsin.

FRIDAY MORNING, 9:00 A. M.

Technical Session: R. F. Schuchardt, Chairman.

The Quality Rating of High-Tension Cable, by D. W. Roper and Herman Halperin, Commonwealth Edison Co.

Tests on High-Tension Cable, by F. M. Farmer, Electrical Testing Laboratories.

The Effect of Internal Vacua in High-Voltage Cable, by W. A. Del Mar and C. F. Hanson, Habirshaw Electric Cable Co.

Some Interconnected-System Operating Problems, by F. G. Boyce, Consumers Power Co.

FRIDAY AFTERNOON, 2:00 P. M.

Technical Session: Arthur Simon, Chairman.

Cooperation Between the Colleges and the Industries in Research

Paper or addresses by:
Wm. E. Wickenden, Society for the Promotion of Engineering Education.
Dean A. A. Potter, Purdue University.
Benjamin F. Bailey, University of Michigan.
Dean Milo S. Ketchum, University of Illinois.
Edward Bennett, University of Wisconson.

Behavior of Radio Receiving Systems to Signals and to Interference, by L. J. Peters, University of Wisconsin.

SATURDAY MORNING

Inspection trips: Cars and guides will be provided for trips to points of interest for those who are unable to take advantage of the trips arranged for Thursday afternoon.

Niagara Regional Meeting May, 26-28

High-grade technical sessions and some unusual entertainment features mark the program of the Regional Meeting which will be held at Niagara Falls, N. Y., May 26-28, under the direction of the Northeastern District of the Institute. The new Niagara Hotel will be headquarters for the meeting.

The technical subjects to be presented include measurement of power factor in dielectrics, transmission, tests of hydroelectric units, speed measurements, rectifiers, transformer design, radio-wave propagation, armature reactance, magnetic-flux measurements, supervisory control, fire protection for generators, etc. A list of the proposed papers is shown in the accompanying tentative program.

A very attractive entertainment program has been arranged, including a trip on Lake Ontario, a scenic and inspection trip in the Gorge, a convention dinner, two interesting lectures and a special illumination of the Falls. Special entertainment features are being planned also for the ladies.

The steamer trip on Lake Ontario is arranged for Wednesday evening, May 26. The party will travel by the Gorge route to Lewiston, where the lake steamer will be boarded. Then a moonlight ride on the lake with dancing for those who desire it will afford enjoyment until a late hour.

A trip down the Niagara Gorge will be made on Thursday afternoon; those taking this trip will see the famous rapids and the whirlpool from both sides of the ravine. Stops will be made at the many points of scenic interest and also at the plants of the Niagara Falls Power Company and of the Hydro-Electric Power Commission of Ontario.

On Thursday evening the convention dinner will be held in the Niagara Hotel and a number of the Institute officers will speak briefly.

Following the dinner there will be given with demonstrations a most interesting lecture on the subject "Modern Reproduction of Sound."

SPECIAL ILLUMINATION OF THE FALLS

A spectacle of great beauty is planned for Thursday night when the Niagara Falls will be specially illuminated with many changing and moving colors. There will be features of this illumination never before shown.

A piano recital together with one of his unique and entertaining interpretations of the music will be given by Vladimir Karapetoff on the evening of Friday, May 28. The many Institute members who have heard Professor Karapetoff in other recitals know that this will be a delightful event.

If possible, the first showing of the new film of the Niagara Falls Power Company will be made on Friday evening in connection with a lecture on the power development of the Niagara Falls. This film will illustrate the possible future power and scenic development of the Falls.

Application has been made for reduced railroad rates under the

certificate plan. If the rates are granted it is hoped that everyone who travels by rail will get a certificate when purchasing his ticket whether or not he intends to make use of the reduced fare. By getting a certificate he will help make up the 250 certificates necessary to obtain the reduction for those who wish to take advantage of it.

The general arrangements for this meeting are being made under the direction of the Coordinating Committee of the Northeastern District of the A. I. E. E. which is as follows: H. B. Smith, Vice-President in Northeastern District; A. C. Stevens, Secretary; J. R. Craighead, E. D. Dickinson, J. A. Johnson, A. E. Soderholm and A. W. Underhill, Jr. The local arrangements are in charge of a committee of which J. A. Johnson is chairman.

TENTATIVE PROGRAM OF NIAGARA FALLS REGIONAL MEETING MAY 26-28, 1926.

WEDNESDAY MORNING AND AFTERNOON, MAY 26

Technical Session—Symposium on Dielectrics and Power-Factor Measurements.

The Power Factor of Dielectrics and Insulation, by J. B. Whitehead, Johns Hopkins University.

The Mechanism of Breakdown of Dielectrics, by P. L. Hoover, Harvard University.

Standards for Measuring Power Factor of Dielectrics, by H. L. Curtis, Electrical Testing Laboratories.

The Significance of Errors in Dielectric-Loss Measurements, by C. F. Hanson, Habirshaw Electric Cable Co.

Use of Dynamometer Wattmeter for Measuring Dielectric Power Loss, E. S. Lee, General Electric Co.

Commercial Dielectric-Loss Measurements, by R. E. Marbury, Westinghouse Elec. & Mfg. Co.

Three Methods of Measuring Dielectric Power Loss and Power Factor, by C. D. Doyle and E. H. Salter, Electrical Testing Laboratories.

Compensation for Errors of the Quadrant Electrometer, by D. M. Simons, Standard Underground Cable Co.

The Dielectric-Loss-Measurement Problem, by B. W. St. Clair, General Electric Co.

Zero Method of Measuring Power with a Quadrant Electrometer, by W. B. Kouwenhoven and P. L. Betz, Johns Hopkins University.

WEDNESDAY AFTERNOON AND EVENING

Special cars will leave for Lewiston following the afternoon technical session, for the steamer trip on Lake Ontario. Executive committee and other committee meetings will be held on the boat.

THURSDAY MORNING

Technical Session

Rectifiers and Their Auxiliary Devices, by O. K. Marti, Cornell University.

Rectifier Voltage Control, by D. C. Prince, General Electric Co.

Radio-Wave Propagation, by E. F. W. Alexanderson, General Electric Co.

Circulation of Harmonics in Transformer Circuits, by T. C. Lennox, General Electric Co.

A Flux-Voltmeter for Magnetic Tests, by G. Camilli, General Electric Co.

THURSDAY AFTERNOON

Scenic Trip in the Gorge and Inspections of Power Plants

THURSDAY, 6:30 P. M.

Convention Dinner

THURSDAY EVENING

After the dinner will come the lecture "Modern Reproduction of Sound" and following the lecture the special illumination of Niagara Falls.

FRIDAY MORNING

Technical Session

Variable Armature Leakage Reactance, by V. Karapetoff, Cornell University.

Fire Protection for A. C. Generators, by J. A. Johnson, Niagara Falls Power Co. and E. J. Burnham, General Electric Co.

Automatic and Supervisory Control of Hydroelectric Generating Stations, by F. V. Smith, Westinghouse Elec. & Mfg. Co.

Tests on Niagara Falls Hydroelectric Units, by J. A. Johnson, Niagara Falls Power Co.

Speed Measurements of Rotating Machines, by P. A. Borden, F. K. Dalton and H. S. Baker, all of the Hydro-Electric Power Commission of Ontario.

FRIDAY AFTERNOON

Technical Session on Power Transmission

Interconnection and Superpower, by S. Q. Hayes, Westinghouse Elec. & Mfg. Co.

European Transmission Practises, by G. F. Chellis, Whitehall Securities Corp.

Lightning and Other Experience on 132-Kv. Transmission Lines, by M. L. Sindeband and P. S. Sporn, American Gas and Electric Co.

Notes on the Vibration of Transmission-Line Conductors, by Theodore Varney, Aluminum Co. of America.

Transmission-Line Sag Calculations, by H. B. Dwight, Massachusetts Institute of Technology.

FRIDAY EVENING

Piano Recital, Vladimir Karapetoff

Lecture on the *Power Development of the Niagara Falls*, Illustrated with motion pictures.

April 13th Meeting of I. E. C. to be Addressed by Prominent European Engineers

On the evening of the first day of the coming plenary session of the International Electrotechnical Commission which is to be held in New York, April 13th to 22nd, a general meeting is scheduled for the Auditorium, Engineering Societies Bldg., 33 West 39th St., New York, which should prove of great interest to all engineers. The program for the evening calls for the opening of the meeting by Dr. C. O. Mailloux, Honorary President of the I. E. C. He will then introduce Dr. Clayton H. Sharp, President of the United States Committee. Dr. Sharp will turn the meeting over to John W. Lieb, Chairman of the Reception Committee who will call upon Professor Elihu Thomson to make the address of welcome to the foreign delegates. There will be a brief response by Colonel R. E. Crompton, C. B., Honorary Secretary of the Commission. Brief address will be given by representatives of France, Poland, Germany, Scandinavia and Japan. The principal address of the evening will be made by Guido Semenza of Milan, Italy, President of the International Electrotechnical Commission on "The Accomplishments and Aims of the International Electrotechnical Commission."

An outline of the program for the entire week was given in the March JOURNAL, page 297.

Doctor R. A. Millikan to Speak on "High-Frequency Cosmic Rays"

The members of the New York Section of the A. I. E. E. and the New York Electrical Society are to have the wonderful opportunity of again listening to an address by Dr. R. A. Millikan, Director, Norman Bridge Laboratory, California Institute of Technology. Dr. Millikan will describe his recent work in

the detection of "High-Frequency Cosmic Rays," carried on at Lake Muir at the summit of Mt. Whitney and Arrowhead Lake in the San Bernardino mountains, also on Pike's Peak in which he determined that these rays, at first called "penetrating radiation" of the atmosphere, come definitely from above. The shortest wave length determined corresponds to a frequency 10,000,000 times higher than that of visible light and that the computed frequencies correspond closely to the energy involved in the simple capture of an electron by a positive nucleus.

Dr. Millikan, as those who have had the pleasure of listening to his previous talks know, can present an intricate and difficult subject in a way which all can understand. He has been the recipient of, among numerous other awards, the Edison Medal in 1922 and the Nobel Prize of the Swedish Academy in 1923.

The meeting will be held in the Auditorium, Engineering Societies Building, 33 West 39th Street, New York, at 8 p. m., on Saturday evening, April 10, 1926.

New York Section to Hold Student Convention

The New York Section will hold its first Student Convention on Friday, April 23, 1926. The plans for this convention have been under way for some time, through conferences of N. Y. Section officers and a committee representing the student body of the eight colleges within the New York Section territory, as follows: College City of New York, Columbia, Cooper Union, New York University, Newark College of Engineering, Polytechnic Institute of Brooklyn, Rutgers University and Stevens Institute of Technology.

The morning of April 23rd will be devoted to inspection trips to the G. E. Lamp Works at Harrison, N. J.; the Bell Laboratories, and the I. R. T. repair shops. An afternoon session in Room 1, Fifth Floor, Engineering Societies Building, 33 West 39th St., New York, will start at 2:30 p. m. with one student speaker from each of the eight colleges. President Pupin will give a short address. A get-to-gether supper will follow at the Fraternity Club. Tickets to be sold at $1.50 each.

The evening program is being arranged by the New York Section officers and is to be of particular interest to students. The session will be held in the Auditorium at 8:15 p. m. Definite announcement of speakers will be made later.

Future Section Meetings

Baltimore

Talk by a Member of the Local Section. Engineers' Club. April 16, 8:15 P. M.

Induction Interference, by H. S. Phelps. Engineers' Club. May 21, 8:15 P. M.

Cincinnati

Electrical Control Equipment, by Mr. Wilms, Allen-Bradley Co. April 8.

Connecticut

Bay of Fundy. New Haven. April 9.

Radio. Bridgeport. April 29.

Detroit Ann Arbor

Motors, Power Factor and Power-Factor Rates, by E. L. Bailey, Cleveland Electric Motor Co. April 23.

Lehigh Valley

Oil Switches, by G. A. Burnham, Condit Electric Mfg. Co., and *Horsepower*, by J. J. Johnson, Westinghouse Electric & Mfg. Co. Hazleton. April 23.

St. Louis

Automatic Stations, by C. A. Butcher, Westinghouse Electric & Mfg. Co. April 21.

Automatic Telephoning in St. Louis. May 19.

Spring Meeting of the American Society of Civil Engineers

On April 14th, at Kansas City, Mo., the American Society of Civil Engineers will open the program of its Spring Meeting with the subject on the Relation of the Railroads to Modern Highway and Urban Traffic. This will be followed on Wednesday by an important session on the question of Urban and Interurban Busses, and on Thursday, April 15th, the Technical Divisions will hold sessions in their various fields. Programs have been arranged by the City Planning, Construction and Sanitary Engineering Divisions, with the presentation of two important papers and discussion thereon. In addition to the comprehensive technical program, a number of delightful social events and sightseeing and inspection trips are planned. The dinner dance will be held in the roof garden and ball room of the Kansas City Athletic Club. The Official program is now available to any wishing to review a copy.

Important Meeting of New England Engineers

With all New England engineering interests joining heartily in the support and promotion of its success, the program of the Providence Sections of the American Society of Mechanical Engineers is being completed for a gigantic gathering of professional interests May 3-6, 1926. The opening session of the meeting will have for its subject Industrial Education, followed, Tuesday morning, by a session on Small Parts Manufacture, Industrial Power and Wood Industries; Wednesday morning's sessions will be devoted to Cold-working of Metals, Central Power Stations Problems and Textiles. Some features for which arrangements have already been consummated include visits to the Narraganset Electric Lighting Company, Brown & Sharpe Mfg. Co., the Providence Gas Company and selected textile and rubber plants. Entertainments will be a reception Monday evening, a men's luncheon Tuesday, a Rhode Island Clam Bake Tuesday evening and an informal dinner Wednesday. On Thursday, the party will visit the Newport Torpedo Station and will be afforded the unusual opportunity of seeing the torpedoes launched and visiting will also include an inspection of the shops training station, the old battleship, Constellation and Newport itself.

Student Convention at Swarthmore

The second annual student convention of the Philadelphia Section of the A. I. E. E., held at Swarthmore College on Monday, March 8th, was an eminently successful continuation of last year's pioneer event. Two hundred and twenty-nine students of electrical engineering, from Delaware, Drexel, Haverford, Lafayette, Lehigh, Pennsylvania, Princetown, Swarthmore and Villa Nova, met for a convention run by themselves on lines quite like those of regular A. I. E. E.

After inspection of the laboratories, the morning sessions were opened by an address of welcome by Dr. Lewis Fussell, Professor of Electrical Engineering, who immediately turned the session over to E. D. Gailey, '26, Chairman of the Swarthmore College Branch. A varied program of four papers drew forth a lively discussion and absorbed the attention of all. This morning session comprised the following papers:

Recent Developments in Power Plants, Herbert Estrade, University of Pennsylvania, 1926

Electricity in Motion-Picture Theatres, F. G. Kear, Lehigh University, 1926

Electron Theory as Applied to the Discharge Tube, Irvin A. Travis, Drexel Institute, 1926

Some Recent Developments in the Incandescent-Lamp Industry, Homer A. Blake, University of Delaware, 1926.

Luncheon, as guests of Swarthmore, was followed by inspections

of buildings and campus, and at 2:30 four parties left by auto for trips of inspection to the following plants:

Chester Waterside Plant of the Delaware County Electric Co., Chester, Pa.

South Philadelphia Works of the Westinghouse Electric and Manufacturing Company, Lester, Pa.

Pine Ridge Automatic Substation, Philadelphia and West Chester Traction Co., Pine Ridge, Pa.

Baldwin Locomotive Works, Eddystone, Pa.

The laboratories were open again from 6 to 7, at which time students and many men of the Philadelphia section learned how complete an equipment is available in this small college. The dinner, of which 119 partook, and the evening session attended by 180, constituted the regular March meeting of the Philadelphia Section, with C. D. Fawcett, past-chairman, in charge. He introduced National Secretary F. L. Hutchinson, who spoke in a most illuminating way of "Institute Activities," pointing out the numerous ways in which the student and the Institute can be mutually beneficial.

Farley Osgood, consulting engineer, and Past-President of the A. I. E. E., spoke in his forceful way on "College—Then What?" bringing clearly to the most casual student the idea that his place in the world is what *he* will make it, and that a technical education is the best possible preparation for any kind of life. A number of interesting "stunts" were then presented, dancing, music, etc., and the day was brought to a close with a few remarks by Dr. Fussell. He stressed the fact that the success of the convention type of meeting, in which the Philadelphia Section is the pioneer, is now established and should insure its continuance as an annual event.

The Student Branch Activities Committee, consisting of Professor Morland King of Lafayette, Professor L. H. Rittenhouse of Haverford, Professor Malcolm Maclaren of Princeton, Professor J. G. Brainerd of University of Pennsylvania, Professor Dean Tanzer of Drexel Institute, and Professor L. Fussell of Swarthmore, Chairman, and the local committees under Mr. Gailey deserve great credit for perfecting the details of an extremely well thought out and smooth running convention.

Adoption of Metric System Discussed

The House Committee on Coinage, Weights and Measures opened hearings in Washington, March 4th, on a bill which proposes to make the metric system effective in this country after January 1935. While opposition as well as approval of the bill was expressed by representative men, it is generally contended that the ultimate good to be derived from the adoption of a universal unit of measure is obvious, in view of which the earlier it is put into effect the sooner will the whole situation be simplified. As Major Fred J. Miller, past-president of the A. S. M. E. expressed it, "A gram of prevention is worth a kilogram of cure." Some of those opposing the bill were Luther D. Burlingame, chairman of the A. S. M. E. Committee on Standardization and Unification of Screw Threads, other representatives of the A. S. M. E. on the National Screw Threads Commission and C. C. Stutz, Secretary of the Institute of Weights and Measures, while the passage of the bill was supported by S. W. Stratton, Gano Dunn, Thomas A. Edison, General Pershing, Samuel Vauclain, and others of representative prominence.

Doctor Whitehead Chosen Exchange Professor to Lecture in France

Doctor J. B. Whitehead, Dean of Engineering of Johns Hopkins University, and a Director of the A. I. E. E., has been selected by seven American universities as their international exchange professor to France. His appointment was made under an arrangement among Harvard, Yale, Columbia, Cornell, University of Pennsylvania, Massachusetts Institute of Technology, Johns Hopkins and the French Government to establish an exchange professorship of engineering and applied science for the two countries.

The course of lectures to be given by Doctor Whitehead at the French universities which he will visit during the first half of 1927, will deal with the subject of "Insulation and the Dielectric Theory." Doctor Whitehead is known throughout the world for his research on the problems of insulation, having delivered many papers on this subject before the A. I. E. E. His research on high-voltage insulation received recognition in Europe last year when he was awarded a triennial prize of the George Montefiore Foundation of Belgium for his series of papers on "Gaseous Insulation in Built-up Insulation." He also received this prize in 1922 for another paper on "The Corona Voltmeter and the Electric Strength of Air." Among other honors for papers in the same general field was his recent receipt of the Longstreth Medal of the Franklin Institute.

This professorship was established at the close of the war for the purpose of exchanging knowledge between France and America through interchanging professors of outstanding ability. Dr. A. E. Kennelly, Professor of Electrical Engineering, Harvard University, Past-President of the Institute, was the first American selected for this exchange (1921-22). During the last four years three other American scientists have had this honor, namely: Dr. E. M. Chamot, professor of Sanitary Chemistry, Cornell University; Dr. D. W. Johnson, Professor of Physiography, Columbia University, and Dr. John Frazer, Dean of the Towne School of Engineering, University of Pennsylvania. In the same period Prof. J. Cavallier, Recteur, University of Lyons; Prof. Emmanuel de Margerie, Geologist, University of Strasbourg, and Prof. Pierre Lemaire, Professor of Mechanical Enginering, University of Lyons, have come from France to the United States.

John Ericsson Medal Established

A gold medal to be known as "The John Ericsson Medal" and to be awarded to Americans of Swedish birth or descent, or to Swedish citizens, as a recognition of distinguished accomplishments in science and engineering, was established in January 1926 by the American Society of Swedish Engineers. This medal which was established in honor of the great engineer and scientist, Ericsson, will be awarded not oftener than once in two years on a recommendation of a medal committee comprising four members each of the Swedish Academy of Engineering Science and the American Society of Swedish Engineers.

The first award will be made at the time of unveiling the John Ericsson monument in Washington, D. C., in May. The American Society of Swedish Engineers, which has headquarters in Brooklyn, N. Y., was founded in 1888 and has a membership of approximately 500.

Medal for Radio Amateurs

A medal for those who serve humanity through radio by bringing aid in time of peril has been offered by the magazine *Popular Radio*. The awards will be made to non-professionals through whose efficient action radio is utilized to alleviate suffering or save life within the territory and waters of the United States.

Those who qualify for this recognition should be brought to the attention of the Committee of Awards, Popular Radio Medal for Conspicuous Service, 627 West 43rd Street, New York.

A World Language For Electricity

Plans to formulate a universal language for electricity will come before a ten-day plenary convention of the International Electrotechnical Commission to be held in New York beginning April 13th, as announced by Doctor Clayton Halsey Sharp, president of the United States Committee of the Commission. National committees of the Commission in America, Great

Britain and countries of the Continent have been developing studies in this field and their reports will be submitted at this meeting, the first to be held in this country. Radio expansion, it is declared, has increased the demand for common terms and symbols, and steps have already been taken as a part of the general program for worlds standards, to meet this situation in an electrical language. An international dictionary of electrical terms is also one of the aims of the Commission.

A. I. E. E. Year Book

The 1926 issue of the Year Book goes to press about April 1st and copies will be available for distribution shortly thereafter.

The book contains an alphabetical and geographical catalog of the membership, revised to January 1, 1924; also the constitution, by-laws, lists of officers and committees, and much additional information relating to the activities of the Institute.

New York Section Nominations for 1926-27

The Nominating Committee of the New York Section has named the following ticket for officers of the New York Section for the year 1926-27: Chairman, E. B. Meyer, Public Service Electric Co.; Secretary-Treasurer, O. B. Blackwell, American Telephone and Telegraph Co.; Executive Committee, J. B. Bassett, General Electric Co. and C. R. Jones, Westinghouse Elec. & Mfg. Co. Mr. H. A. Kidder, the present chairman, automatically becomes Junior Past Chairman on August 1st and makes the fifth member of the Executive Committee. The ballots for the above ticket are now before the Section membership and final results will be announced at the April 23rd meeting of the Section.

PERSONAL MENTION

Frederick W. Walker has closed his Chicago office, and, effective March 1st, 1926, has been appointed vice-president of the Northwestern Mutual Life Insurance Company, Milwaukee, Wis.

Joseph Rogoff, who was industrial engineer for the Salt's Textile Company, Inc., Bridgeport, Conn., has been appointed superintendent of the Gaynor Electric Company, Inc., of that city.

Bertram Wardle, who was chief draftsman for the English Electric Co. of Canada, Ltd., has recently identified himself with the Canadian General Electric Co., Peterboro, Ontario, Canada.

W. J. Moulton-Redwood, of the engineering staff of the Canadian National Carbon Company and the Prest-O-Lite Company of Canada, has resigned from these interests and gone to Auckland, N. Z., for Commercial engineering work.

J. Maldonado, formerly electrical engineer for the Brooklyn Edison Company, has signed a contract with the Worthington Pump and Machinery Corporation of New York and will assume the managership of their Barcelona Offices, Compania de Bombas Worthington, Plaza Universidad, 2, Barcelona, Spain.

George L. DeMott, after seven years' service as examiner in the United States Patent Office in charge of the Electrical Measuring Instrument art and having completed a four years' course in law in addition to his previous technical training, has become associated with the Union Switch and Signal Company of Swissvale, Pennsylvania, as assistant patent counsel.

S. R. Williams, formerly special representative of the Westinghouse Electric and Manufacturing Company, with headquarters at South Bend, Indiana, has been appointed their street lighting engineer at Boston. Mr. Williams was also at one time connected with the Philadelphia office of the company, assisting in the sale of street lighting equipment. He is a graduate of the Westinghouse student sales and engineering course.

H. J. E. Reid, an Associate of the Institute, on January 1, 1926, was appointed Engineer-in-charge of the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics at Langley Field, Virginia. Mr. Reid received his engineering education at Worcester Polytechnic Institute and for the past five years has been chief of the Instrument Section of the laboratory of which he is now in charge. He has the honor of being the youngest man to receive appointment to such an important position in aeronautical research.

Obituary

Albert Cavallo Jewett, who joined the Institute in 1906 and the following year was elected to Life Membership, died on February 3d, 1926, at Papeete, on the Island of Tahiti. Mr. Jewett was born in Henderson County, Kentucky, December 20th, 1869, and for four years after he was of eligible age, studied under a private tutor. His technical education was acquired while he was in the employ of the General Electric Company. From 1890 to 1892 he was with the Thomson Houston Electric Company, Colorado and California, after which he spent a year with the General Electric Company. In December of the year 1903 he went to Messrs. John Taylor & Sons, London, England and from then, the first of December 1905, entered the employ of H H. The Maharajah, Jammu and Kashmir, as electrical advisor to the Government of India. The installation of the original Redlands transmission line was done by Mr. Jewett in 1893, and this was followed by the installation of many other equally important systems in California districts up to the year 1900.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Detroit, Mich.
2.—H. R. Bailey, Electric Bldg., Portland, Ore.
3.—I. Bergenstrahle, 425 West 114th St., New York, N. Y.
4.—Hubert L. Clary, 782 West 24th St., Milwaukee, Wis.
5.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
6.—Ralph Elsman, 120 Broadway, New York, N. Y.
7.—Chas. A. Foust, 10505 93rd St., Woodhaven, N. Y.
8.—George Frasher, 1209 So. 4th Ave., Louisville, Ky.
9.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
10.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
11.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
12.—Charles L. Leaf, 175 Dodd St., East Orange, N. J.
13.—John E. Lewis, 376 Meyran Ave., Oakland Sta., Pittsburgh, Pa.
14.—Charles W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
15.—J. A. McDermott, Y. M. C. A., Lima, Ohio.
16.—Raymond W. Noddins, 230 East Ohio St., Chicago, Ill.
17.—G. C. Poulson, 500 Danforth St., Syracuse, N. Y.
18.—Robert H. Russell, 1128 Warren West, Detroit, Mich.
19.—Lieut. A. G. Scott, 68 West 107th St., Apt. 2D, New York, N. Y.
20.—Kermit G. Seaman, P. O. Box No. 68, Boulder, Colo.

21.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Nat'l Bank, Cincinnati, Ohio.
22.—C. D. Smith, 857 St. Charles St., New Orleans, La.
23.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
24.—Howard J. Tyzzer, 13 Upham St., Melrose, Mass.
25.—Leo A. VanEtsen, 1100 Park Ave., New York, N. Y.
26.—John D. Walker, 2686 Woodstock Ave., Swissvale, Pa.
27.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.
28.—I. H. Worley, 2124 E. St., Lincoln, Nebr.
29.—M. L. Younger, 1814 Diamond St., Philadelphia, Pa.

Extracts from Annual Report for 1925

The year has been one of steady operation, unmarked by unusual occurrences. The number of users of the Library was practically the same as in 1924, amounting to about 70% of the membership of the Founder Societies.

The budget adopted for 1925 called for the expenditure of $44,200 for the general maintenance of the Library. The actual expenses were $41,176.89. But while the cost has been kept within the budget, this should not be taken as an indication that more money should not be appropriated for Library work. To accomplish this result, it has been necessary to decline to undertake many activities that are desired by members and that would be permanent improvements.

There is, for example, a distinct need for more ample indexing of the output of current periodical literature. This has reached the point where few engineers can afford the time necessary to examine it; as a consequence they must rely upon bibliographies and abstracts to guide them. Here there is a wide field for developments that would be useful to every member.

There have also been opportunities during the year to purchase private libraries of unusual importance, which could not be accepted. Similar opportunities will undoubtedly again arise from time to time, and it is highly desirable that your Board be in a position to take advantage of them.

Your Board constantly regrets its inability to develop the work in these and other ways that are suggested from time to time. It realizes, however, that its first duty is to restrict the cost of its operations to the sums set apart for the purpose and so confines the work to what can be done with the funds available.

The equipment of the Library is generally in satisfactory condition.

During the year the lighting of the reading room was investigated and found below the best practise of the day. Methods for its improvement are now being studied.

The accessions during 1925 and the book stock on 31 December, 1925, are as follows:

	Vols.	Pamphlets	Maps	Searches	Total
On hand Jan. 1, 1925....	100,111	4,001	1,641	3,991	109,744
Added during 1925......	3,746	818	159	129	4,852
Total................	103,857	4,819	1,800	4,120	114,596
Withdrawn during 1925.	2,828	1,449	——	——	4,277
Net accessions, 31 Dec., 1925................	101,029	3,370	1,800	4,120	110,319

FINANCIAL STATEMENT
31 DECEMBER, 1925

Maintenance

REVENUE

Founder Societies..................	$32,000.00	
Associate Societies..................	1,200.00	
Endowment Income (net)............	4,883.33	
Book Loans........................	284.51	
Miscellaneous......................	175.00	
		$38,542.84

EXPENDITURES

Salaries: Maintenance...............	$31,625.20	
Books............................	1,367.71	
Book Loans........................	265.86	
Periodicals........................	2,844.88	
Binding...........................	2,554.85	
Supplies and Miscellaneous..........	1,355.57	
Equipment.........................	190.57	
Insurance.........................	972.25	41,176.89
Operating Deficit Dec. 31, 1925....		2,634.05
Special Contributions..............		2,634.05
Operating Balance Dec. 31, 1925....		0.00

Service Bureau

REVENUE

Search Department..................	$7,776.37	
Photostat Department...............	6,839.12	
Miscellaneous......................	.50	
		$14,615.99

EXPENDITURES

Salaries, searchers..................	8,319.60	
Salaries, photographers..............	4,330.94	
Supplies, search.....................	688.46	
Supplies, photographic...............	1,808.85	15,147.85
Operating Deficit..................		$ 531.86
Credit Balance Dec. 31, 1924........	$1,398.12	
Less Accounts charged off and adjusted (net)....................	10.01	
		1,388.11
Credit Balance Dec. 31, 1925................		$ 856.25
Accounts Receivable Dec. 31, 1925...........		$ 830.67

Book Reviews

THE RELAY HANDBOOK.

Prepared by the Relay Subcommittee, Electrical Apparatus Committee, and Technical National Section of the National Electric Light Association in collaboration with the Relay Subcommittee and Protective Devices Committee of the American Institute of Electrical Engineers, a volume to be known as the Relay Handbook is now available through the offices of the National Electric Light Association, Engineering Societies Building, New York.

The first point of the book is given over to many valuable tables of carefully computed engineering data, followed by text descriptive of relays and their uses, tests and maintenance and concluded with information of calculations applying to the subject. There is also an extensive bibliography, arranged sectionally and in chronological order under the several important heads. The possibilities of protecting electrical systems from faults involving the energy within the system have made such marked progress within recent years has made the publishing of the present handbook a great asset to the profession. The increasing size and extensive interconnection of the systems is also safeguarded in this publication of theory as well as practise. It reduces a volume of data to usuable form, well proportioned with regard to scope, authority and comprehensiveness.

POPULAR RESEARCH NARRATIVES.

Volume II of "Popular Research Narratives" has been published through the Engineering Foundation, 29 West 39th Street, New York. From the preface "Mankind must progress or regress—let us go forward seeking the truth and using it for the betterment of all mankind" is best descriptive of the effort and purpose of the work, which is a collection of fifty brief stories of research, invention and discovery by such eminent scientists as Doctor

M. I. Pupin, H. C. Hayes, Major General George O. Squier, Chief Signal Corp of the U. S. Army, Doctor Arthur E. Kennelly, Member of the National Academy of Sciences; Chevalier Legion d'Honneur, William G. Houskeeper, Research Laboratories of the American Telephone and Telegraph Company, Sir Ernest Rutherford, President of the British Association for the Advancement of Science, Messrs. Arnold and Elmen of the Research Laboratories of the American Telephone and Telegraph Company and the Western Electric Co., Inc., and many others who have contributed greatly to the research and application of science. The book is a convenient size, 5 x 7, contains 160 pages and sells for $1.00.

THE FUNDAMENTAL CONCEPTS OF PHYSICS in the Light of Modern Discovery. Williams & Wilkins, Baltimore, Md.

This work, by Paul R. Heyl, Ph. D., Physicist, Bureau of Standards, Washington, contains three lectures: The Eighteenth Century: The Century of Materialism; The Nineteenth Century; The Century of Correlation; and The Twentieth Century; The Century of Hope. 112 pages. Size of Volume 5 x 7. Price $2.00.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (FEBRUARY 1-18, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ANNUAIRE POUR L'AN 1926.

France. Bureau des Longitudes. Paris, Gauthier-Villars, 1926. 665 + 337 pp., 6 x 4 in., paper. 8 fr.

The 1926 edition of this well-known reference book contains the usual collection of data on the calendar, the earth, astronomy, weights and measures and physical and chemical constants, and is a valuable compilation of information frequently wanted by physicist, chemists, astronomers, etc. In addition it contains a lengthy account of the International Research Council and the Astronomical Union, by B. Baillaud, and an article by G. Pervier, entitled the Geodesic Reasons of Terrestrial Isostasy.

DAS DEUTSCHE PATENTRECHT.

By F. Damme and R. Lutter. 3rd edition. Berlin, Otto Liebmann, 1925. 692 pp., 9 x 6 in., paper. 28.-mk.

A new edition of a standard text on German patent law and practise, prepared by a former and the present director of the Patent Office. The discussion is comprehensive and practical as well as thoroughly up to date.

DIESEL MASCHINEN. Sonderheft, V. D. I. Zeitschrift 1925. 97 pp., illus., diagrs., plates.

ENTGASEN UND VERGASEN. Sonderheft, V. D. I. Zeitschrift, Bd. 69. 116 pp., illus., tables.

TECHNISCHE MECHANIK. Erganzungsheft, V. D. I. Zeitschrift, Bd. 69. 84 pp., illus., diagrs.

Berlin, V. D. I., Verlag, 1925-26. 3 vols., 12 x 8 in., paper. Prices not quoted.

These three publications contain collections of important articles on their various subjects, selected from recent issues of the Zeitschrift des Vereines deutscher Ingenieure and reprinted in this form for convenient use. The volume on Diesel engines contains articles on the Diesel locomotive from the viewpoint of locomotive construction, Diesel engines and gearing for large oil locomotives, high speed Diesel engines for vessels, compressorless Diesel engines, etc.

The volume entitled "Entgasen und Vergasen" considers various problems of fuel preparation and utilization. Among these are coal dressing, gas distribution, the improvement of coking coal at the mine, dry cooling of coke, the distillation of low-grade fuels, the Lurgi distillation process, the mechanical influence of fuel in gas generators, and new knowledge in firing practice.

Among the papers on technical mechanics are a criticism of thermal engines, heat transfer from oil to water and loss of pressure in cooling apparatus, heat transmission and loss of pressure in pipe coils, parallel flow and turbulence in circular pipes, resistance to flow in pipes, errors in the measurement of the temperature of flowing gases, fine measuring tools for tension in machine parts, the solution of statically indeterminate systems by means of the Nupubest instrument.

ECLAIRAGE ELECTRIQUE.

By P. Maurer. Paris, Gauthier-Villars et Cie., 1925. 143 pp., diagrs., 10 x 6 in., paper. 20 fr.

A text-book on electric lighting which is confined to a brief presentation of fundamental theory and of its application in practice. The author first discusses general principles and photometry. He then studies the different types of incandescent and arc lamps, after which he takes up the layout of lighting for various types of buildings. The final section is devoted to the installation of interior lighting systems.

ELECTRIC RAILWAY ENGINEERING.

By C. Francis Harding and Dressel D. Ewing. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 489 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

A textbook for students in technical schools who wish to specialize in electrical railway engineering, in which present theory and practice in the important branches of the subject are brought together in convenient form.

The new edition has been completely revised and enlarged. A new chapter on motor-bus transportation has been added. The chapter on "Power Station Location and Design" has been replaced by one entitled "Sources of Electrical Energy," which contains a recent, very complete contract for electrical energy.

ELEKTROMETALLURGIE.

By K. Arndt. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 124 pp., illus., 6 x 4 in., cloth. 1,50 mk.

A brief review of the subject written in easily understood language. After a short introductory account of electrochemical principles, the author describes the recovery of copper, the precious metals, zinc, lead, tin, iron, etc., from aqueous solutions. The production of aluminum, magnesium, sodium, etc., by the electrolysis of fused salts is then described. The final section discusses the electrothermal processes for producing iron and its alloys.

ELEMENTARY ELECTRICAL TECHNOLOGY FOR ENGINEERING STUDENTS.

By A. M. Parkinson. Lond., Oxford University Press, 1925. 179 pp., 8 x 5 in., cloth. $2.00. (Gift of Oxford University Press. American Branch).

Confined to the elementary technology of electric circuits and aimed to present the principles as simply as possible, this book is intended to furnish the fundamental theory required as a foundation for a three or four years' course in applied electricity.

ELEMENTS OF ALTERNATING CURRENTS AND ALTERNATING CURRENT APPARATUS.

By J. L. Beaver. N. Y., Longmans, Green & Co., 1926. 370 pp., illus., diagrs., 9 x 6 in., cloth. $4.00 (Gift of Author).

A textbook for beginners in the study of alternating currents. The first eight chapters give an elementary presentation of principles, while the remaining four study the commonest types of alternating-current apparatus. Questions and numerical problems are appended to each chapter. The book is planned for a course of sixty to ninety hours.

FESTSCHRIFT ANLASSLICH DES 100 JAHRIGEN BESTEHENS DER TECHNISCHEN HOCHSCHULE FRIDERICIANA ZU KARLSRUHE. Karlsruhe, C. F. Müller, 1925. 542 pp., illus., diagrs., tables, 10 x 7 in., ¾ cloth.

A handsome volume commemorating the centenary of the oldest technical college in Germany. It contains 38 papers by members of the faculty, dealing with various subjects—mathematical, economic, mechanical, electrical, chemical and physical. A history of the beginnings of technical education is included.

Among the papers of especial interest to engineers are: Simplification of arch calculations, Methods of colonizing, City planning and building as a province of engineering, The influence of repeated loads on the elasticity and strength of concrete and reinforced concreto, Band spring drives, Calculation of shearing stress produced by punching, Heat transmission to water in a tube, Experiments on the straightening of crooked rods, Safety and economy of electric power transmission.

GALVANIZING.

By Heinz Bablik. Lond., E. & F. N. Spon; N. Y., Spon & Chamberlain, 1926. 168 pp., illus., tables, 9 x 6 in., cloth. $5.00.

As the manager of a large Austrian galvanizing works, the author has carried out various scientific investigations on the subject, which are assembled in this book. His purpose is to explain, in the light of modern scientific conceptions, processes already known in outward form.

Opening with a discussion of rust and its prevention, succeeding chapters deal with the structure of galvanized coatings, pickling, fluxes, hot galvanizing, raw materials and waste products, electro-galvanizing, sherardizing, metal spraying, and the testing of products.

MODERN MAGNETICS.

By Felix Auerbach. N. Y., E. P. Dutton & Co., 1925. 306 pp., diagrs., 9 x 6 in., cloth. $6.00.

Professor Auerbach has attempted to give a picture of the present state of the theory of magnetism, complete enough for the needs of every one except the specialist within the limits of one small volume. He has succeeded admirably, having produced a book that will not only interest engineers and teachers, for whom it is primarily intended, but can also be read by any general reader in search of knowledge on the subject. The style is easy and fluent, mathematics is reduced to a minimum, and the text is illustrated by numerous figures. A valuable select bibliography is appended.

POPULAR RESEARCH NARRATIVES, vol. 2; collected by the Engineering Foundation. Baltimore, Md., Williams & Wilkins Co., 1926. 174 pp., ports., 8 x 5 in., cloth. $1.00. (Gift of the Engineering Foundation).

The wide general interest that the first volume of "Research Narratives" excited has led the Engineering Foundation to publish a second volume. Here are fifty brief stories of useful inventions and discoveries, showing how the scientist and engineer proceed in advancing the welfare of mankind. The accounts are written in non-technical language, with unusual brevity, by men of experience in the subjects treated.

PRACTICAL PHOTO-MICROGRAPHY.

By J. E. Barnard and Frank V Welch. 2d edition. N. Y., Longmans, Green & Co., Lond., Edward Arnold & Co., 1925. 316 pp., illus., 9 x 6 in., cloth. $6.00.

A straightforward detailed account of the methods used in photographing microscopic objects, written by experienced workers. The book discusses the microscope, the optical equipment, sources of illumination, cameras, color screws, plates and photographic processes.

PRACTICAL RADIO, INCLUDING THE TESTIHG OF RADIO RECEIVING SETS.

By James A. Moyer and John F. Wostrel. 2d edition. N. Y., McGraw-Hill Book Co., 1926. 271 pp., illus., diagrs., 8 x 5 in., cloth. $1.75.

Attempts to present the fundamentals of the subject so simply and clearly that the average reader may understand and apply them. It also gives working drawings and specifications for the construction of a number of good receiving sets of various types. The new edition has been revised and a number of new subjects treated.

RAILROAD CONSTRUCTION.

By Walter Loring Webb. 8th edition. N. Y., John Wiley & Sons, 1926. 849 pp., illus., diagrs., tables, 7 x 4 in., fabrikoid. $5.00.

In addition to the revision of several chapters to conform with recent practice and the addition of several minor topics that have become important, special attention has been given in this edition to the relations of locomotive power to grade. A more exact method of computation has been introduced in the chapter on locomotive power, which has been rewritten and also used in the chapter on grade to show the effect of undulatory grades on power.

SCIENCE IN THE MODERN WORLD.

By Alfred North Whitehead. N. Y., Macmillan Co., 1925. (Lowell lecturers, 1925). 296 pp., 9 x 6 in., cloth. $3.00.

This volume, by the Professor of Philosophy in Harvard University, is a study of some aspects of Western culture during the past three centuries, in so far as it has been influenced by the development of science. Dr. Whitehead gives a thoughtful analysis of the reactions of science in forming that background of instinctive ideas which control the activities of successive generations. He points out the primary concepts upon which science seated itself during the period under consideration; calls attention to the recent breakdown of the seventeenth century settlement of physical principles and criticizes the current philosophy of scientists.

SIGNAL WIRING.

By Terrel Croft. N. Y., McGraw-Hill Book Co., 1926. 349 pp., illus., diagrs., 8 x 6 in., cloth. $3.00.

As signal wiring is principally a matter of knowledge of circuits, this book is chiefly a collection of circuit diagrams. Over 460 circuits are illustrated, including those usually wanted for wiring bells and annunciators, burglar alarms, hospital and hotel signals, time-clock signals, autocall signals, telephones, fire alarms, police calls, power station signals, water-flow and pressure alarms, elevator, mine, railroad and miscellaneous signals. A chapter is devoted to methods of wiring.

SUPERPOWER, ITS GENESIS AND FUTURE.

By William Spencer Murray. N. Y., McGraw-Hill Book Co., 1925. 237 pp., diagrs., maps, 9 x 6 in., cloth. $3.00.

As the Engineering Chairman of the United States Government Superpower Survey, Mr. Murray is already widely known as an authority on the question of the interconnection of power plants. The present book considers the question from a broader viewpoint than the government report and is intended for a wider audience. Stress is placed upon the social and economic advantages to be gained by "superpower" production and distribution, although the engineering problems are by no means neglected. Throughout, the main purpose is to present the principal features of the problem clearly and logically and to point out the benefits to be expected from "superpower."

TECHNICAL EDUCATION; Its Development and Aims.

By C. T. Millis. N. Y., Longmans, Green & Co.; Lond., Edward Arnold & Co., 1925. 183 pp., 8 x 5 in., ½ cloth. $2.25.

An account of the several movements which have led up to the present position of technical education in Great Britain, with some discussion of the problems that have arisen during its development. Starting with the Mechanics Institutes of 1824, the author traces the history of the various agencies, considers the principles of technical instruction and draws some conclusions.

THEORIE GENERALE SUR LES COURANTS ALTERNATIFS; pt. 2, Les Alternateurs.

By M. E. Piernet. Paris, Gauthier-Villars et Cie., 1926. 145 pp., diagrs., 10 x 6 in., paper. 30 fr.

A complete study, limited to fundamental practical ideas, of the technique of alternating-current machines and circuits.

The book supplements the author's previous work on continuous-currents and is intended for class-room use.

DIE TRANSFORMATOREN.

By Milan Vidmar. 2d edition. Berlin, Julius Springer, 1925. 751 pp., illus., diagrs., 9 x 6 in., cloth. 36 -r.m.

This, the most comprehensive of modern works on the transformer, is distinguished by its thorough grasp of the scientific principles involved and by its illustration of the application of these principles in actual design. The book will be useful to designers especially. The new edition has been carefully revised and considerable new matter has been added.

LES VEHICULES AUTOMOBILES.

By A. Boyer-Guillon. Paris, J.-B. Baillière et fils, 1926. 378 pp., illus., diagrs., 9 x 6 in., paper. 55 fr.

As head of the testing laboratory of the Conservatoire National des Arts et Métiers, the author of this book has made numerous tests of automobiles. In this work he has acquired a thorough knowledge of the functioning of these vehicles and their organs and has had an opportunity to compare different devices. The results of his experience are presented in this engineering study of the automobile, which presents a number of new points of view.

WELLENTELEGRAPHIE UND WELLENTELEPHONIE.

By M. G. Weinholz. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 132 pp., illus., diagrs., plates, 9 x 6 in., boards. 3,40 gm.

Intended as a textbook for use in technical and trade schools, where a practical course in radio communication is offered. The treatment is clear and non-mathematical, paying especial attention to the fundamental theory.

Past Section and Branch Meetings

SECTION MEETINGS

Boston

Testing of High-Tension Cable, by F. M. Farmer, Electrical Testing Laboratories. February 19. Attendance 265.

Chicago

The Problem of the Electrical Engineer from the Standpoint of a Physicist, by Max Mason, University of Chicago. Dinner Dance. February 6. Attendance 240.

The Financing of Public Utilities, by M. J. Insull, Middle West Utilities Co. Joint meeting with Electrical Section of the Western Societies of Engineers. March 1. Attendance 215.

Cincinnati

Electric Power Development in the Cincinnati District, by Monroe, Sargent and Lundy. Illustrated with slides. February 11. Attendance 174.

Graphic Measurements in Industry, by D. J. Angus, Esterline-Angus Company. Illustrated with slides. March 11. Attendance 50.

Connecticut

The Value of Patents, by Karl Fenning, Assistant to Attorney General, Department of Justice. February 16. Attendance 18.

Denver

Electrical Transmission of Pictures over Wires , by M. B. Long, Bell Telephone Laboratories, Inc. February 12. Attendance 55.

Detroit-Ann Arbor

D-C. Motor Maintenance, by L. Bogardus. Packard Motor Car Co.,

A.C. Motor Maintenance, by O.R. Candler, Dodge Brothers, Inc., and

Railway-Motor Maintenance, by A. C. Colby, Department of Street Railways. A motion picture, entitled "The Story of the Spark Plug," was shown. January 19. Attendance 125.

Long Telephone Cables, Their Possibilities and Problems, by F. B. Jewett, American Telephone and Telegraph Co. A motion picture showing the inauguration of the Ford Air Transportation Service was shown. February 16. Attendance 110.

Indianapolis-Lafayette

The Use of Graphic Records in Industry, by D. J. Angus, Esterline Angus Co., March 5. Attendance 32.

Ithaca

Hydro-Electric Power Development, by J. A. Johnson, The Niagara Falls Power Co. Illustrated with slides. January 15. Attendance 60.

Steam-Electric Power Development, by F. R. Ford, Philadelphia Electric Co. Illustrated with slides. February 19. Attendance 75.

Kansas City

The Manufacture of Rubber-Covered Wire, by R. J. Wiseman, Okonite Callender Cable Co. Illustrated with slides and moving pictures;

Maintenance of Electrical Equipment in Large Generating Stations, by C. B. Kelley, Kansas City Power and Light Co. February 8. Attendance 39.

Los Angeles

Forecasting Growth of Population an Aid to System Planning, by N B. Hinson, Southern California Edison Co.,

Application of Protective Equipment to Electric Transmission Systems, by E. R. Stauffacher, Southern California Edison Co., and

Steam Generation of Power and the Mercury Vapor Turbine, by F. G. Philo, Southern California Edison Co., March 2. Attendance 187.

Lynn

Social Meeting. March 1. Attendance 400.

Mexico

Technical Publications in the United States, by Mr. Cota. March 4. Attendance 18.

Milwaukee

The Work of the State Highway Department, by J. T. Donaghey, State Highway Engineer. January 20. Attendance 50.

The Vacuum Tube, by R. W. King, Editor of the Bell System Technical *Journal*. February 17. Attendance 500.

Minnesota

Dinner Dance. February 16. Attendance 60.

The Telephone System in Minneapolis, by the Commercial Department of the Northwestern Bell Telephone Co. A motion picture, entitled "The Audion," was shown. March 1. Attendance 100.

Niagara Frontier

Checking the Tuning Fork by Radio, by F. K. Dalton, Consulting Engineer. Illustrated with slides; and

The High-Voltage Air-Insulated Current Transformer, by L. C. Nicholson, Niagara Lockport and Ontario Power Co. Illustrated with slides. Mr. Dalton also gave an account of the destruction of a farm house due to lightning striking a radio aerial. February 19. Attendance 43.

Panama

Automatic Telephones, by J. K. Barrington, Automatic Electric Co. A short talk was also given by W. G. Ferris, Electric Bond and Share Co. February 10. Attendance 26.

Philadelphia

Supplying Electric Power to Downtown Philadelphia, by H. S. Davis and C. L. Gilkeson, Philadelphia Electric Co. Illustrated with slides. February 8. Attendance 180.

Pittsburgh

Voltage-Control Equipment for Interconnecting Power Systems, by J. S. Lennox, General Electric Co. Illustrated with slides. February 16. Attendance 160.

Pittsfield

Volcanoes and Earthquakes, by B. R. Baumgardt. Illustrated with slides. February 16. Attendance 700.

Lighting, by F. W. Peek, Jr., General Electric Co. Illustrated with slides and moving pictures. February 23. Attendance 75.

Ice by Wire—Electric Refrigeration, by W. P. White, General Electric Co. March 2. Attendance 175.

Portland

Social Meeting. February 10. Attendance 210.

Providence

Remote Supervisory Control, by R. J. Wensley, Westinghouse Elec. & Mfg. Co. Illustrated with slides. February 12. Attendance 20.

The Fynn-Weichsel Unity-Power-Factor Motor, by E. W. Goldschmidt, Wagner Electric Corp. March 9. Attendance 40.

Saskatchewan

Rural Electrification in Western Canada, by C. A. Clendening, Power Commission, Province of Manitoba. January 29. Attendance 42.

Turbine Development, by W. W. Johnson, General Electric Co., and

Measuring Output of A-C. Generators, by E. G. Fiske, General Electric Co. February 24. Attendance 40.

Schenectady

Aviation, by Major J. F. Curry, Illustrated with slides. January 22. Attendance 350.

Some Aspects of Corporate Industry's Relation to Society, by C. E. Eveleth, General Electric Co. February 12. Attendance 400.

Rambles in Asia, by B. A. Tozzer, Niles Bement Pond Co. Illustrated with slides. February 26. Attendance 300.

Seattle

Development in Illuminating Streets and Public Thoroughfares, by W. A. Turner, Department of Public Works, and

Transformer Design, by J. G. Corrin, Pittsburgh Transformer Co. Illustrated with slides. February 17. Attendance 52.

Sharon

The Klydonograph, by J. F. Peters, Westinghouse Elec. & Mfg. Co. A Smoker followed the meeting. March 2. Attendance 86.

Spokane

Automatic Substations, by C. E. Carey, Westinghouse Elec. & Mfg. Co. February 19. Attendance 40.

Springfield

The Quest of the Unknown by H. B Smith, Worcester Polytechnic Institute. Ladies Night. February 26. Attendance 100.

Toledo

Late Developments on A-C. Elevators, by E. B. Thurston, Haughton Elevator and Machine Co.;

My Experiences in the Early Days of the Electrical Industry, by Mr. Jeanin, Jeanin Motor Co.; and

Radio Sets, by E. B. Featherstone, Scott and Libbey High Schools. A talk was also given by Gilbert Southern on the functions of the Electric League, now being organized in Toledo to stimulate better wiring of residences. February 26. Attendance 34.

Toronto

International High-Tension Conference, Paris, 1925, by A. E. Davison, Hydro Electric Power Commission of Ontario, February 19. Attendance 65.

Metal Clad-Switchgear, by C. A. Stephens, A. Reyrolle and Company. March 5. Attendance 60.

Utah

The Structure of Atoms, by Dr. Oran Tugman, University of Utah. January 27. Attendance 45.

The Transmission of Photographs over Telephone Wires, by M. B. Long, Bell Telephone Laboratories. February 10. Attendance 70.

Vancouver

Motion Picture, entitled "From Mine to Consumer," was shown. Joint meeting with Engineering Institute of Canada. March 2. Attendance 120.

Washington

Interesting Things about Radio Transmission, by G. C. Southworth, American Telephone & Telegraph Co. Joint meeting with the Washington Academy of Sciences. March 9. Attendance 159.

Worcester

The Quest of the Unknown, by H. B. Smith, Worcester Polytechnic Institute. After the meeting an inspection of the 1,000,000-volt transformer in the laboratory of the Worcester Polytechnic Institute was made. February 23. Attendance 75.

BRANCH MEETINGS

Alabama Polytechnic Institute

Business Meeting. February 3. Attendance 24.

Epoch-Making Engineering Achievement, by Mr. Crawford, student; *The Hudson River, The Tennessee Valley and The Dead Sea Projects*, by Mr. Moore, student; and *Advantages of Electricity on the Farm*, by Mr. Phillips, student. February 18. Attendance 24.

Kv-A. Meters, by Ira Knox, student. February 24. Attendance 16.

Business Meeting. March 3. Attendance 23.

Opportunities of the Engineer Outside of the Big Corporations, by Professor Hill. A motion picture, entitled "Letting Dynamite Do It," was also shown. March 10. Attendance 24.

University of Arizona

The Development of Electrical Production, by Professor Paul Cloke. February 6. Attendance 21.

Motion picture, entitled "The Westinghouse Institution," was shown. February 13. Attendance 19.

Improvement in Laundry Operation, by E. Brooks; *The Mercury Type Wattour Meter*, by W. R. Brownlee; and *The Westinghouse Student Course*, by W. Butler. February 20. Attendance 20.

Proceedings of Society for Advancement of Science, by Professor Paul Cloke; *The New Gas-Electric Truck*, by J. A. Denzer; and *Photographing the Interior of a Rifle Barrel*, by J. W. Cruse. February 27. A motion picture, entitled "A Telephone Call," was also shown. February 27.

University of Arkansas

Motion Pictures, entitled "The Audion" and "Speeding Up on Deep Sea Cables," were shown. February 16. Attendance 32.

Henry Ford's Life and the Ford Industry, by C. W. Collier; and *Need of Increased Efficiency in Use of Coal*, by Gilbert Cecil. March 2. Attendance 19.

Brooklyn Polytechnic Institute

The Operation of the Dial System, by E. H. Goldsmith, New York Telephone Co. February 17. Attendance 42.

University of California

Social Meeting. February 18. Attendance 90.

Carnegie Institute of Technology

The Outlook of the Electrical Industry, by W. E. Caven, student; and *Radio Reception*, by J. R. Balsley, Westinghouse Electric & Mfg. Co. January 20. Attendance 55.

Smoker. February 12. Attendance 100.

Side-Bands in Transatlantic Radio Telephony, by R. F. Riegelmeier, student; and *Conditions Which a Graduate Engineer Must Face after Graduation*, by Fred Coggswell, Pittsburgh Railways Company. March 3. Attendance 23.

Catholic University of America

Motion pictures, entitled "History of the Telephone" and "The Making of a Telephone Desk Set," were shown. February 16. Attendance 20.

University of Colorado

Recent Developments in the Art of Communication, by M. B. Long, Bell Telephone Laboratories. February 15. Attendance 150.

The Possibilities of the Engineering Graduate in Industry, by R. F. Carey, Westinghouse Electric & Mfg. Co. February 16. Attendance 60.

Motion Pictures, showing the plants of the Westinghouse Electric & Mfg. Co., were shown. February 17. Attendance 70.

The Oscillograph, by L. E. Swedlund; *Automatic Substations*, by O. V. Miller; and *High-Voltage Insulators*, by P. M. Brown. March 3. Attendance 110.

University of Denver

High-Temperature Insulation, by Bruce MacCannon. Illustrated with slides. February 3. Attendance 11.

Motion picture, entitled "Temperature and Motor Endurance,' was shown. March 2. Attendance 43.

Drexel Institute

Automatic Motor Control, by F. R. Fishback, Electric Controller and Mfg. Co. February 19. Attendance 50.

University of Florida

The Electrification of Railroads in Chile, by L. S. Boggs, Westinghouse International Co. February 22. Attendance 20.

The Utilization of the Peat Bog of Florida, by Robert Ranson. March 8. Attendance 22.

Georgia School of Technology

A motion picture, entitled "Okonite," was shown. March 2. Attendance 35.

Iowa State College

The Bell System from the Standpoint of an Engineering Student, by L. S. Lambert, Northwestern Bell Telephone Co. March 3. Attendance 95.

Power Station Operation, by J. M. Drabelle, Iowa Railway and Light Co. March 10. Attendance 73.

State University of Iowa

Opportunities at the Bell Telephone Co., by C. W. Davis; and *Listen to Your Speaker*, by J. R. Eyre. February 17. Attendance 43.

Mercury-Vapor Steam Cycle, by W. E. Evitts. February 24. Attendance 38.

Lightning, by K. C. DeWalt; *The Oil-Electric Locomotive*, by S. L. Eppel; and *Engineering-Report Writing*, by E. P. Farrel. March 3. Attendance 42.

Lafayette College

Modern Telephony, by C. L. Craven and P. O. Farnham, students. Illustrated with slides and motion pictures. February 24. Attendance 21.

Lewis Institute

Business Meeting. March 4. Attendance 15.

Marquette University

Railway Signalling, by H. F. Dennett and U. G. Carneiro, students. January 14. Attendance 28.

The Design of Induction Motors, and Their Application, by Frazier Heffrey, Allis-Chalmers Mfg. Co. Illustrated with slides. February 4. Attendance 26.

Massachusetts Institute of Technology

Inspection trip to Edgar Station, at Weymouth, of the Edison Electric and Illuminating Company. March 1. Attendance 31.

University of Michigan

A motion picture, entitled "The Rochester Gas, Electric Light and Power Company," was shown. February 26. Attendance 50.

School of Engineering of Milwaukee

America in the Balances, by James Quarles. A motion picture, entitled "Beyond the Microscope," was also shown. February 23. Attendance 32.

A motion picture, entitled "Wizardry of Wireless," was shown. March 9. Attendance 35.

Missouri School of Mines and Metallurgy

Motion pictures, entitled "Transportation" and "Waterpower," were shown. March 10. Attendance 42.

Montana State College

Carrier Telephony on High-Voltage Power Lines, by W. V. Wolfe, Bell Telephone Laboratories, Inc. February 15. Attendance 161.

Electric Power and Light Utility, by Thomas Heal. February 22. Attendance 154.

University of Nevada

My Experiences in Mexico, by Mr. Johnston. A motion picture, showing college life at the University of Nevada in the year 1914, was shown. February 24. Attendance 40.

College of the City of New York

Business Meeting. The following officers were elected: Chairman, James Wilson; Vice-Chairman, Frank Kulman; Secretary, Joseph Leipziger; Treasurer, E. F. Day; Publicity Manager, Jacob Herson. February 11. Attendance 23.

The Manufacture of Weston Instruments, by Mr. Corby, Weston Electrical Instrument Corp. Illustrated with slides. March 4. Attendance 36.

University of North Carolina

Business and Social Meeting. The following officers were elected: President, M. L. Murchison; Vice-President, G. M. Wilson; Secretary, D. M. Holshouser; Treasurer, F. A. Urbston. February 11. Attendance 34.

University of North Dakota

Life and Work of Oliver Heaviside, by Norman Bue, student. March 8. Attendance 19.

Northeastern University

Some Problems of a Public Utility Company, by L. L. Elden, Edison Electric Illuminating Co. February 15. Attendance 215.

Resistance and Impedance Amplification, by Professor R. G. Porter. February 26. Attendance 42.

Ohio State University

Mr. Allen Smith, Columbus Railway Power and Light Co., gave a talk on his experiences since his graduation in 1923. February 12. Attendance 80.

Oklahoma Agricultural and Mechanical College

A motion picture, entitled "Queen of the Waves," was shown. January 27. Attendance 87.

Pennsylvania State College

Salary Statistics of Alumni, by W. B. Watkeys; *A Study of Engineering Graduates*, by E. R. Queer; and *Adverse Comments on Engineering Prospects*, by John Doe. February 24. Attendance 35.

Purdue University

Distribution Transformers, Their Design, Development and Selection, by E. A. Wagner, General Electric Co. Illustrated with slides. February 25. Attendance 425.

Synchronous Apparatus, by W. T. Berkshire, General Electric Co. Illustrated with slides. March 9. Attendance 50.

Rensselaer Polytechnic Institute

Industrial Control Problems, by H. L. Perdiue, General Electric Co. Illustrated with slides. February 23. Attendance 150.

Rhode Island State College

Flux Linkage vs. Flux Cutting, by Mr. Laycock and Mr. Harvey. January 22. Attendance 16.

Business Meeting. February 5. Attendance 17.

Rose Polytechnic Institute

Motor Applications, by H. W. Rogers, General Electric Co. Illustrated with slides. March 4. Attendance 52.

Rutgers University

Radio Control of Transformers, by Arthur Pahne, General Electric Co. February 8. Attendance 25.

University of South Dakota

Outstanding Developments in the Electrical Industries, by Stverak; and

Developments in High-Voltage Power Transmission, by Mr. Brackett. January 12. Attendance 10.

Developments in Switchboard and Portable Instruments, by Mr. Doohen. Illustrated with slides and motion pictures. February 12. Attendance 71.

University of Southern California

Business Meeting. January 14. Attendance 25.

Business Meeting. The following officers were elected: Chairman, J. H. Shideler; Vice-Chairman, B. L. Iris; Secretary, E. E. Smith; Treasurer, Willard Bausman. January 21. Attendance 27.

Syracuse University

Theoretical Aspects of Conduction in Vacuo and in Gases, by Leroy Mickey. February 15. Attendance 19.

Practical Aspects of Conduction in Vacuo and in Gases, by E. J. Stanmyre. February 22. Attendance 19.

Texas Agricultural and Mechanical College

Induction, by C. M. Thorne, student, February 19. Attendance 65.

University of Texas

Business Meeting. February 11. Attendance 16.

The Midwinter Convention of the A. I. E. E., by Professor J. M. Bryant. February 25. Attendance 20.

Virginia Polytechnic Institute

The Electron Theory, by F. L. Robeson. March 3. Attendance 41.

State College of Washington

Business Meeting. The following officers were elected: President, E. L. Clark; Vice-President, Stanley Bobel; Secretary, Harry Meahl; Treasurer, Mr. Beattie. January 28. Attendance 18.

Washington University

The New KMOX Broadcasting Station, by Mr. McNammie, Kennedy Radio Co. February 4. Attendance 26.

University of Washington

Obstacles Encountered by the Engineer in the Business World, by Glen Smith. February 3. Attendance 25.

The Telephone System, by F. D. Carroll, Pacific Bell Telephone Co. March 4. Attendance 13.

West Virginia University

Inside-Frosted Lamps, by W. F. Davis; *Porcelain Insulators*, by E. H. Braid; *An Epoch-Making Engineering Achievement*, by H. S. Muller; *Electrical Research as Applied to the Phonograph*, by J. W. Schramm; *Hydro-Electric Project in the Tennessee Valley*, by W. A. Williams; *Electric Elevators in Practise*, by K. D. Stewart; *Advantages of Highway Lighting*, by L. S. Davis; *Electric Elevators*, by P. S. Shobe; *A-C. Effects on Telephones*, by G. E. Meintel; *Measuring Sag*, by D. E. Akins; *Dangers Due to Over-Motoring*, by J. Cricchi; *World War Radio*, by A. M. Kalo; *Over-Motoring*, by W. L. Nuhfer; and *Electric-Elevator Practise*, by I. L. Smith. February 19. Attendance 30.

Electric Railways, by R. W. Beardslee; *Engineers at Camp Custer*, by J. U. Neill; *Electrification of N. & W. Railroad*, by E. A. Berry; *Concrete Lighting Poles*, by C. M. Borror; *Recent Oscillograph Developments*, by G. H. Cornell; *Resistance of Electrical Connections*, by G. R. Latham; *Under-Sea Telephones*, by H. S. McGowan; *New Brush-holder*, by A. L. Schneichal; *Tennessee Power Project*, by C. B. Binns; *Two-Winding Motors*, by *W. W. Reed*; *Photo-Electric Cell*, by J. L. Kessinger; *Radiodynamics*, by B. R. Shafer; *Standardization of Electron Tubes*, by W. E. Vellines; and *Electrification of N. Y., N. H., and Hartford Railroad* by R. L. Cole. February 26. Attendance 35.

Electric Transmission for Internal-Combustion Engines, by W. F. Davis; *Mica Insulation*, by E. H. Braid; *Use of Resin in Paper Making*, by H. S. Muller; *Electric Furnaces*, by J. W. Schramm; *How Edison Won the War*, by K. D. Stewart; *Electric Furnace Applications*, by D. E. Akins; *Electrolyzing Glass*, by E. R. Long; *Automatic Office-Building Sub-Stations*, by A. M. Kalo; and *Soldering Aluminum*, by W. L. Nuhfer. March 5. Attendance 28.

Micarta Products, by C. M. Barror; *High-Frequency Currents*, by G. H. Cornell; *Unattended Lighthouses*, by G. R. Latham; *Induction Brass Furnace*, by H. S. McGowan; *Renewing Bearings for Railway Motors*, by A. L. Schmeichel; *Cables on Bear Mountain Bridge*, by C. B. Binns; *High-Torque Synchronous Motors*, by W. W. Reed; *Experiences on the Road*, by L. S. Davis; and *Telephoning Beneath the Sea*, by B. R. Shafer. March 12. Attendance 24.

University of Wisconsin

Electrochemistry—a Factor in Electrical Engineering, by Professor L. Kahlenberg. February 23. Attendance 27.

University of Wyoming

Accident Prevention, by Corlis Van Horne. February 25. Attendance 11.

Yale University

Opportunities in Radio for the Electrical Engineer, by O. E. Dunlap, Radio Editor, *New York Times*. March 9. Attendance 39.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DESIGNER, technical graduate, who has had at least two or three years' experience, in design in all kind of transformers of less than 5 K. W. Location, Massachusetts. R-8682.

ELECTRICAL ENGINEER, young, technical graduate, with 2-2½ years' experience, preferably with cable company. Work will be testing and research on cables. Apply by letter. Salary up to $48 a week. Location, New York. R-8851.

SALES ENGINEER, electrical, not over 42, to take charge of syndicate sales. Salary $7500 a year. Apply only by letter. Headquarters, New York City. R-9040.

SALES ENGINEER, to sell heavy machinery to public utilities. Must know public utility trade. Apply only by letter. Salary $6000 a year. Headquarters, New York City. R-9042.

ELECTRICAL SWITCH DESIGNER, for automatic control of direct and alternating current motors. Opportunity. Apply by letter stating technical training, experience, age and required salary. Location, New York City. R-9039.

DRAFTSMEN, under 40, with technical education and several years' experience. Resident of West Philadelphia preferred. Permanent. Opportunity. Apply by letter. Location, Pennsylvania. R-8605.

GRADUATE ELECTRICAL ENGINEER, as technical assistant to engineer in charge of meter work in public utility. Opportunity. Apply by letter with complete details of age, education, training, experience and salary desired with recent photograph. Location, New York City. R-9229.

MEN AVAILABLE

ELECTRICAL ENGINEER, seven years' experience in distribution engineering with two large power companies, desires position with a moderate sized public utility company or industrial concern in the Middlewest. C-964.

SALES ENGINEER, age 26, married, graduate M. I. T., one year construction, three years apparatus design, desires position with a growing concern where a thorough technical knowledge combined with design ability will assist in increasing sales, servicing products, and opening new fields. Employed. Available in one month. Location Anywhere. Minimum $3000. C-307.

CORNELL GRADUATE, E. E. '20, age 27, fourteen months Westinghouse shop and student course, twenty-two months substation operation, nine months test, and twenty-two months general engineering with large public utilities. At present employed. Desires permanent connection with opportunity for advancement. B-4484.

ELECTRICAL ENGINEER, age 32, single, technical graduate, one and one-half years G. E. test, and four years' marine experience. At present chief engineer on Coast Guard destroyer. Desires permanent employment in electrical engineering field with good opportunity for advancement. Available on reasonable notice. Location immaterial. C-396.

ELECTRICAL ENGINEER, age 28, married, eighteen months G. E. Company, six years design, construction and maintenance with electric utilities. Now employed on automatic substation design. Desires permanent connection with utility in Middlewest. Available on thirty days' notice. C-326-308.

SUPERINTENDENT OF ELECTRIC CONSTRUCTION, age 34, married, thoroughly competent to take complete charge of large installations. Six years' actual experience on commercial buildings, city schools, power house and signal stations. Would also consider plant maintenance. Master license. Available immediately. Location, N. Y. B-9638.

PRACTICAL MANUFACTURER AND ENGINEER, married, age 38. Has controlled manufacture and distribution of $250,000,000 of products in eight plants, all of which he reorganized, improved, financed, and managed with resultant increased earnings. He is among the nationally known younger executives. Available within reasonable time. If you desire increased production, distribution, and earnings, write C-699.

ELECTRICAL ENGINEER, age 29, married, graduate Ohio State University in electrical engineering, one and one-half years work in Commerce College, majored in economics and accounting. Experience; two years electrical contracting, and two years sales and production analysis in manufacturing corporation. Available within three weeks' notice. Prefers Ohio or vicinity. B-9865.

ELECTRICAL ENGINEER, age 27, single, speaks, reads and writes fluently English, Spanish and German. Five years' experience in technical, sales and instruction work. Prefers public utility company, or large mining, or metallurgical concern. Location, Mexico or Latin America, preferably Mexico. Salary desired $3000 U. S. currency. C-1027.

RADIO ENGINEER of Spielman Electric Corporation, age 22, single. In radio manufacturing business for himself from 1923-26. Executive ability, and production manager, and designer of sets. Available on two weeks' notice. Location, New York City. C-1020.

ELECTRICAL ENGINEER OR SUPERINTENDENT, age 34, married, eleven years' experience power plant construction, operation and maintenance of same on steam and hydro, including electric railway, substations, power distribution, transmission. Broad experience on industrial electrifications. Can make estimates and layout work. Desires connection with power or engineering company. C-761.

ADVERTISER having twenty years design and construction of power plants, etc., will proceed Pacific Coast permanently this Fall, and desires connection as sales engineer, representative or similar for engineering equipment, electrical or mechanical. Four years with manufacturer's agent abroad handling wide variety engineering apparatus, part of time manager branch office. 41, married, now in New York. B-7371.

PLANT ENGINEER OR MASTER MECHANIC, 39, experienced United States and British steam, gas, hydraulic, electric power plant construction and operation, also industrial and building maintenance. Now employed Middle Northwest, desires good industrial connection. $4000 minimum. Specialty, revamping, harmonizing and maintaining plants up to 5000 K. W. C-987.

ELECTRICAL ENGINEER, 32, college graduate, desires position on general electrical construction, or outdoor substation design. Has had four years of construction, repair and operating experience, three years of drafting and design experience on outdoor substations. Available on two weeks' notice. C-991.

ELECTRICAL ENGINEER, age 31, married, experienced in design, layout, and supervision of construction on indoor and outdoor substations and industrial installations. Location, South America, or Southwest United States. Available fifteen days' notice to present employer. C-1002.

ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING in strong state university, desires position with progressive, growing educational institution. 34, health excellent, married, eleven years' teaching experience covering all basic and many specialized electrical engineering courses, both theory and laboratory. Experience construction, maintenance with small public utility. Opportunity to do graduate work desirable, but not essential. Available in September. C-1040.

GRADUATE ENGINEER, desires position as chief engineer with concern manufacturing small electrical apparatus, such as motor driven appliances, and also heating devices. Has had experience in design and development, as well as in manufacturing. Age 39. Now employed. A-4660.

MANUFACTURERS' REPRESENTATIVE located in Sydney, N. S. W., Australia, desires additional agencies for American products of electrical and mechanical nature. Technical training, experience, knowledge of conditions. C-798.

ELECTRICAL ENGINEER, graduate Polytechnic Institute of Turin (Italy), 25, single, two years' experience in central station and substation work with the Brooklyn Edison Company. Thorough knowledge relay and protection problems. Desires position with public utility of manufacturing company. Location, vicinity New York. Available on one week's notice. B-8751.

ELECTRICAL ENGINEER, age 44, technical graduate, desires an executive position with public utility, or managment company located in New York City. Last eight years supervised electrical design construction and operation of large mining company in South America. Successful in handling men and interested in personnel work. Available at once. C-1074.

MEMBER A. I. E. E. having connections with important electrical and mechanical concerns abroad for representation in United States, wishes to connect with New York concern to utilize his ability and business relations. B-8609.

INSTRUCTOR ELECTRICAL ENGINEERING, desires for coming (1926-27) collegiate year a change, with promotion to assistant or associate professorship in Eastern or Midwestern university. Man with initiative; ability as teacher. At present teaching the more advanced subjects. Has outgrown present position which can offer no promotion. M. S., B. S. degrees, age 30, married. Eight years' professional and teaching experience. B-3376.

ELECTRICAL ENGINEER, age 27, energetic, inventive and tactful. Past experience, electrical testing and charge of electrical testing apparatus and research. Good references. Desires position developing and research of electrical apparatus or machinery. At present employed, but available on two weeks' notice. Greater New York preferred. B-7270.

INDUSTRIAL ENGINEER, technical, mechanical, electrical engineer, with ten years' practical experience in factory operation, organization and management, wishes change in location. Present position, production manager of factory of twelve hundred employees, branch of one of world's largest corporations. Responsible and in charge of everything except accounting which comes under business manager. C-1070.

ELECTRICAL ENGINEER, age 28, single, wishes position as executive, or assistant electrical engineer. Good character, pleasing personality. German, English, French. Familiar theory and practice electrical and scientific measurements, electrical instruments, meters, relays. Transmission, distribution, protection, dielectric circuits. Three years research laboratory, two years designing. Location, preferably New York. Minimum salary $3500. Available on month's notice. C-930.

ELECTRICAL ENGINEER, age 24, technical graduate, thirteen months G. E. test, year and one-half on electric division of railroad. New York City. Shop experience, testing, inspection, maintenance, cars, locomotives, supervision of car construction, drafting, design. Desires position with power company, industrial, or engineering concern in New York or New England. C-1048.

GRADUATE ELECTRICAL ENGINEER, age 30, with commercial sense, excellent technical training, practical and commercial experience. Familiar with best up to date practice in industrial and central station electrical practice. Available immediately for industrial, or central station engineering management position. Location, North Central States. C-1071.

ELECTRICAL ENGINEERING GRADUATE, with special ability in writing, and the preparation of technical literature, desires position with a manufacturer or distributor of radio equipment, in sales or publicity work. Radio experience before attending college. Available upon graduation in June. Married, 24. Prefers Pacific Coast. C-1067.

CORNELL GRADUATE, with twenty years' experience in design, construction, operation and management of hydro and steam power systems. Now employed, desires change, preferably in New York, San Francisco, or foreign position. Four years in Latin America. Capable of managing entire property, including finances. 39, married. A-3494.

E. E. AND M. E. Graduate, married, six months telephone switchboard installer for Western Electric, one year G. E. test course, one year with a large public utility in the switchboard and substation engineering department, wishes position with future. C-1068.

HIGH GRADE EXECUTIVE AVAILABLE, sixteen years' experience in large and moderate sized electrical and mechanical manufacturing plants in East and Middlewest covering production, equipment, product design, sales and industrial engineering. Engineering education, age 37, married. Employed as departmental manager, but wishes to broaden opportunities. C-1050.

ENGINEER, with twenty years' hydro and steam power plant experience; last ten years in management, four years in Latin America. Cornell training. Now employed. Prefers New York, San Francisco, or foreign position. A-3494.

DEVELOPMENT OR PRODUCTION ENGINEER, age 37, married, graduate M. I. T. electrical engineering. Experience covers manufacture small electrical apparatus, trouble shooting on assemblies, specification writing, technical correspondence, laboratory work organizing manufacture of delicate A. C. measuring apparatus. Have canvassed for sales. Can be of service on development of electrical specialties, or on production working between development engineers and factory. Available at once. Location, New York City. C-1018.

ELECTRICAL ENGINEER, age 28, single, technical graduate, desires position with manufacturer electrical apparatus. Five years' experience with engineering department of large company manufacturing industrial control equipment. A little sales experience. Minimum salary $2500. Available on reasonable notice. B-6274.

ELECTRICAL ENGINEERING GRADUATE, age 30, now student at a prominent university, accurate with mathematical calculations, desires summer work with engineering firm in New York. Can do drafting, but prefers engineering calculations. Available about July 1st. to September 30th. B-7526.

ENGINEER, 27, married, Stanford graduate, 1920, mechanical engineering. One year managing engineer gas and fuel company, five years engineering department, desires business end of engineering position. Can make investment. Available at once. Location, California. C-1057-2-C-10.

PRACTICAL ELECTRICAL AND TELEPHONE SUPERINTENDENT, age 38, construction, reconstruction, operation or maintenance; nine years Latin America. Returning to States on account of schooling for children. References. C-1088.

WORKS MANAGER-EXECUTIVE ENGINEER, post graduate electrical engineer, age 43, twenty years engineering, shop management, sales; development engineer, Westinghouse, six years, manager five years manufacturing department large electrical company. Traveled abroad, negotiating important contracts. Now executive engineer, assisting sales reorganization old established concern. Consider only managing position. Would go abroad. Salary $7500. C-30.

TECHNICAL GRADUATE IN ELECTRICAL ENGINEERING, age 32, married, desires a position with a public utility having an underground cable system. Very familiar with cable failure locating devices, U. G. operating problems, electrolysis surveys. Absolutely reliable and hard worker. Willing to go anywhere. Available anytime with reasonable amount of notice to present employers. C-1093.

MECHANICAL-ELECTRICAL ENGINEER, age 30, mechanical engineering graduate 1916, two years of plant equipment supervision, three years of research and design in radio for Navy Department, three years as assistant to consulting engineer with general practice. Has spent eighteen years actively in radio field. Desires position giving sales training, no objection to traveling. Minimum salary $3000. Available after notice of one month. C-2003.

1925 GRADUATE ELECTRICAL ENGINEER, Georgia Tech, Age 24, sales and business experience, desires position with possibilities for advancement with public utility, or electrical contracting company. Location, preferably Florida or Georgia. C-2004.

ENGLISH CONSTRUCTION ENGINEER, age 38, with wide factory and power station experience, desires responsible position abroad. Accustomed to tropical climates and handling of native labor. C-1092.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MARCH 16, 1926

AAROE, ERLING, Designer, Electric Bond & Share Co., 71 Broadway, New York; res., Brooklyn, N. Y.

ALGER, CLERE SEWELL, Meter Tester, Puget Sound Power & Light Co., Seattle, Wash.

ALLSCHWAGER, ORA R., Statistical Clerk, Northern States Power Co., 15 S. 5th St., Minneapolis, Minn.

ANDERSON, DEXTER PERRY, Telephone Switchboard Equipment Engineer, Western Electric Co., Chicago, Ill.

*ANDERSON, WILLIAM BENTON, Design Engineer, Power Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

APPS, WALTER G., Student, School of Engg., Milwaukee, Wis.

BASURTO, RICARDO, Inspector, Control Electrotecnico de Mexico, Secretaria de Industria y Comercio, Capuchinas No. 30, Mexico D. F.; res., Tacuba, D. F., Mex.

BAUER, CONRAD ARTHUR, Electrical Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BAUERSCHMIDT, GERALD JOHN, Electrical Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BAUM, SYDNEY H., Technical Dept., Chas. Freshman Co., 240 W. 40th St., New York; res., Brooklyn, N. Y.

BENYO, GEORGE, Draftsman, New York Edison Co., Irving Place & 15th St., New York; res., Brooklyn, N. Y.

BERK, HENRY H., Meter Tester, Puget Sound Power & Light Co., 7th & Olive, Seattle, Wash.

*BEST, ALBERT O., Ignition & Repair Service Station, 21401 Sherman Way, Owensmouth, Calif.

*BIOSCA, LOUIS F., Radio Research Engineer, Federal Radio Corp., 1738 Elmwood Ave., Buffalo, N. Y.

BLACK, WILLIAM LINDSAY, Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Nutley, N. J.

BLANDING, WILLIAM P. T., Substation Operator, Bureau of Power & Light of Los Angeles, 207 S. Broadway, Los Angeles, Calif.

*BOBB, LEO CHARLES, Junior Engineer, Pennsylvania Power & Light Co., 135 S. 4th St., Sunbury, Pa.

BOYCE, EDWARD O., Engineer, Design Section, Trans. & Distribution Dept., Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.

BOYCE, WILLIAM HOWARD, Designing Engineer, Delta Star Electric Co., 2433 Fulton St., Chicago, Ill.

BOYER, QUINN ODELL, Draftsman, Inside Plant, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BRADFIELD, CHARLES WILLIAM, Chief U. G. Field Man, Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.

BRONSKI, CHESTER RUSSELL, Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

BROWN, GEORGE ROMAINE, Chief of Electrical Laboratory, Western Electric Co., Hawthorne Sta., Chicago, Ill.

*BRUGGER, KARL ANTHONY, Ass't. Construction Engineer, Public Utility Co., East Dubuque, Ill.

BUDDEN, ARTHUR NAPIER, Engineer, General Electric, S. A., Mexico D. F., Mexico.

BUELL, ROY C., Engineer, General Electric Co., Schenectady, N. Y.

BUNCE, LEWIS I., Supt., The Belamose Corp., Rocky Hill, Conn.

BUTTON, FRANK E., Hudson View Gardens, West 180th St. & Pinehurst Ave., New York, N. Y.

CADAVERO, ALFRED, Electrical Tester, New York Telephone Co., 547 Clinton Ave., Brooklyn; res., New York, N. Y.

*CARNEY, JOHN S., Laboratory & Instrument Man, Narragansett Electric Lighting Co., Providence, R. I.

CARR, ARTHUR V., Designer, Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.

CARRIGAN, WILLIAM WALTER, Line Foreman, City of Norwich Gas & Elec. Dept., 34 Shetucket St., Norwich, Conn.

CASKIN, JOHN M., Lineman, Danvers Elec. Lighting Dept., Danvers, Mass.

*CHARLTON, OAKLEE EDGAR, Research Assistant, Elec. Engg. Dept., Mass. Institute of Technology, Cambridge, Mass.

CHAWNER, WILLIAM RUPERT, Commercial Agent & Engineer, Southern Sierras Power Co., Riverside, Calif.

*CHURCHILL, HOMER, Engineering Assistant, Public Service Production Co., 80 Park Place, Newark, N. J.

CLARK, GEORGE DEWEY, Design Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

CLARK, JOSEPH, Engg. Assistant, Brooklyn Edison Co., Inc., Pearl & Willoughby Sts., Brooklyn, N. Y.

CLARK, SAM W., Consulting Engineer, 6a Aguascalientes No. 162, Mexico, D. F., Mex.

*COBB, PHILIP GARDNER, Metallurgist, Weston Electrical Instrument Corp., Weston Ave., Newark, N. J.

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BAXTER, NORMAN McLEOD, Engineer, The Ohio Public Service Co., Sandusky, Ohio.
CALL, CHARLES ARTHUR, Inspector, Ohio Insulator Co., Barberton, Ohio.
CRAMP, WILLIAM, Professor of Elec. Engg., University of Birmingham, Edgvaston, Birmingham, Eng.
HECHT, JULIUS L., Vice President, Public Service Co. of No. Ill., 72 W. Adams St., Chicago, Ill.
HORGAN, JAMES GALVIN, General Power Sales Engineer, Ohio Public Service Co., Cleveland, Ohio.
KNOST, JOHN HENRY, Jr., Engineer, Power & Industrial Dept., Westinghouse Elec. & Mfg. Co., 420 S. San Pedro St., Los Angeles, Calif.
KOPP, OTTMAR HUGO, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
ROUGHEN, RICHARD HARVEY, Supt., Sub-Sta. Dept., Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.
VICKERS, HERBERT, Professor of Elec. Engg., Head of Dept. of Mech. Engg., University of British Columbia, Vancouver, B. C., Can.

TRANSFERRED TO GRADE OF FELLOW MARCH 19, 1926

COATES, WILLIAM A., Metropolitan Vickers Electrical Export Co., Tokyo, Japan.
DIXON, AMOS F., Systems Development Engineer, Bell Telephone Laboratories, New York, N. Y.
McIVER, GEORGE W., Jr., Asst. Manager, Electrical Dept., Toledo Edison Co., Toledo, O.
THOMS, ALEXANDER P., Asst. Supt., Street Department, Commonwealth Edison Co., Chicago, Ill.
WILLIAMS, SAMUEL B., Telephone Engineer, Bell Telephone Laboratories, New York, N.Y.

TRANSFERRED TO GRADE OF MEMBER MARCH 19, 1926

ADKERSON, BRANCH O., Inside Plant Engineering, American Tel. & Tel. Co., New York, N. Y.
AMBUHL, FRANK F., Asst. Chief Engineer, Toronto Hydro-Electric System, Toronto, Ont., Can.
ARCEO, ANTONIO, Supt. of Distribution, Mexican Light & Power Co., Ltd., Mexico City, Mex.
BANNISTER, ALBERT, Chief Assistant, Switchgear Sales Dept., Metropolitan Vickers Electrical Co., Ltd., Manchester, Englnd.
BELL, JOHN H., Telegraph Engineer, Bell Telephone Laboratories, New York, N. Y.
BOSTATER, HERBERT L., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.
DAVIS, URIAH, Load Dispatcher, Commonwealth Edison Co., Chicago, Ill.
EASTHAM, MELVILLE, President and Engineer, General Radio Co., Cambridge, Mass.
ENGLE, MELVIN D., Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.
EVANS, ROBERT D., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
FRIEND, HENRY M., Cable Engineer, Hugh L. Cooper & Co., New York, N. Y.
GARY, LAURENCE A., Engineer, Transmission Dept., Pacific Tel. & Tel. Co., San Francisco, Calif.
HASTINGS, MILTON B., Vice-President, Powerlite Devices, Ltd., Toronto, Ont., Can.
INNES, FRANK R., Asst. Editor, "*Electrical World*," New York, N. Y.
KERSEY, GLEN B., Field Engineer, Commonwealth Edison Co., Chicago, Ill.
McDOWELL, H. E., Electrical and Mechanical Engineer, Texas Power & Light Co., Dallas, Tex.
NASH, JOHN F., Electrical Engineer and Division Manager, Appalachian Power Co., Bluefield, W. Va.
RADER, RAY, Assistant Engineer, Puget Sound Power & Light Co., Seattle, Wash.
ROBERTS, SPENCER, Engineer, Day & Zimmerman, Philadelphia, Pa.
SCOFIELD, EDWARD H., Engineer of Power, Twin City Rapid Transit Co., Minneapolis, Minn.
SMITH, GEORGE S., Instructor of Electrical Engineering, University of Washington, Seattle, Wash.
STEVENS, THEODORE, Consulting Engineer, London, England.
VANHALANGER, L. J., Sales Engineer, Westinghouse Electric & Mfg. Co., Chicago, Ill.

WAY, HOWARD E., Special Agent, Electrical Equipment Div., Bureau of Foreign and Domestic Commerce, Washington, D. C.

WREAKS, HUGH T., Manager, Detroit Office, Boston Insulated Wire & Cable Co., Detroit, Mich.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held March 8, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

DWIGHT, HERBERT BRISTOL, Professor, Massachusetts Institute of Technology, Cambridge, Mass.

HEINZE, CARL A., Electrical Engineer in charge of Distribution, Department of Water & Power, City of Los Angeles, Los Angeles, Calif.

OEHLER, ALFRED G., Editor—Railway Electrical Engineer, Electrical Editor—*Railway Age*, New York, N. Y.

To Grade of Member

ANDERSON, EDWARD T., Electrical Engineer, Board of Water & Electric Light Commissioners, Lansing, Mich.

BACKUS, CYRUS D., Principal Examiner, U. S. Patent Office, Washington, D. C.

BOHNERT, ARTHUR M., District Engineer, Ohio Brass Co., San Francisco, Calif.

BOLLINGER, HOWARD M., Supervisor of Plant Methods, Chesapeake & Potomac Telephone Co., Washington, D. C.

Brockway, R. M., Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

CARPE, ALLEN, Engineer, Dept. of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

CLAPP, ROBERT H., Telegraph Engineer, American Telephone & Telegraph Co., New York, N. Y.

COLBURN, WELLEN H., Electrical Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.

CRESSEY, JOHN A., Control Engineer, South Wales Power Co., Upper-Boat Power Station, Treforest, Pontypridd, Glamorgan, England.

FINCH, WILLIAM G. H., Radio Editor and Engineer, International News Service, New York, N. Y.

GIBSON, E. S., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

HEILBRUN, RICHARD Head of Firm, Dr. Richard Heilbrun, Manufacturer of Electric Appliances, Berlin, Germany.

JACKSON, DUGALD C., JR., Asst. Professor of Electrical Engineering, Trinity College, Durham, N. C.

RAMIREZ, JAVIER P., Consulting Engineer, Professor—Escuela de Ingenieros Mecanicos Electricistas, Mexico City, Mex.

RORTY, M. C., President International Telephone Securities Corp.—Vice-President, International Tel. & Tel. Corp., New York, N.Y.

SAATHOFF, GEORGE W., Chief Construction Engineer, Henry L. Doherty & Co., New York, N. Y.

SPORN, PHILIP, Assistant to Electrical Engineer, American Gas & Electric Co., New York, N. Y.

SPRACKLEN, EMERY E., Electrical Engineer in charge of Design, Ohio Public Service Co., Massillon, Ohio.

TAYLOR, NEWTON S., Manager, Switchboard Section, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WARFIELD, S. C., President & Engineer, M. O. & W. Engineering Corp., Morton, Va.

WHIPPLE, CLYDE C., Asst. Professor of Electrical Engineering, Polytechnic Institute, Brooklyn, N. Y.

APPLICATIONS FOR ELECTIONS

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1926.

Allen, T. D. N., U. S. Veterans' Bureau, Washington, D. C.
Allen, T. S., (Member), Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Andrews, S. W., Foundation Co., Pittston, Pa.
Ballew, R. E., Great Western Power Co., Oakland, Calif.
Banton, F. B., New Orleans Public Service Co., New Orleans, La.
Becker, F. A., Canadian General Co., Toronto, Ont., Can.
Beckett, W., (Member), Georgia Railway & Power Co., Atlanta, Ga.
Berting, G. A., The North Electric Mfg. Co., Galion, Ohio
Bettinger, L.W., U. S. S. Concord, c/o Postmaster, New York, N. Y.
Blenkarn, W. O., Salt Creek Electric Plant, Midwest, Wyoming
Beyrodt, K., Bond Service Repair Co., New York, N. Y.
Bodelsson, A. Pratt Institute, Brooklyn, N. Y.
Brown, H. H., Wisconsin Trac. Lt. Ht. & Pr. Co., Appleton, Wis.
Brown, R. E., Rhode Island State College, Kingston, R. I.
Burdin, A. J., Western Electric Co., Hawthorne Sta., Chicago, Ill.
Burkhardt, C. E., Municipal Power & Ice Plant, Sebastian, Fla.
Cady, W. M., Development Work, 108 Clinton Ave., Newark, N. J.
Carolan, W. A., 712 Putnam Ave., Brooklyn, N.Y.
Carpenter, H. W., Sangamo Electric Co., Boston, Mass.
Cates, R. V., American Tel. & Tel. Co., Charlotte, N. C.
Chant, A. E., Dept of Telephones, Regina, Sask., Can.
Clark, O. S., Union Gas & Electric Co., Cincinnati, Ohio
Clarke, P. C., General Electric Co., West Philadelphia, Pa.
Colvin, A. L., Lockport & Ontario Power Co., Angola, Ind.
Csepely, J. A., The Western Electric Co., Inc., New York, N. Y.
Crawford, W. K., Brooklyn Edison Co., Brooklyn, N. Y.
Davis, A. E. H., Frank J. Yorke Co., Detroit, Mich.
Davis, H. F., Monongahela West Penn. Public Service Co., Fairmont, West Va.
DeDona, A. J., Postal Telegraph Co., New York, N. Y.
de Zamacona, L., Mexican Light & Power Co., Mexico City, Mex.
Dreyfus, J., New York Tel. Co., Brooklyn, N. Y.
Duncanson, P., Western Electric Co., Kearny, N. J.
Dunstan, R. A., General Electric Co., Schenectady, N. Y.
Eighmy, G. W., General Electric Co., Buffalo, N.Y.
Ellis, C. R., Louis T. Klauder, Philadelphia, Pa.
Elword, A., (Member), C. M. & S. Co., Ltd., Trail, B. C., Can.
Engelken, R. C., Brooklyn Edison Co., Brooklyn, N. Y.
Engh, J. S., Automatic Electric, Inc., Chicago, Ill.
Farrell, J. J., Great Western Power Co., Caribou Plumas Co., Calif.
Fleshiem, R. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
(Applicant for re-election)
Flory, A. C., (Member), Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Foltz, J. P., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Forkel, W. H., Metropolitan Electr. Manufacturing Co., Long Island City, N. Y.
Foster, H. B., Wireless Specialty Apparatus Co., Boston, Mass.
Fowler, J. R., Westchester Lighting Co., Mt. Vernon, N. Y.
Galer, F. C., Lancashire Dynamo & Motor Co., Toronto, Ont., Can.
Gigat, A. W., (Member), Granby Consolidated Mining, Smelting & Pr. Co., Anyox, B. C., Can.
Haddock, C. C., Brooklyn Edison Co., Brooklyn, N. Y.
Haig, C. M., New England Tel. & Tel. Co., Boston, Mass.
Hankey, W. J., The Cleveland Railway Co., Cleveland, Ohio
Harrington, G. W., Pratt Institute, Brooklyn, N.Y.
Harrison, A. T., Pacific Gas & Electric Co., Cassell, Calif.
Hepinstall, W. G., Lignite Utilization Board, Bienfait Sask., Can.
Herrera, R. O., General Electric Co., Schenectady, N. Y.
Hindman, E. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Holton, T. R., 62 West Street Worcester, Mass.
Hudson, A., General Electric Co., Schenectady, N. Y.
Hudson, F. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hughes, G. O., Bureau of Pr. & Lt., City of Los Angeles, Saugus, Calif.
Ishii, T., Japanese Government Railways, New York, N. Y.
Jeannin, H. W., (Member), The Jeannin Electric Co., Toledo, Ohio
Jones, F. A. M., The Pacific Tel. & Tel. Co., San Franscisco, Calif.
Jones, J. P., Consulting Engineer, Cleveland, Ohio
Jund, D., with W. C. Lagerway, New York, N. Y.
Kelhofer, L. M., Commonwealth Power Corp., Jackson, Mich.
Khalifah, A. A., Baldwin Locomotive Works, Philadelphia, Pa.
Klein, F. A., Public Service Electric & Gas Co., Newark, N. J.
Kovalsky, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kovediaeff, B. E., 1018 W. 73rd St., Los Angeles, Calif.
Kupferle, A. T., Union Gas & Electric Co., Cincinnati, Ohio
Lamantia, J. C., Brooklyn Polytechnic Institute, Brooklyn, N. Y.
Lappin, J. L., General Electric Co., Bloomfield, N. J.
Lauth, E. H., Street Lighting Sec., City of St. Louis, St. Louis, Mo.
Lewis, F. M., Northwestern Electric Co., Portland, Ore.
Mahood, E. T., Southwestern Bell Telephone Co., St. Louis, Mo.
(Applicant for re-election)
Manning, E. R., Weston Electrical Instrument Corp., New York, N. Y.
Markovits, J. A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Marshall, A. E., The Philadelphia Electric Co., Philadelphia, Pa.
Martini, J. A., Postal Telegraph Co., New York, N. Y.
McGinnis, N. W., H. C. Reid & Co., San Francisco, Calif.
McGrath, M. H., Standard Underground Cable Co., Pittsburgh, Pa.
McIntyre, R. J., Gray Electric Chemical Laboratory, Bayonne, N. J.
McKeon, J. B., Rochester Gas & Electric Corp., Rochester, N. Y.
McLean, J. S., (Member), J. G. White Engineering Corp., New York, N. Y.
Mimmack, A., City Electrician, City Hall, Beverly Hills, Calif.

Mororo, D. G., 513 W. 145th St., New York, N. Y.
Morse, A. W., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Moss, J. E., West Penn Power Co., Washington, Pa.
Murphy, J. A., McClellan & Junkersfeld, Inc., St. Louis, Mo.
Nemetz, V. W., Commonwealth Power Corp., Jackson, Mich.
Nerges, F. A., U. S. S. Owl, No. 2, Hampton Roads, Va.
Overfield, G. B., Burke Electric Co., Erie, Pa.
Panton, H. A., Buffalo General Electric Co., Buffalo, N. Y.
Pasayiotis, G. N., Book-News & Novelty Co., Reading, Pa.
Petersen, H. N., Great Western Power Co. of California, Oakland, Calif.
Peterson, J. R., Western Union Telegraph Co., San Francisco, Calif.
Pettit, Z. T., Los Angeles Gas & Electrical Corp., Los Angeles, Calif.
Phelps, M. W., Pittsburgh Transformer Co., Buffalo, N. Y.
Philipson, R. E., Electric Bond & Share Co., New York, N. Y.
Pimentel, O., Cia Minera San Rafael y Anexas, Pachuca, Hgo., Mex.
Pyle, A. J., Univ of Penna., Philadelphia, Pa.
Ragg, F. C., Textile Dyeing Co. of America, Paterson, N. J.
Ransford, H. E., Henry N. Muller Co., Pittsburgh, Pa.
Reifsnyder, S. E., Chas. Cory & Son, Inc. Philadelphia, Pa.
Reilly, F. J., Tork Co., New York, N. Y.
Rodgers, K. F., Bell Tel. Laboratories, Inc., New York, N. Y.
Royere, J. E., Electrical Testing Laboratories, New York, N. Y.
Schroeder, E. H., Western Electric Co., Inc., Philadelphia, Pa.
Scott, T. W., Baltimore & Ohio R. R., Connellsville, Pa.
Siskind, R. P., Harvard Engineering School, Cambridge, Mass.
Smith, H. L., Southern Ontario Gas Co., Merlin, Ont., Can.
Snow, H. B., Public Service Production Co., Newark, N. J.
Snyder, F. L., Westinghouse Elec., & Mfg. Co., Sharon, Pa.
Spector, B., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Steeb, G., Niagara Lockport & Ontario Power Co., Gardenville, N. Y.
Steinkamp, W., X-Ray & Electro Medical Equipment, Rochester, N. Y.
Stempfle, F., 105 W. 57th St., New York, N. Y.
Stevens, E. J., Jr., Gurney Elevator Co., Inc., New York, N. Y.
Stinson, M. J., Montville Power Station, Uncasville, Conn.
Szappanyos, A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Thomas, R. E., Westinghouse Elec. & Mfg. Co., Detroit, Mich.
Thompson, C. S., (Member), Consulting Engineer, Oklahoma City, Okla.
Thompson, W. S., Michigan Bell Telephone Co., Detroit, Mich.
Torres, S. E., Transcontinental Pet. Co., La Barra Refinery, Tampico, Mexico
Tracy, G. F., University of Wisconsin, Madison, Wis.
Trainor, J. F., Underwriters Laboratories, Boston, Mass.
Turner, W. F., Brooklyn Edison Co., Brooklyn, N. Y.
Wagner, V. C., Fischbach & Moore, Inc., New York, N. Y.
Wardell, D. P., National Sugar Refinery Co., Long Island City, N. Y.
Washburn, J. C. B., Narragansett Elec. Lighting Co., Providence, R. I.
Watling, R. G., So. California Telephone Co., Los Angeles, Calif.
Watson, H. K., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Westbye, J., (Member), Gibbs & Hill, New York, N. Y.
Westbrook, J. A., Commonwealth Edison Co., Chicago, Ill.
Wiley, F. H., (Member), Westinghouse Elec. & Mfg. Co., Denver, Colo.
Williams, G. S., Central Maine Power Co., Augusta, Me.
Williard, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Wissmann, J. T., Radio Corp. of America, Riverhead, N. Y.
Womer, C. E., Shamokin-Mt. Carmel Transit Co., Boston, Mass.
Wood, G. E. Chelsea Hotel, New York, N. Y.
Woods, O. B., Newfoundland Power & Paper Co., Deer Lake, Newfoundland
Zielinski, H., Kny-Scheerer Corp. of America, New York, N. Y.
Zimmerman, E. F., Southwestern Bell Tel. Co., St. Louis, Mo.
Total 143

Foreign

Blythe, G. E. K., Messrs. C. A. Parsons & Co., Ltd., Heaton, Newcastle-on-Tyne, Eng.
Donaldson, L. J., Brown, Boveri & Co., Ltd., of Switzerland; For mail, Sidney, N. S. W.
Forrest, F., (Member), Birmingham Corp., Birmingham, Eng.
Gallego, A., (Member), Obras Sanitarias de la Nacion, Buenos Aires, Arg. Rep., S. Amer.
Haskell, M. E., Morajee Soculdass & Co., Bombay 1, India
Hemsley, S. H., Messrs. Ferranti, Ltd., Hollinwood, Lancashire, Eng.
Hussain, S. M., (Member), Bellary Electric Supply Co., Ltd., Bellary, Madras Presidency, India
Lebon, J. D., The Burmah Oil Co.'s Power Station, Thittabwe, Nyaunghla P. O., Upper Burma, India.
Lott, H. C., (Member), Balfour, Beatty & Co., Ltd., London, E. C. 4, Eng.
Lydon, R. J. B., Central Technical College, Brisbane, Queensland, Aust.
Martinov, Central & Substa. Dept., State Electrotechnical Trust, Leningrad, Russia
Moitinho, R., Electrical Public Services, Estado do Rio de Janeiro, Nictheroy, Brazil
Pougy, A. M., Cia Docas de Santos, Santos, Brazil, So. America
Reid, M., St. George County Council, Kogarah, Sydney, Australia
Thompson E., St. George County Council, Kogarah, Sydney, Australia
Webb, H., (Member), Wanganui-Rangitikei Elec. Pr. Board, Wanganui, N. Z.
Total 16

STUDENTS ENROLLED

Abbott, John N., Univ. of Delaware
Alexander, Philip, Jr., Alabama Poly. Inst.
Anders, Milton, Univ. of Minnesota
Andersen, John A., Brooklyn Poly. Inst.
Archer, George E., Georgia School of Technology
Arima, John K., Univ., of Washington
Baker, Harold D., Drexel Inst.
Baldwin, Rex G., Ohio State Univ.
Barnard, Marill M., Texas A. & M. College
Barrera B., Fernando, Escuela de Ingenieros Mecanicos y Electricistas
Bausman, Willard, Univ. of Southern California
Beckett, W. J. Oklahoma A. & M. College
Bennett, Leon S., Northeastern Univ.
Bickford, Chaloner L., Northeastern Univ.
Biggi, Louis C., Villanova College
Bitter, A. Romeyn, Univ. of Denver
Black, Leonard J., Univ. of California
Blakeslee, Theodore M., Univ. of Southern Calif.
Bohn, Louis G., Jr., Stevens Inst. of Tech.
Bolster, William, Univ. of Washington
Bonanno, Joseph L., Stevens Inst.
Bracken, William W., Washington Univ.
Brandt, Clifford A., Univ. of Minnesota
Brandt, Ralph H., Stanford Univ.
Brookins, Harry, Queens Univ.
Brown, Joseph R., Clarkson College of Tech.
Brown, Richard H., Yale Univ.
Brunner, Harry C., Washington Univ.
Bruzina, Russell, Milwaukee School of Engg.
Buckley, Arthur, Northeastern Univ.
Byrd, Oscar, Univ. of Florida
Campbell, Neil H., Univ. of Southern Calif.
Carlisle, William H., Jr., Mass Inst. of Tech.
Carpenter, Earl, M., Tufts College
Cerveny, Philip F., State College of Washington
Chalmers, Archibald C., Northeastern Univ.
Chrestensen, Carl E., Univ. of Wisconsin
Christison, Donald C., Univ. of Wisconsin
Cifuentes, Joseph, Columbia Univ.
Clark, Fred Stevens, Univ. of Minnesota
Clark, Roy W., Washington State College
Cole, David D., Univ. of Michigan
Collett, Nelson E., Univ. of Calif.
Conners, George W., Jr., Stanford Univ.
Connors, Edward T., Catholic Univ. of America
Corey, Raymond E., Univ. of New Hampshire
Coulson, Arthur G., Univ. of Nebraska
Crabs, Lester J., Oklahoma A. & M. College
Crawford, Duncan A., Mass Inst. of Tech.
Crowley, Homer L., Univ. of Calif.
Davis, Ralph L., Milwaukee School of Engg.
De Jordan, Roy, Univ. of Wisconsin
Dickinson, Raymond L., Yale Univ.
Dodd, Nathan M., Univ. of Nebraska
Dracopoulos, P. T., Yale Univ.
Driscoll, John J., Mass. Inst. of Tech.
Du Bois, J. Harry, Univ. of Minnesota
Dunstan, Gilbert H., Univ. of Southern Calif.
Dyson, Horace R., Mass. Inst., of Tech.
Dytrt, Lumir, Iowa State College
Ellingwood, Mallard E., Northeastern Univ.
Erskine, Arthur J., Univ. of Wisconsin
Farmer, J. Woodruff, Northeastern Univ.
Firestone, Samuel, Univ. of Michigan
Fitz Gerald, Donald D., Yale Univ.
Fitzgerald, Edward P., Johns Hopkins Univ.
Flodin, Carl R., Jr., Univ. of Washington
Frandsen, Dallas J., Univ. of Colorado
Gail, Charles P., Mass. Inst., of Technology
Gast, Raymond W., Stevens Inst. of Tech.
Gilmore, Frank W., Mass. Inst. of Tech.
Gipson, Bernard, Univ. of Southern California
Glenn, Bruce, Oklahoma A. & M. College
Gould, David W., Northeastern Univ.
Graham, Veto J., Univ. of Texas
Gray, Truman S., Univ. of Texas
Grimes, Edgar S., Northeastern Univ.
Grogan, Russell M., Catholic Univ. of America
Gubin, I. Paul, Univ. of Calif.
Gupta, Birjendr N., Mass. Inst. of Technology
Hahn, Paul, College of the City of New York
Halloran, Thomas V., Villanova College
Hampe, George W., Washington Univ.
Hansen, John C., Univ. of Utah
Hardy, Edward J., Case School of Applied Science
Harry, Joseph Paul, Univ. of Southern California
Hawley, Thomas S., Catholic U. of Washington
Hayley, Frank D., Alabama Poly. Inst.
Hemmenway, Donald L., Northeastern Univ.
Hicks, James C., Northeastern Univ.
Hodge, Frederic G., Univ. of Calif.
Holder, Lyman F., Univ. of Wisconsin
Horton, Hal M., Oklahoma A. & M. College
Hovey, Bertram, Univ. of Minnesota
Hovick, Robert L., Univ. of Wyoming
Hughes, John G., Virginia Poly. Inst.
Hulsebus, Albert, Univ. of North Dakota
Hummel, Frank S., Univ. of Utah
Hurteau, John E., Milwaukee School of Engg.
Jacobson, Morris, Northeastern Univ.
Jepson, Milton W., Northeastern University
Johnson, Gustave F., Univ. of Minnesota
Jones, Archibald L., Northeastern Univ.
Jones, Clifton E., Univ. of Delaware
Jones, Fred, Georgia Tech.
Jones, John A., Villanova College
Jurgens, William F., Broooklyn Poly. Inst.
Karrer, Lawrence Edison, Univ. of Washington
Kasai-Girey, Alim N., Univ. of Southern Calif.

Keane, Paul H., Univ. of Calif.
Keeler, George H., Georgia Tech.
Kersey, Wyatt, D., Georgia Tech.
Kietzmann, Emil A., Kansas University
King, Wilfred T., Univ. of Illinois
Kingston, Clarence R., Cornell Univ.
Kinsburg, Boris J., Univ. of Southern Calif.
Kirkbride, Louis A., Univ. of Nebraska
Kleff, Arnold J., Jr., Johns Hopkins Univ.
Knighton, William S., Johns Hopkins Univ.
Knox, Ira L., Alabama Poly. Inst.
Koch, Percy J., Washington State College
Koerper, Erhardt C., Univ. of Calif.
Kolisch, Emil, Mass. Inst. of Technology
Kranzfelder, Edgar, Columbia Univ.
Krotser, George R., Leland Stanford Univ.
Lakatos, Emory, Stevens Inst.
Lane, John P., Yale Univ.
Larason, George E., Oklahoma Agri. & Mech. College
Lawrence, Philip, Stevens Inst., of Tech.
LeCompte, Joe., State College of Washington
Lenzen, Theodore L., Stanford Univ.
Little, Chester B., Univ. of Southern Calif.
Longley, Richard M., Univ. of New Hampshire
Loxley, Benjamin R., California Inst. of Tech.
Lyman, Harold T., Jr., Yale Univ.
Macferran, Mabel, Stanford Univ.
MacLean, Kenneth G., Northeastern Univ.
MacLeod, Donald R., Queens Univ.
Madden, Harry E., Univ. of Calif.
Madeheim, Huxley, Stevens Inst. of Tech.
Maedel, George F., Jr., Columbia Univ.
Mahan, Guy S., Rose Poly. Inst.
Maki, Hjalmar S., Univ. of New Hampshire
Mancini, Philip S., Mass. Inst. of Tech.
McCall, D. B., Jr., Univ. of Texas
McClung, Joseph E., McGill Univ.
McClure, Lindley W., McGill Univ.
McCormick, Lawrence O., Johns Hopkins Univ.
McCune, Francis E., Univ. of Calif.
McElwee, James F., Jr., Georgia Tech.
McFarland, G. Earl, Milwaukee School of Engg.
McFarland, James D., Univ. of Texas
McLean, Corbett, Stanford Univ.
McMullen, Robert B., Univ. of Washington
McRae, Horace T., Univ. of New Hampshire
Mendez, August R., Univ. of Minnesota
Messenger, Uram H., Oregon State Agri. College
Meyer, Vincent J., Univ. of Southern California
Meyers, Stanley T., Steven Inst. of Tech.
Miller, Verne B., Univ. of Southern Calif.
Mills, Roy V., Johns Hopkins Univ.
Montin, Andy G., Univ. of Calif.
Moody, Frank B., Univ. of New Hampshire
Moses, Marlowe G., Univ. of Minnesota
Munzer, Louis F., College of the City of New York
Nason, Horace E., Mass. Inst. of Tech.
Nathan, Simon S., Cornell Univ.
Nergaard, Leon S., Univ. of Minnesota
Newton, Oscar A., Newark Tech. School
Nichol, J. M. D., Virginia Poly. Inst.
Nilson, Leonard V., Purdue Univ.
Niswander, Roy Frank, Univ. of Calif.
Nussbaum, H. Weldon, Stanford Univ.
Obergfell, Frederick, Cooper Union Inst.
Obold, Francis X., Catholic Univ. of America
O'Brien, Joseph E., Catholic Univ. of America
Oudahvihin, Michael, Univ. of Calif.
Paradis, Ernest J., Univ. of Washington
Park, William H., Univ. of Calif.
Payette, Sedric, Univ. of Washington
Pflug, Charles E., Univ. of Nebraska
Pierson, Israel S., Univ. of Utah
Poole, Arthur B., Cornell Univ.
Priebe, Lloyd H., Univ. of Washington
Probst, Henry O., Newark Technical School
Rancourt, Louis E., Catholic Univ. of America
Rapport, Adolph H., College of the City of New York
Rayburn, Gordon I., Univ. of Southen Calif.
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Schultheis, John R., Johns Hopkins Univ.
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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Disconnecting Switches.—Bulletin 25403, 4 pp. Describes the design and engineering specifications of types R and RA disconnecting switches. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Ball Bearings.—Booklet F 910, 12 pp., "Precision Ball Bearings for Fractional Horse Power Motors." The Norma-Hoffman Bearings Corporation, Stamford, Conn.

Theatrical Equipment.—Catalog M, 128 pp. Describes a complete line of lighting specialties and lighting effects for the stage, for theatres, motion picture studios, window displays, show rooms, exhibitions, outdoor flood lighting, and many other applications. Kliegl Bros., 321 West 50th Street, New York.

Instruments.—Catalog 8931, 24 pp. Describes various instruments of medium and small size for a number of purposes, including a-c. and d-c. applications in radio work, in checking operation of motor starters and starting controllers, in power plants to check opens and shorts on relay circuits, and many others. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Ground Wire Clamps.—Circular describes newly developed ground wire clamp particularly adaptable to "Copperweld" ground rods. The clamps are permanently secured to the ground rods by mechanical means, eliminating the use of soldered connections, although solder may be used, if desired. Exceptional strength is claimed for the new clamp. Copperweld Steel Company, Rankin, Pa.

Power Factor.—Bulletin GEA 232, 32 pp., "Power Factor and Means for Its Improvement." This booklet presents in a simple and systematic manner authoritative information on means for power factor improvement in industrial plants. It is a practical treatise on power factor with the mathematics reduced to simple arithmetic. General Electric Company, Schenectady, N. Y.

Static Condensers.—Bulletin 1670A, 24 pp., "Static Condensers for Power Factor Correction." One section is devoted to a discussion of power factor, its correction and the selection of corrective equipment; another part describes LD static condensers; the third part is devoted to low-voltage static condensers, describing the construction assembly and application. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Lighting Data.—A series of bulletins. LD 101B, 28 pp., "Effect of Maintenance and Color of Surroundings on Resultant Illumination;" LD 103C, 36 pp., "The Lighting of Show Windows and Show Cases;" LD 126A, 40 pp., "Lighting for Recreations;" LD 146A, 48 pp., "Stage Lighting;" LD 0A, 16 pp., "Index of Information Contained in Lighting Data Bulletins as of January 1, 1926." Edison Lamp Works of General Electric Company, Harrison, N. J.

NOTES OF THE INDUSTRY

The Sterling Varnish Company, Pittsburgh, Pa., announces that J. S. Applegate, formerly of the Wagner Electric corporation has joined its staff as metallurgical engineer and consultant for users of insulating varnishes.

New G. E. Electric Plant at Los Angeles.—The new General Electric service plant in Los Angeles at 5201 Santa Fe Avenue was formally opened on March 23. This new plant, comprising three buildings, a three-story warehouse, a two-story office building and a service shop, will have a total of 88,000 square feet of floor space.

The American Brown Boveri Electric Corporation, New York, has appointed L. J. Galbreath to take charge of publicity and sales promotion, and as assistant to Earl G. Hines, recently appointed general sales manager. Mr. Galbreath was formerly ted with the Bridgeport Brass Company.

Increased Power Demands in the South.—It has been found necessary to add considerably to the central station facilities this year in several sections of the south. In Florida two new stations have been built totalling 75,000 kw., and in Texas additional turbines totalling 50,000 kw. are being added to the central stations of Dallas and Houston. All the new turbines, three of 25,000 kw. capacity, and two 12,500 kw. units, will be furnished by the General Electric Company.

The Okonite Company, Passaic, N. J., has received an order from the Puget Sound Power & Light Company for 46,800 feet of three-conductor submarine armored cable which will be used to span Puget Sound between Edmonds, on the mainland side, and President's Point, on the Olympic Peninsula, and thus connect the properties which the company recently acquired on the peninsula with the mainland system of interconnected power plants. Two cable connections will be made between the points mentioned and each cable will be capable of furnishing 10,000 h. p. The total weight of the cable will be approximately 750,000 pounds.

Keel Laid of New Electric Passenger Ship.—The keel of the first large electric passenger ship was laid at Newport News, March 20, at the plant of the Newport News Shipbuilding & Dry Dock Company. The vessel, the largest commercial craft built in the United States, will be the first of three sister ships, costing approximately $21,000,000, and will enter the New York California passenger trade in 1927. The new liner will be 601 feet long and will have a speed of 17 knots. Oil burners will furnish steam to two 9000 horse power General Electric turbine generators which will drive the motors connected to the two propellers.

Westinghouse Adds to Mansfield Plant.—A new four-story brick and concrete building with a floor space of 142,600 square feet, has recently been added to the Mansfield plant of the Westinghouse Electric and Manufacturing Company. The new manufacturing unit, which is of the most modern fireproof construction, will be devoted to the construction and assembly of ranges and electric irons. With the addition of this building, the Westinghouse plant at Mansfield has now a total floor space of 330,530 square feet, or seven and a half acres, devoted to the manufacturing of electric ware, hotel appliances, ranges and safety switches.

G. E. Suggestion Awards.—Awards totalling $38,938 were paid 3433 employees of the General Electric Company during 1925 for suggestions made by workers which improved working conditions or tended to increase the efficiency of the company's operations. During the year 11,325 suggestions were offered, of which more than 30 per cent were accepted. During the previous year 12,217 suggestions were made and 26 per cent accepted, and in 1923 but 21 per cent of those offered were accepted. The awards, which ranged up to $500, were paid at the option of the recipient either in cash or G-E Employees Securities Corporation bonds, which yield 8 per cent so long as the original holder remains in the employ of the company.

Foote, Pierson & Company, Inc., New York, manufacturers of photometers and electrical instruments, at a recent annual meeting elected George F. Lewis, president, formerly secretary and treasurer; Malcolm G. Pierson, vice-president and secretary; William R. Stout, assistant secretary and assistant treasurer. Mr. Lewis, a son of Colonel Lewis, inventor of the Lewis machine gun, succeeds Henry G. Pierson, who served as president of the company since its incorporation, and who was made Chairman of the Board. Mr. Lewis was in active service during the war and later he commanded the Engineering Officers Training School at Fort A. A. Humphrey, Va., with the rank of Lieutenant-Colonel. Malcolm G. Pierson is a son of the former president and has been acting as general sales manager. Mr. Stout has been associated with the company for the past twenty years acting as cashier.

JOURNAL OF THE A·I·E·E·

MAY 1926

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Annual Business Meeting, New York, N. Y., May 21
Annual Convention, White Sulphur Springs, W. Va., June 21-25
Pacific Coast Convention, Salt Lake City, Utah, September 7-10

Regional Meetings

Great Lakes District, Madison, Wis., May 6-7
Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

National Fire Protection Association, Atlantic City, May 10-13
National Electric Light Association, Atlantic City, May 17-21
Electric Power Club, The Homestead, Hot Springs, Va.
The American Physical Society, Oakland, California, June 17
The American Society of Civil Engineers, Seattle, Wash., July 14-16

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Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Address of Welcome to the I. E. C.*

Once upon a time a Greek philosopher said that to "know thyself" is the first step to wisdom. He might have added that to "know thy neighbour" is the second step to wisdom. I learned this second step when still a boy in my native village.

There are some twelve peasant villages within a circle of a radius of ten miles, of which my native village is the center. Five different races live in these villages: Serbs, Slovaks, Rumanians, Germans, and Hungarians. These simple peasant folk meet each other regularly on market days. Each village has one or two market days during the year, and on such days it is visited by the peasants of the neighboring villages. There the different races meet and greet each other by the Serbian word "komshiya," neighbour. This is the most popular word in their interracial vocabulary. These peasants learn that without the komshiya, the neighbour, one cannot exchange the things which he has for the things that he has not; and above all, one cannot enrich his own experience by the experience of his neighbors. This knowledge is a great help to him who strives to reach that lofty level which is described in the words: "Love thy neighbour as thyself." I do not say that these simple peasant folk in my native district ever reached that lofty level, but I do say that I never saw a small district which looks like glacial moraine of different races where the Serbs, Slovaks, Rumanians, Hungarians, and Germans are so sincerely attached to one another. With them, the difference in breed and creed counts for very little. but identity in the aims of their simple lives counts for very much. This identity of aims acts like a catalyst; it brings their hearts into closer contact and convinces them that they all have the same human hearts and souls in spite of the difference in race and religion.

As I look around this festive board and remember that our beloved guests represent so many different nations and religions I am reminded of my childhood days when I saw my father, an enthusiastic Serb, shaking hands with Hungarians, Slovaks, Germans, and Rumanians from neighboring villages, greeting them with the magic word komshiya, neighbour. I extend to you the same greeting today: Welcome komshiya, welcome our dearly beloved neighbours! Nay, you are even closer to us than neighbours. Do not the names Volt, Ohm, Ampère, Farad, Henry and Gauss; Watt, Coulomb, and Joule, remind us that we all have the same household gods, the same Lares and Penates? And, besides, do we not worship at the altars of the same patron saints: Kelvin, Helmholtz, Maxwell, and Hertz; Siemens, Gramme, and Pacinotti?

We are, indeed, members of the same family, and every meeting of the International Electrotechnical Commission looks more and more like a family reunion. I wish that the Mayor and the Board of Alderman of New York were with us today and that the Congressmen and Senators were with us to study our reunion and learn that scientists and engineers have discovered a secret greater than any secret in science; namely, the secret of laying a true foundation for a League of Nations. Let others follow and the world will soon become a Paradise Regained.

M. I. PUPIN.

*At the Luncheon in honor of the International Electrotechnical Commission, April 14, 1426.

Some Leaders of the A. I. E. E.

PAUL MARTYN LINCOLN, from 1914-1915 twenty-seventh president of the A. I. E. E., was born Jan. 1, 1870 in Norwood, Michigan. In 1880 the family moved to Painsville, Ohio, through the high schools of which town Mr. Lincoln received his early schooling. In 1888, a year in the Western Reserve University, Cleveland, convinced him that his capabilities inclined more to the technical than the classical and upon completion of one year at the Western Reserve University, he entered Ohio State University, from which he received his degree of M. E. in Electrical Engineering June 1892. Immediately upon the close of his final semester, he engaged with the Short Electric Company, of Cleveland, but in December of that year, went to the Westinghouse Electric and Mfg. Co., Pittsburgh, to take up important work for them. Two and a half years later he was chosen electrical superintendent in charge of the water power development of Niagara Falls for the Niagara Falls Power Company. This was the beginning of modern hydroelectric development, and the amount of power generated, transmitted and distributed by this first plant was so far in excess of anything accomplished up to that date as to make it unique, with new problems involved in its progress constantly arising to be solved. In 1902, Mr. Lincoln returned to the Westinghouse Company and for six years was in charge of their Power Division of the Engineering Department. 1910 he was appointed general engineer

for the Company, in which capacity he served until he tendered his resignation in 1919.

From 1911 to 1915, Mr. Lincoln was head of the electrical school at the University of Pittsburgh, still carrying on his work with the Westinghouse Electric & Mfg. Co. while caring for his educational responsibilities. The Lincoln Electric Company had been organized by an older brother in 1894 and it was to join this brother that Mr. Lincoln's resignation was tendered to the Westinghouse Company. He remained with his brother until taking up his duties as director of the School of Electrical Engineering, Cornell University, November 1, 1922.

Beside serving the Institute as its President, Mr. Lincoln was, for five consecutive years, from 1909 to 1914, chairman of its Sections Committee, performing a most efficient service to the professional world in this capacity. The synchroscope, a device now in universal use wherever a-c. machines are parallelled, was one of his inventions for which in 1902 he received the John Scott Medal award from the City of Philadelphia upon the recommendation of the Franklin Institute.

Street Lighting

Street lighting has been a problem ever since men began to herd together in cities. At first the problem was solved by each citizen who ventured out at night carrying a lantern or hiring a link boy to carry a torch before him.

This didn't amount to much as protection from highwaymen, although it did help some in getting over, around, or through the mud puddles. During that period the easiest and most popular solution of the street lighting problem was to stay at home after dark.

By and by came oil lamps, stuck on poles, to help out the hand lanterns. Then gas lamps took the place of oil; and so, by degrees, we come to our modern age of electric lighting.

It is well within the truth to say that, even in America, street lighting is still in a primitive stage. We have of course our "White Way" in every city of any importance, but once outside this area, the streets are often dismal and dangerous after dark. The average community seems to spend just enough on street lighting to make the darkness more confusing. There is a popular notion that street illumination costs much money, but the latest investigation shows that the per capita cost is only about 75 cents a year.

Scientific and adequate street lighting is a social question of paramount importance in the modern world.

First of all we have the fact of vastly accelerated out-of-door movement among all classes of people. Shut in by day, the masses and classes alike are impelled to stir abroad at night. In the threater and shopping district, it has become the recognized practise to make the streets as light as day. What the community fails to furnish, the stores and places of amusement make up as part of their sales and advertising budget.

There are three reasons, among many others, why every city and town and many country roads must from now on be properly lighted.

First, the safety, happiness and comfort of all the people demand it.

Second, the enormous increase in power transportation brings us to the point where traffic growth must cease unless folks can see where they are going. This refers to pedestrians equally with those in automobiles, busses and street cars.

Third, according to an ancient scripture, where the carcass is the birds will gather together. With the streets thronged at night at the centers, it means that the *home* streets, roads and byways will all have belated travellers at night. This brings the hold-up man and other criminals to their harvest. Good street-lighting is second only to a good police force as a crime deterrent. Men love darkness rather than light when their deeds are evil. Crime diminishes as light increases.

Recognizing the great social value of good street-lighting, the scientific and engineering resources of the leading lighting laboratories have been directed towards a solution of this problem with extraordinary success. We have the lamps and the electric energy and we know how to use both to the best advantage in street-lighting. When the people wake up to the necessity of proper street-lighting, half the job will have been done.—*Light*, March, 1926.

Distribution Networks

After much debate the system most favored is the three-phase, four-wire alternating-current network for the supply of light, power or the combination of light and power. But, unfortunately, most services and equipments are 110 volts or 220 volts today, and the electrical relations in the three-phase circuit make it possible only to obtain service at either 115 and 199 volts or 120 and 208 volts with simple transformation ratios. The relative merits of these combinations have been debated thoroughly and especially their effects on service using present standard equipment. No unanimous decision has been reached and both types of networks are in service. Both systems give satisfactory service when standard equipment is used, for, fortunately, lamps may be had at either 115 or 120 volts and single-phase and polyphase motors have tolerances whereby satisfactory operation may be had between, roughly, 110 and 120 volts single-phase and 200 and 240 volts three-phase. But, of course, when operated at points near the tolerance limits the margins of departure from the average motor characteristics are changed, and a design based on either system as a standard would have a wider field of satisfactory application.—*Electrical World*.

Important Features of a Successful Plan for Rural Electrification

BY G. G. POST[1]
Associate, A. I. E. E.

***Synopsis.**—Electric service in rural districts is considered to be a necessity, and a plan for bringing this about in southeastern Wisconsin is outlined in this paper. The main features discussed are: (1) organization for the work, (2) rural rates and financing of line extensions, and (3), advertising and education. A type of economical line construction which will render reliable service is described. The outstanding feature of this line construction is the use of 300-ft. spans. Interesting data, obtained in a survey of a number of rural lines, are presented. The paper shows that in the territory served there were 2740 farms receiving service under the rural rate on January 1, 1926.*

It also shows that the general plan, which has been followed since 1920, encourages the extension of lines and extensive use of the service after farms have been connected.

GENERAL

THE necessity for rural electrification and its economic importance have been widely discussed and there is general agreement that electric service should be made available to our rural population as rapidly as possible. To accomplish results in this direction requires that definite and effective plans be developed and adopted by those electric service supply companies which are in position to serve rural territory.

Plans for bringing about rural electrification vary considerably. Utilities in quite similar territories often differ on important points. Then, there are differences inherent in the territory to be served, such as the density of population and the farming resources, depending in large measure upon productivity of the soil and general knowledge of farming methods. It is not the writer's purpose to discuss or compare various plans but rather to outline a certain plan which has been worked out on a fairly extensive scale and has proved to be effective.

The territory in which these plans are in operation includes 11 counties or portions of counties in eastern and southeastern Wisconsin served by The Milwaukee Electric Railway & Light Company and its associated companies—the Wisconsin Gas and Electric Company and the Badger Public Service Company. Fig. 1 is a general map of the lines of these companies. There is a total of 21,000 farms in the territory.

ORGANIZATION FOR THE WORK

The most essential thing in a rural electrification plan is a proper organization to carry on the work. No company would consider the prosecution of a new and important undertaking without putting some one in charge and making that person responsible for the results.

Rural electrification is a new and important undertaking. It covers a field differing from any that has ever been covered before by electric utilities. If rural electrification is to succeed as fully as it should, the utilities must give it the same careful thought and effort they have given other important activities that have confronted them in the past and that have been successfully handled. The only way to do this is to establish a rural service commercial division, or department composed of a rural agent and such assistants or rural

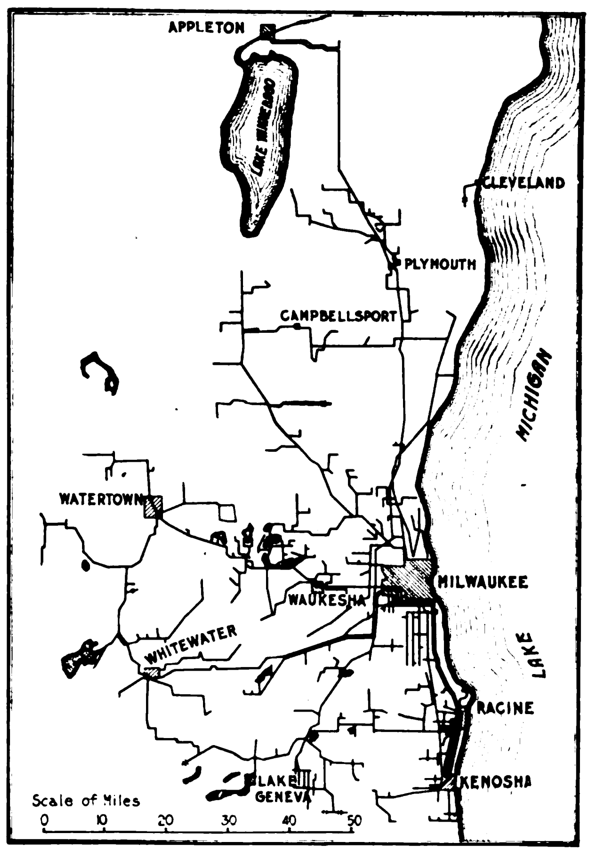

FIG. 1—DISTRIBUTION LINES OF THE MILWAUKEE ELECTRIC RAILWAY AND LIGHT COMPANY AND ASSOCIATED COMPANIES

service salesmen as may be required, to adequately promote the use of electric service and electric equipment by the farmers of the territory the utility serves. The Milwaukee Electric Railway & Light Company employs a rural agent and from four to six rural service salesmen. These men have worked on farms, know the language of the farmer, and at the same time are ex

1. Electrical Engineer, The Milwaukee Electric Railway & Light Co., Milwaukee, Wis.

To be presented at the Regional Meeting of District No. 5 of the A. I. E. E., Madison, Wis., May 6-7, 1926.

perienced commercial engineers. They study all phases of the rural electrification problem, take such action as may be necessary to follow up advertising, keep prospective consumers interested in the service, carry on negotiations for line extensions, introduce new uses for the service, and do any other work which the proper conduct of the business requires.

Rural Rates and the Financing of Line Extensions

Before any organization can be effective, a system of rates and a method of financing line extensions, consumers wiring, and equipment must be developed.

It is a sound principle that country dwellers are not much different in their fundamental nature and aspirations than those residing in urban districts and that in establishing rates and line extension policies the same general principles should govern in rural as in urban districts. If it is right and equitable to have the equivalent of a demand charge (active rooms) in residence rates, and if a demand charge in commercial and power rates is right and equitable is it not proper that there should be the equivalent of a demand charge (active rooms and minimum charge per connected h. p.) in the rural rate? Fundamentally, the farm is the farmer's residence and factory and the rate to be equitable must include the characteristics of plain residence rates and those of commercial or power rates. The rate must also be one which will discourage the use of motors of excessive h-p. rating and encourage the consumption of kw-hr. To express it in another way, the rates should encourage the consumer to operate at a high load factor and make the fullest use of the service. With this idea in mind a rural rate, substantially as follows, was developed in 1920:

Rural consumers are defined as consumers generally located outside of the limits of cities and villages who are engaged in farming, stock raising, or dairying.

Rural consumers located upon existing distributing lines or who contribute to the cost of constructing extensions in accordance with the Company's rules and who execute the Company's standard form of rural service contract for a period of not less than two years may purchase single-phase electric service at the following rates.

(*a*) *Service Charge.* Two dollars per month for four or less active rooms plus forty cents per month for each active room in excess of the first four.

Service charge shall include energy consumption equivalent to five kw-hr. per active room per month or not less than 20 kw-hr., in case the active rooms are less than four.

(*b*) *Energy Charge.* Three and one-half cents per kw-hr. for all energy consumed in excess of five kw-hr. per active room, or in excess of 20 kw-hr. in case the active rooms are less than four.

The number of active rooms shall be computed on the following basis:

(1) All rooms contained in the residence shall be counted as active, except bathrooms, basements, garrets, closets, halls, pantry, unwired storage rooms, and three rooms used as bedrooms or sleeping quarters but not used for other purposes.

(2) Rural installations having barns, poultry houses, or greenhouses, but not wired, shall have the residence count increased by one active room.

(3) Rural installations having barns, poultry houses, or greenhouses wired, shall have their counts increased by one active room for each separate horse-barn, dairy-barn, poultry house, and greenhouse actually connected to the distribution system and receiving energy.

(4) Sheds or open barns used to shelter live stock, grains, feeds, or machinery (and not regularly used as horse barns or dairy barns), garages, and miscellaneous buildings, even though wired, shall be exempted from the active room count, excepting such garages, blacksmith shops, and other buildings that may be conducted for and open to the general public as repair or service shops. Each building so conducted shall be counted as an active room.

(5) A barn used as a combination horse and dairy barn shall be counted only as one active room.

(6) Where rural consumers, as herein defined, are located within the limits of cities and villages, such consumers may obtain service on either the rural rate or residence rate applicable in such localities.

The foregoing rate shall apply to all energy used for household purposes, including cooking, and for miscellaneous power purposes, providing the total nominal rated capacity of motors does not exceed three h. p. and providing the motors are not operated between sundown and 11:00 p. m. Service for additional motors will be supplied at the foregoing rates plus an additional charge of fifty cents per month for each h. p. or fraction thereof in excess of three h. p.

The foregoing rate does not include renewals of any incandescent lamps, but is subject to the Company's standard prompt payment discount of five per cent on the first $25.00 and one per cent on amounts in excess of $25.00 on monthly bills paid on or before the last discount date. Bills will be issued as far as practicable 10 days prior to the last discount date.

The gross bills under this schedule may be calculated from the following table.

Monthly Bills for Farm Customers

The minimum charge in this table allows (a) three h. p. in connected motor load and (b) energy consumption of five kw-hr. per active room, or 20 kw-hr. total for less than four rooms.

For connected motor load in excess of three h. p., add 50 cents per month for each h. p. or fraction thereof in excess of three h. p.

For energy consumption, add three and one-half cents for every kw-hr. in excess of five kw-hr. per active room (or 20 kw-hr. total for less than four rooms).

No. of Active Rooms	Kw-Hr. Consumption Allowed on Minimum Charge	Minimum Monthly Charge
4 or less	20	$2.00
5	25	2.40
6	30	2.80
7	35	3.20
8	40	3.60
9	45	4.00
10	50	4.40

As far as the supply company is concerned, there is only one essential difference between rural and urban service, *i. e.*, the greater distances between consumers in the country than in urban territory. This necessitates more line investment per consumer in rural than in urban territory, making it necessary that some means be found for providing for the excess investment.

Before rural service was seriously considered, utility companies found it necessary to devise a plan under which lines could be extended to supply isolated consumers in the fringe surrounding urban territory where the extensions were so long that the revenue would not justify the investment. It became necessary, under such circumstances, for prospective consumers to assist in financing the lines. It was only logical that this principle should be applied in extending lines in rural communities. Consequently the plan was adopted of requiring the prospective consumers to contribute toward the cost of extending the service to them an amount equivalent to the difference between the cost of the extension and the estimated three-years' gross revenue. At the same time provision was made that if other consumers were connected to the extension and it was not necessary for them to contribute toward the cost of their extensions, half of their net bills would be used as a refund to those contributing to the cost of the original extension. Such refunds are discontinued when the original extension has been in service three years, and the total refunds must not exceed the total of the original contributions.

It is usually found that some farmers desire the service more than others, or at least are willing to invest more money in getting it if necessary. Some farmers have been willing to use the service but have been unwilling to contribute anything toward the cost of the line. Others not only are willing to agree to use the service on as extensive a basis as possible, but are willing to contribute a reasonable amount where necessary in order to get the line constructed and the service furnished. It is not possible in these cases to get the farmer consumers on a rural line to bear an equal portion of the investment the company has to make in excess of the amount warranted by the revenue. It has been found necessary to lay the amount to be advanced and the complete proposition, before the group and have them decide among themselves how they will finance the excess cost. One of the farmers, agreeable to both the group and the company, is designated as the official representative of the group and he executes the line extension agreement and turns over to the company the part of the investment required to be advanced by the farmers under the line extension agreement. He may have paid it all himself or he may have collected various parts of it from different farmers. Along with every line-extension agreement there is a blue-print showing the line as constructed and the services connected thereto. This record is carefully preserved and in the future, if there are refunds to the group to be made by the company due to additional consumers coming on the line, they are made to the official representative of the group who executed the line extension agreement and he is responsible for distributing these refunds to the farmers in a manner mutually satisfactory or in accordance with a basis previously agreed upon among themselves.

Although the ownership of lines partially financed by the consumers rests entirely in the utility, the amount contributed is not included in the utility's valuation for rate-making purposes. No special fixed charge is, therefore, included in the rates to cover any extra investment in rural lines and for this reason the monthly charge per kw-hr. is considerably lower than it would be if the utility carried all of the investment.

It must be borne in mind that, ultimately, there will be a vast network of distribution lines serving cities, villages and rural districts alike, and if rural consumers are to remain satisfied there must not be a special fixed charge in their rate to make their cost per kw-hr. higher than that of the urban consumers who may live next to them along the border lines of cities and villages.

Recognizing that it requires a considerable amount of money to contribute toward the cost of lines, to wire farms, and to purchase equipment, a plan has been devised under which the utility advances the money for the purchase of appliances or other equipment and wiring and the rural consumer pays it back on the installment plan in accordance with the terms of certain agreements.

Under the general plan for financing line extensions, farmers are encouraged to install as much equipment as possible so as to increase the gross revenue from the line and cut down the amount which must be contributed toward line extensions. In a good many cases it has been found that this results in the installation of electric ranges or other equipment which would probably not be otherwise installed.

The farmer is thus enabled to make immediate and full use of the service and derive the benefits which electric service always affords.

Advertising and Education

Advertising is just as important in the extension of electric service to the farmers as in any other line of endeavor. The farmer cannot be expected to want it if he is not told about its many benefits. Personal work with the farmers is most effective. The rural agent and his rural service salesmen are most valuable in establishing personal contacts with farmers and acquainting them with all known phases of rural electrification. The efforts of the rural service division are supplemented by the knowledge and experience of the company's regular advertising forces which are especially helpful in advertising in rural papers, in preparing special posters, talking at booster meetings in rural territory, etc. The specific plan adopted is to inform the farmer by all feasible means available as to the special applications and advantages of electric service to each individual farmer. Instead of waiting for the farmers to apply for electric service, the electric service company endeavors to develop the interest of all the farmers in the use of electric service and especially cooperate with those who already have the desire for the service in getting other farmers along the pro-

posed route of the line interested, so that the line may be constructed and the service furnished at the lowest possible cost to any of the farmers. In connection with this work, farmers are being circularized and furnished booklets which show what electric service means to them. Advertisements are being inserted in local newspapers, and demonstrations are being held at various points where an audience of sufficient size to warrant a demonstration and exhibit can be gotten together. At these demonstration meetings well-informed representatives of the company are present, and an effort is made to furnish to the farmers any information desired regarding electric service and electric equipment and how they may be obtained.

The rural service salesmen always stress the point that the utility is not in the business of selling line extensions but rather the service and that it is desirable for the consumer to spend as much as he can afford on equipment which will enable him to make the most use of the service not only in the farm operations but in his home where the convenience of the service is so much appreciated and enjoyed by the housewife.

A roadside sign set up on a farm where a rural line extension is being installed is very helpful in attracting new customers. In some cases, as at the beginning of a line extension where service is available, these signs are illuminated. They are very effective, however, without illumination.

Much effective work is also done by establishing rural electrification booths at state and county fairs. These are strictly educational and informational displays to emphasize to farmers the benefits of the service.

Line Construction

Because of the small number of consumers per mi. of line it is important that the cost of line construction be kept down to the minimum, consistent with reasonable service. This keeps fixed charges within reason and reduces to a minimum the amount which prospective consumers must contribute toward the cost of line extensions.

Utilities should not come to the conclusion that service to farmers can be less reliable than that to the ordinary small city or village. When a farmer installs a range upon which he depends for the cooking of his meals when he installs a milking machine with which he expects to milk the cows, when he installs a heating plant which depends upon electric service for its operation, when he installs a motor-driven pump to furnish water to his stock or for the house, and when he installs other electrically driven equipment upon which his farm processes and operations depend, it is a serious matter if reasonably continuous service is not given and the farmer cannot be expected to electrify his farm if the service is not reliable.

The line construction employed, although it must of necessity be reasonable in cost, must embody all of the features which contribute to make possible safe and continuous operation.

The principal features of the line construction which has been adopted as most reasonable in cost and which at the same time meet the requirements for good service are as follows:

Size of poles	30 ft., 7 in. top, (western red cedar)
Spacing of poles	300 ft.
Size and kind of conductors	No. 2 A. W. G., A. C. S. R.
Size and kind of crossarms	3¼ by 4¼ by 5 ft. 7 in. fir
Size and kind of pins	No. 581 malleable clamp pin (St. Louis Malleable Casting Company)
Insulators	No. 9404 Ohio Brass (or equivalent)
Operating voltage	5000 primary, 120/240 secondary

Every tenth pole an anchor structure.

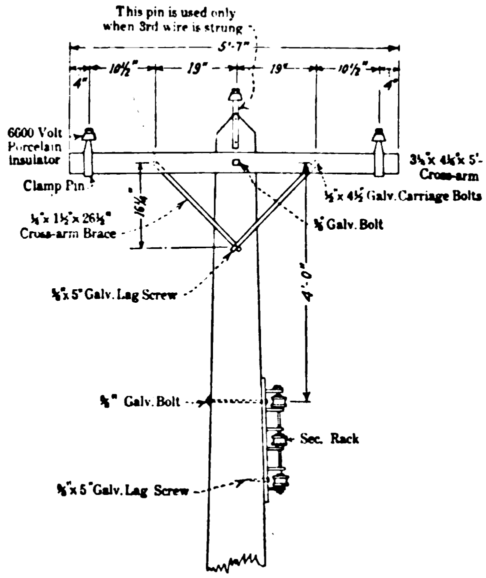

Fig. 2—Arrangement of Pole Top

The details of the construction are shown in Figs. 2, 3, 4, 5, 6, and 7. The cost of a single-phase primary line, exclusive of transformers, lightning arresters, secondary mains, and services is approximately $750 per mi. in country where there is little trouble with trees and where there is neither rock nor too much gravel to interfere with pole setting. If tree conditions are bad or if rock or gravel is encountered, the cost will of necessity be increased. The details of cost are shown in Table I.

That the construction is safe is shown by the following:

Conductor Stresses:

Elastic limit	1860 lb.
Ultimate strength	2660 lb.
Stress at 0 deg. fahr. with ½ in. ice and 8 lb. wind pressure	1860 lb.

Conductor Clearance from Ground:

Clearance at 0 deg. fahr. with ½ in. ice	19.7 ft.
Clearance required by National Electrical Safety Code	18.0 ft.

Resisting Moments of Poles:
Safe loading of 30-ft., 7-in. top western cedar, 30-in. circumference at ground line........... 17,800 ft-lb.
Required by loading ½-in. ice and 8-lb. wind..... 14,870 ft-lb.
Conductor Spacing:
Provided by this construction (three-phase).... 29½ in.
Required by National Electrical Safety Code for 300-ft. spans............................ 18¾ in.
Pins and Insulators:
Lateral stress with ½ in. ice and 8-lb. wind pressure.................................. 263 lb.
Stress in direction of line (conductors broken)... 1860 lb.
Stress which two pins on anchor structure will safely withstand........................ 1950 lb.
Stress which insulators will withstand.......... 4000 lb.
Crossarms:
Stress in direction of line which single arms will safely withstand........................ 1880 lb.
Stress in direction of line (maximum loading) one conductor broken........................ 1860 lb.

TABLE I
ESTIMATED COST PER MILE FOR THE EXTENSION OF TWO NO. 2 A. C. S. R. USING 300 FOOT SPANS

Material	Unit Cost	Quantity	Amount
No. 2 A. C. S. R.	$0.0208	10,700 ft.	$222.56
5/16 in. guy wire	0.018	440 ft.	7.92
30 ft. western cedar poles	7.14	18	128.52
35 ft. western cedar poles	11.92	2	23.84
Everstick Anchors	1.52	4	6.08
No. 4 X insulators	0.27	8	2.16
Pole shims (large)	0.12	16	1.92
2 bolt guy clamps	0.42	32	13.44
5 ft. 7 in. cross-arms	0.69	20	13.80
Cross-arm braces	0.24	32	7.68
No. 581 clamp pins	0.457	40	18.28
5/8 by 12 in. galvanized machine bolts	0.083	16	1.33
5/8 by 16 in. galvanized machine bolts	0.105	2	0.21
5/8 by 5 in. galvanized lag bolts	0.0411	16	0.66
1-1/2 by 4-1/2 in. galvanized carriage bolts	0.0315	32	1.01
6600 volt pin type insulators	0.14	40	5.60
Aluminum sleeves (2 sleeves per joint)	0.16	4	0.64
Aluminum armor for insulator ties	0.35	2.9 lb.	1.02
No. 6 tie wire (annealed aluminum)	0.33	3.0 lb.	.99
Total Material			457.66
Labor			
Pole crew	5.94	12 hrs.	71.42
Line crew	3.75	16 hrs.	60.04
Supervision and engineering			19.72
			151.18
Sundries			
Truck	0.65	28 hrs.	18.20
Tools and injuries—5 per cent of labor			7.43
Right-of-way			54.08
			79.71
Contingencies			
Grand Total			58.35
			$746.90

Note: Pole Work—1 foreman, 1 driver and 6 polemen can set 12 poles per day of 8 hr.
Line Work—1 foreman, 2 linemen and 2 groundmen can install cross-arms, string wire and tie in 1 mi. in 2 days of 8 hr. each.

Where secondary mains are necessary, 30 ft., 6 in., top poles spaced 150 ft. apart are used except for transformer poles which must have not less than 7 in. tops. This permits the use of No. 6 or larger, hard-drawn copper secondary mains installed on racks. All transformer connections are of copper and the copper conductors are connected to the aluminum conductors with approved clamps.

Results Achieved

During the fall and winter of 1925-1926 some interesting data were collected on a few rural lines.

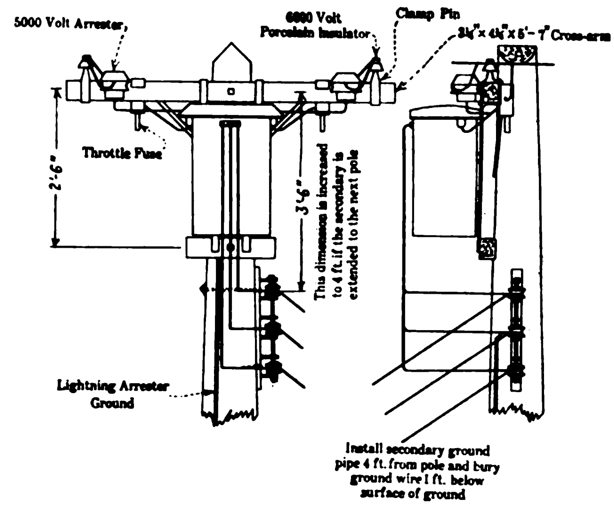

FIG. 3—TRANSFORMER INSTALLATION SUPPLYING SERVICE DROP

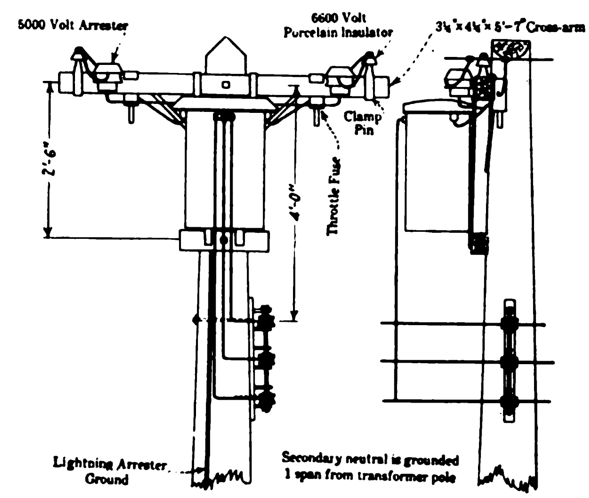

FIG. 4—TRANSFORMER INSTALLATION SUPPLYING SECONDARY MAIN

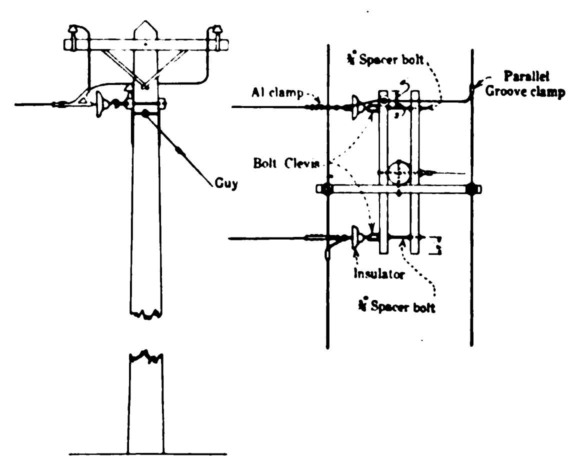

FIG. 5—METHOD OF MAKING DEAD-ENDS AND BRANCH-LINE TAPS

TABLE II
RURAL LINE SURVEY—AVERAGE LINE, TRANSFORMER AND CUSTOMER DATA

	Line No. 1	Line No. 2	Line No. 3	Line No. 4	Line No. 5	Average
Date of special test period	10/23/25 to 10/30/25	1/8/26 to 11/14/26	1/7/26 to 1/13/26	12/17/25 to 12/24/25	1/18/26 to 1/26/26	Winter
Number of customers per line	6	6	13	23	25	14.6
Length of line in mi	0.57	0.75	1.73	4.93	3.70	2.34
Average number of customers per mi	10.5	8.	7.5	4.66	6.75	6.*
Average size of farm served—acres	74.	63.	43.	88.	59.	66.*
Average load applied for at time customers requested service—kw.	9.25	4.54	3.34	6.15	5.63	5.59*
Average initial connected load at time customers were given service—kw	7.75	5.68	3.70	6.51	3.81	5.11*
Average kw. connected load per customer at time of special test period—Total	9.69	7.296	4.613	8.684	5.65	6.88*
Average kw. connected load per customer at time of special test period—Lighting	0.877	0.708	0.552	0.875	0.845	0.80*
Average kw. connected load per customer at time of special test period—Ranges	7.08	3.785	2.691	5.350	3.318	4.20*
Average kw. connected load per customer at time of special test period—Laundry equipment	0.708	0.466	0.695	0.834	0.554	0.667*
Average kw. connected load per customer at time of special test period—Pump motors	0.685	2.090	0.59	0.557	0.746	0.761*
Average kw. connected load per customer at time of special test period—Cream separator motors	0.12	0.15	0.044	..	..	0.031*
Average kw. connected load per customer at time of special test period—Miscellaneous equipment	0.22	0.097	0.041	1.068	0.172	0.421*
Average size of transformers on line—kv-a	7.5	4.5	2.6	6.6	4.5	5.24*
Average 15 min. kv-a. demand on transformers during test period	3.60	2.64	1.61	3.11	2.19	2.63
Average transformer demand factor during test period (1)	0.19	0.298	0.32	0.273	0.333	0.28
Maximum 15 min. kw. demand of line during test period	5.54	6.6	8.45	15.4	12.	9.60
Line power factor at time of maximum demand	94%	89%	97%	96%	93.8%	94%
Demand factor of line during test period (2)	0.095	0.151	0.141	0.077	0.085	0.109
Diversity factor between line and transformer demands (3)	0.514	0.654	0.57	0.344	0.342	0.48
Per cent line, transformer and meter losses (4)	19.5%	24.4%	37.4%	32.8%	28.9%	28.6%
Annual kw-hr. delivered to customers—Average per customer	1694.	826.	640.	1401.		1046*†
Month and kw-hr. of maximum use of energy—Average per customer	239 July	160 Aug.	80 Oct.	124 Sept.		121 Jul.*†
Month and kw-hr. of minimum use of energy—Average per customer	91 Mar.	32 Sept.	28 Apr.	78 Mar.		69 Mar.*†

*Weighted averages.

†New line. Kw-hr. figures not available or considered in determining weighted averages.

1. Transformer demand factors are the ratios obtained by dividing the maximum 15-min. transformer demands by the total transformer connected loads.

2. Line demand factors are the ratios obtained by dividing the maximum 15-min. line demands by the total connected loads on the line.

3. Diversity factors of line and transformers are the ratios obtained by dividing the maximum 15-min. line demand by the sum of the individual maximum 15-min. transformer demands.

4. Per cent losses are based upon the difference between measured kw-hr. line input and kw-hr. recorded on customers meters over an extended period of time.

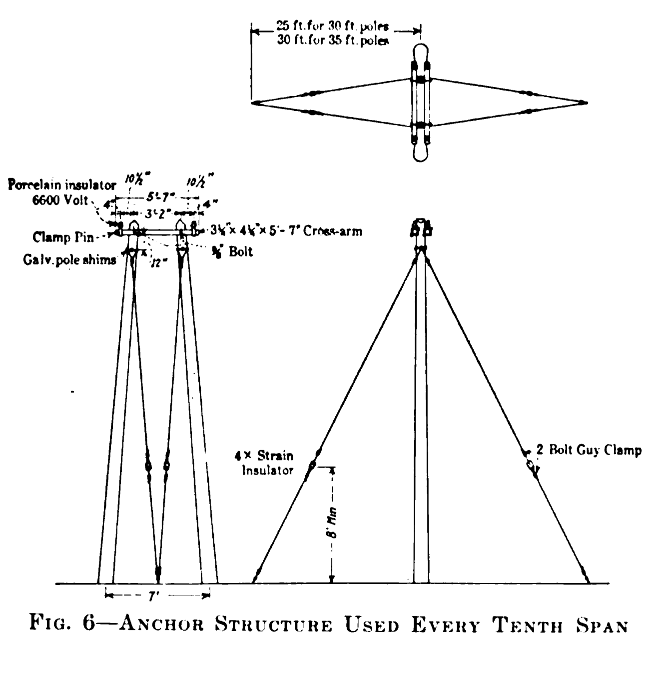

FIG. 6—ANCHOR STRUCTURE USED EVERY TENTH SPAN

These data are shown in Table II. It is interesting to observe that in general more load was found connected than the farmers agreed to connect when contracting to take the service. While the average contracted for was 5.59 kw., the average found connected was 6.88 kw.

Another fact of interest is that the transformer loading was found to be low. It is known from individual consumers' records that the maximum consumption is very apt not to occur in the winter, when these data were taken. This may be partly due to the fact that in the summer the farmer uses his electric range while in the winter he uses a wood range. He also does more pumping in the summer and carries on other operations more extensively. Comparable data taken during the summer months will show whether transformers larger than necessary have been furnished or not.

The power factor at time of maximum load was found to vary from 89 per cent to 97 per cent on the various lines tested. Annual kw-hr. per consumer on the vari-

ous lines averaged from 640 to 1694. Line, transformer, and meter losses were found to vary from 19.5 per cent to 37.4 per cent.

Fig. 8 shows the number of consumers served under the rural rate by years from 1920, when the rate was adopted, to January 1, 1926, when there were 2740 rural consumers connected.

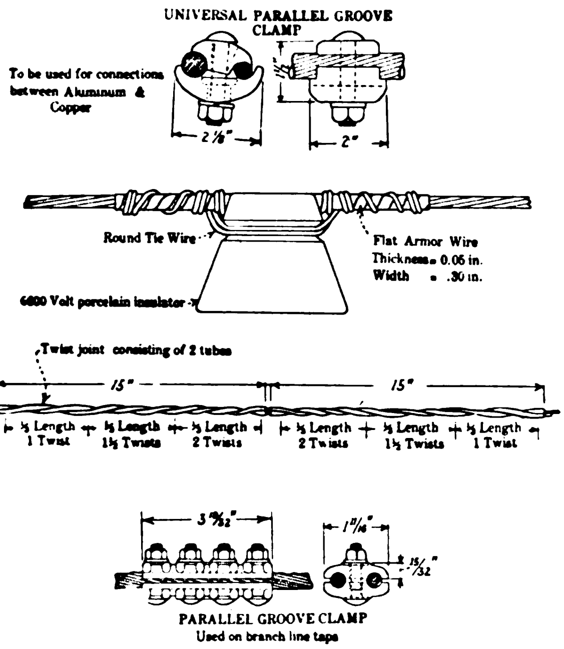

Fig. 7—Clamps, Splice and Tie

Conclusion

Utility companies must view the rural business broadmindedly and provide a reasonable line extension plan, and rate schedule which will encourage the use of the service. A rate schedule designed to pay full returns on investment from the very start, by using burdensome minimum charges or high rates per kw-hr., will produce the opposite result.

A financing arrangement has been found to be necessary, because a rural line extension project involves a number of farmers, all of whom must arrive at the buying point at one time. Where the farmers' activities are somewhat varied, all may not have the funds available at the time the project is developed to the final stage. If it cannot be concluded then but has to be postponed because some do not have the funds available, when it is reopened, some of the others may not have the funds available, and often a project is delayed for an indefinite period of perhaps a year or two. A farmer who can afford to go into such a project at all will have the funds available at sometime within a year. A plan whereby his financial obligations can be taken care of satisfactorily until such time as he has the funds available leaves no obstacle in the way of concluding the negotiations when all agree upon terms.

Experience has demonstrated that the all important thing in general rural electrification is to make the service available to the farmers. The records show that as soon as the service is available the farmers will find new and increasing ways of utilizing it as industries in the urban centers have done and are continuing to do. Every farm can be made a laboratory in a greater or lesser degree for carrying on experimental work, and the greater the number of farms carrying on such work, the greater will be the increase of new applications for the service. It is important, therefore, for utilities to cover their rural territories as quickly as possible with suitable supply lines. This can be done with reasonable assurance that load not contemplated now will develop as new uses for the service are found and as the people come to realize, as they can only through use and reasonable encouragement on the part of the utility, its many and varied advantages.

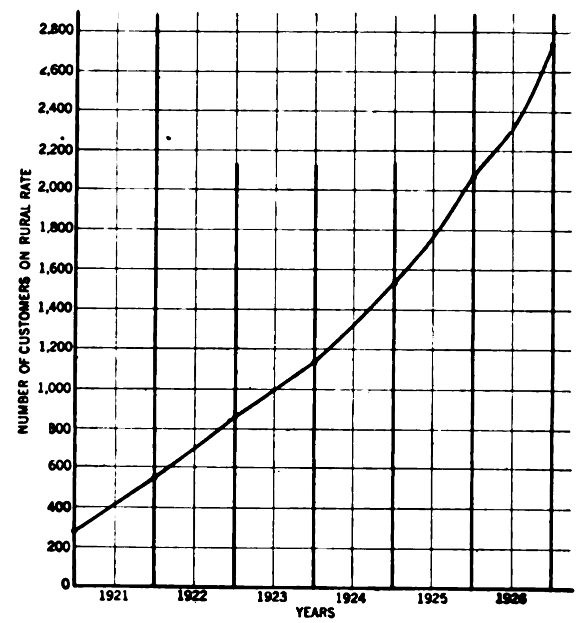

Fig. 8—Number of Rural Customers on Line of the Milwaukee Electric Railway and Light Company and Associated Companies by Years

ELECTRIC "EYE" SORTS CIGARS

A cigar sorting machine has been perfected for use by cigar manufacturers, which has proved exceptionally accurate and speedy in its work. Cigars are sorted according to the shade of their coloring into no less than thirty separate grades, and to do this successfully requires, in a human, an exceptionally well trained eye. Recently an electrically operated machine has been developed for this purpose which will do this work with greater speed and accuracy. As this device automatically picks up each cigar and holds it up to its "eye," a photoelectric cell, the various shades of brown cause varying reactions in the photoelectric cell, and relays actuated by these different currents select the compartment in which the cigar belongs. The machine grades sixty cigars every minute.

A Contribution to Research on the Experimental Determination of the Losses in Alternators

BY EDOUARD ROTH[1]
Associate, A. I. E. E.

Synopsis.—In this paper the author deals with one of the questions with which the International Electrotechnical Commission is at present occupied; namely, the determination by simple tests of the actual losses in alternators. The author first reviews the existing rules and then states the variation of the losses in alternators as a function of the load and as a function of the power factor. His paper contains records of experimental researches which he has made and which serve on the one hand as a basis for discussion of the theoretical considerations which he develops and on the other hand to compare the actual losses with those obtained by the methods given in the rules at present in force. The author does not present definite conclusions since, in his opinion, these investigations ought to form the basis for a program of future researches and ought to serve as the basis for discussions in the Rating Committee of the International Electrotechnical Commission.

* * * * *

Introduction

The separate loss method is still often considered as sufficient for the experimental determination of the efficiency of electric machines. In this method a no-load test at the normal voltage gives the mechanical losses, friction and windage losses, as well as the core or magnetic losses. The electrical losses due to the current in the armature and the excitation circuit are calculated on the basis of the resistances, when hot, of the various circuits and the currents in these circuits. This method gives, of course, good results in the case of small machines and it is not desired to supersede it, but in the case of large machines, and especially in large alternators it gives absolutely incorrect results. In fact, this method does not take into account either the actual electrical losses, or the fact that the iron losses correspond to an internal voltage higher than that at the terminals, and it totally excludes the phenomena by which the no-load conditions differ from the conditions under load. In short, it neglects the stray load-losses.

Therefore, the modern tendency is to investigate methods by which, with simple tests, the actual losses in the machines may be determined with great accuracy when carrying full load.

The American Institute of Electrical Engineers was the first of the electrical associations in any of the various countries to establish elaborate rules on this subject.

In what follows the excitation loss will not be taken into consideration since this can be determined with sufficient accuracy by simple tests. In fact, rules established by these associations give methods which make it possible to calculate the exciting current on load from the no-load and the short-circuit characteristics. Besides, it is always possible to get the exact value of the excitation loss by a test on load. It is much more difficult to determine the magnetic loss and particularly the electric loss in the armature.

1. Engineer-in-Chief, Société Alsacienne de Constructions, Mécaniques, Belfort, France.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

With regard to core loss, the Standards of the A. I. E. E. (1925 revision) read as follows:

"7-468 Core losses.—Drive the machine from an independent motor, the output of which shall be suitably determined. The brushes shall be in contact, and the machine shall be excited, so as to produce at the terminals a voltage corresponding to the calculated internal voltage for the load under consideration. The difference between the output obtained by this test and that obtained by test under paragraph 7-467 shall be taken as the core loss.

The internal voltage of synchronous machines shall be determined by correcting the terminal voltage for the resistance drop only."

To determine the losses on load, these Standards propose to augment the core losses by the stray load-losses. In regard to the stray load-losses they read as follows:

"7-470 Stray Load Losses.—These include iron losses, and eddy-current losses in the copper, due to fluxes varying with load and also to saturation.

Stray load-losses shall be determined by operating the machine on short-circuit and at rated-load current. This, after deducting the windage and friction and $I^2 R$ loss, gives the stray load-loss for polyphase generators and motors."

This method of obtaining the stray load-losses from the short-circuit tests has likewise been adopted in France. However, the following method may also be used alternatively:

"With the rotor removed and the stator winding carrying normal current at rated frequency, the power input is measured.

This value, after deduction of the $I^2 R$ losses, represents the supplementary losses."

Several comments will be made on these rules: First, it is easy to see that the geometrical addition of the ohmic drop to the normal voltage has no influence whatever on the value of the iron loss to be introduced in the calculation of the efficiency. However, this rule shows that a certain correction should be made to the normal voltage to account for the actual core loss on

load. One of the main objects of this study is to determine the precise amount of this correction.

Then, with regard to losses other than the core loss, that shall be accounted for on load, two questions should be answered; first, do the two tests give the same result and second, in what proportion is this result to the actual losses.

It is well known that in turbo alternators or in general, in high armature reaction alternators, the *short-circuit losses* measured are very much too high; the tests reported hereafter were made to determine whether or not this is the case with salient pole alternators of small size and small armature reaction. It is essential to know the value of the armature reaction in determining the accuracy of the short-circuit test as a method of measuring the stray load-loss. Several authors[2] have already given reasons for this experimental feature in the case of turbo alternators, and it is needless to go into them here. However, these reasons cannot be applied to salient pole alternators; but contrary to what is generally admitted, it seems that the iron loss on short circuit cannot be neglected

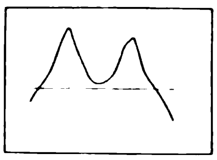

FIG. 1—FIELD CURVE ON SHORT-CIRCUIT

on account of the well-known shape of the field curve. See Fig. 1 as an example of such curves.

On the contrary, the results of the test with *rotor removed* seem to be nearer actual conditions, even in the turbo alternators. One objection to this test is that it is carried out with a very low power factor which implies a lack of accuracy in the readings of the wattmeters, especially if current transformers are used.

Reviewing the situation it may be stated that the core loss determined according to the A. I. E. E. Standards is certainly too small, while the electrical losses resulting from the short-circuit test are often too large. However, it may be possible, as already expressed at the Hague, that the sum of these two indications is sufficiently close to the actual value of the losses on load. In the event that this could be proved for a sufficient number of very different machines, the prescribed rules of the Standards would hold good.

We trust that the tests reported hereafter will shed some light on these various questions. These tests have been carried out at the works of the Société Alsacienne de Constructions Mécaniques, at Belfort. These measurements are very delicate, and in order that definite conclusions be reached other manufacturers should make similar tests. We consider the present study more as a basis for discussion and as a program for further investigations.

Definitions. As in the plain separate loss test the losses will still be segregated into mechanical, magnetic and electric. No special comment is necessary with regard to the first; these include the sum P_0 of the friction losses in the bearings, the friction losses of the brushes, etc., as well as the windage and the ventilation losses. By *magnetic* losses is meant those due to flux. These are developed principally in the active iron, however, they can develop elsewhere. They include, for example, the losses at the surface of the pole pieces, those in the fastening bolts and in the end-bells or end-plates, where they are generated by the leakage flux of the inductor. They vary with the load and are in consequence a function of both the current I and the voltage U. By *electric* losses are meant the losses proportional to the square of the current. They appear not only in the copper of the armature but in every part of the machine where currents are induced by the main current, such as end-bells, end-plates, dampers, etc.

Neglecting, as stated above, the excitation loss in the machine, the total losses, P, can be represented by the following equation:

$$P = P_0 + f(U, I) + a I^2 \qquad (1)$$

The above definitions do not mention the stray load losses as these are included either in the magnetic or electric losses.

Electric losses. The coefficient a in the expression $a I^2$ is equal to the resistance r of the winding, multiplied by a factor k greater than unity.

$$a = k r$$

It should be noted here that the electric losses are not necessarily proportional to the square of the current. When the solid parts subjected to the induced currents become saturated by flux, it may happen that some of these terms vary according to another law. But, as stated above, we will neglect such variation and assume the law of the square.

In what follows we will assume that for a given temperature of the machine and consequently for a well determined value, r, of the resistance, the value of k is independent of the value of the current and of its phase angle.

Variation of the magnetic loss with the load. Curve I of Fig. 2 represents the no-load losses of an alternator running as a synchronous motor at no-load, with minimum current. This curve we shall call the "no-load loss characteristic." It is desired to find on this curve the value of the virtual internal voltage corresponding

2. S. F. Barclay, "The Mechanical Design and Specification of the Turbo Alternator Rotor." *Jour.* I. E. E., 1919, p. 483.

E. Roth, "Les pertes supplémentaires dans les machines électriques" *Bulletin de la Société Francaise des Electriciens,* 1923, p. 497.

E. Roth, Les alternateurs de 40,000-kw. construits par la Société Alsacienne de Constructions Mécaniques pour la Centrale de Gennevilliers de l'Union d'Electricité. *Revue Générale de l'Electricité,* 24 Février 1922, XIII, p. 311.

to the magnetic loss on load, for a given current and a given phase angle, which voltage we will call the "magnetic loss voltage."

Let $O\,A$ (Fig. 3) represent the normal voltage U_0 at the terminals, or else the flux in the machines; add geometrically to $O\,A$ the ohmic drop $A\,B = k\,r\,I$, also the inductive drop $D\,B = x\,I$, due to the leakage flux, to obtain the total electromotive force $O\,D$ (or $O\,D'$ in the case of a leading angle of phase when running as a generator).

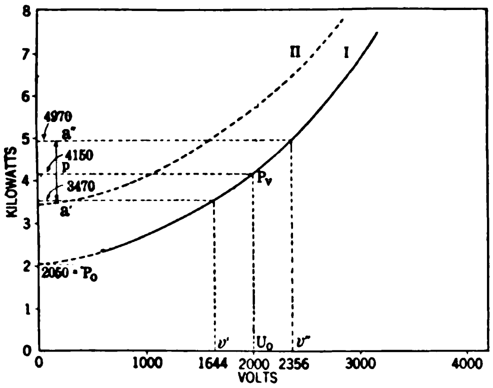

Fig. 2—Characteristics of Core Losses

It would be very simple, as it has been proposed, to adopt for the value of the magnetic loss voltage that corresponding to the vector $O\,D$, as the inductive drop $B\,D$ due to leakage can be measured with sufficient accuracy without difficulty.[3]

This method has already been proposed at the Hague and it may be possible that the results of the studies now in progress will lead to its insertion in the rules.

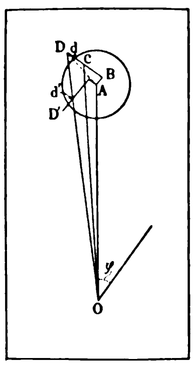

Fig. 3

However, there are several reasons why the voltage $O\,D$ does not represent the magnetic loss voltage.

First, the inductive drop $B\,D$ due to the leakage is composed of two parts: the one $B\,C$ corresponding to the leakage in the end turns of the coils, the other $C\,D$, due to the leakage in the slots. But the flux in the core is only $O\,C$, so that taking the voltage $O\,D$ as the magnetic loss voltage will, therefore, give too high values.

Further, the leakage flux in the slots tends to saturate the teeth which separate the slots belonging to two different phases when the alternator runs on a capacitive load, and tends to weaken the flux in the teeth when it runs on an inductive load, which increases the losses in the first case and reduces them in the second.[4]

Obviously, it may be inferred that it would not be correct to add vectorially the total inductive drop $B\,D$ to obtain the magnetic loss voltage; it seems that a virtual inductive drop $x_p\,I = D\,d$ should be added, (less than $B\,D$), to obtain this voltage. Running with a lagging phase angle, the losses would be smaller than those corresponding to the inductive drop $O\,D$; while with a leading angle of phase they would be higher since $O\,d'$ is greater, in that case, than $O\,D'$.

But a very important experimental fact invalidates these conclusions in great proportion. It is known that the field curve along the surface of the poles of salient-pole alternators varies considerably with the phase angle of the current.

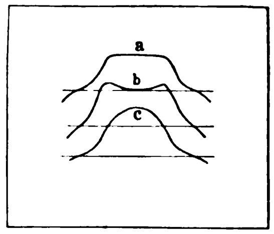

Fig. 4—Field Curves of Alternator
a. No load b. Lagging c. Leading

This curve inflects with lagging armature current (field over-excited) and swells, becoming nearly a sine wave with leading current (field under-excited).

Fig. 4 is an example of such curves. Fig. 4A represents a field curve at no-load and Figs. 4B and 4C correspond to lagging and leading phase angles respectively. But the curves of the type of Fig. 4B give higher losses than those of the shape of Fig. 4C; this is proved theoretically and confirmed by tests. Thus the points d and d' draw nearer again to D and D^1. See Fig. 3. It is proposed to precisely determine, by suitable tests, whether, and by how much, the virtual inductive drop $B\,d = x_p\,I$, which we call the "inductive drop of loss" differs from the inductive drop of leakage $B\,D$.

Owing to the secondary phenomena we have just mentioned there is nothing to indicate that the reactance of loss, x_p, is independent of the phase angle for a given current. However, in the following developments we will assume that the reactance x_p is constant. On this assumption, the current being constant, when the phase angle varies, the point d describes a circle around A

3. E. Roth, "Critique de quelques méthodes de mesure de la resistance due aux fuites de l'induit des machines électriques rotatives a courants alternatifs." *Revue Générale de l'Electricité* du 7 Juin 1925, XVII, p. 217.

4. E. Roth, "Les pertes supplementaires dans les machines electriques," *Bulletin de la Société Francaise des Electriciens*, 1925, p. 495.

as a center, with $A\,d$ as a radius. This assumption as well as that of the constancy of the factor k shall be justified by tests.

Determination of the constants k and x_p from measurements of the losses, the machine being run as a synchronous motor at no-load, with variable current:[5] It is possible to run an alternator approximating normal conditions at no load as a synchronous motor, either over-excited or under-excited at nearly zero power factor, the current being the same in each case. The power input in these two tests represents the losses, and will not only give the reactance of loss x_p and consequently the magnetic loss, but also the electric losses and, therefore, the factor k.

The conclusions that can be drawn from these tests amply justify the assumptions, for these are the limiting values of the secondary phenomena and particularly of the variation of the shape of the field curve.

In fact, for the over-excited conditions, the total losses P'' may be expressed for a three-phase alternator by

$$P'' = P_0 + 3\,k\,r\,I^2 + f\,(U'') \tag{2}$$

r being the resistance per phase. U'' is the loss voltage corresponding to these running conditions (Fig. 2) and as shown in Fig. 5 is approximately:

$$U'' = O\,N'' = U_0 + x_p\,I\,\sqrt{3} \tag{3}$$

x_p being the reactance of loss per phase.

Similarly, in the under-excited conditions:

$$P' = P_0 + 3\,k\,r\,I^2 + f\,(U') \tag{4}$$

where

$$U' = O\,N' = U_0 - x_p\,I\,\sqrt{3} \tag{3 a}$$

Subtracting (4) from (2)

$$p = P'' - P' = f\,(U'') - f\,(U') \tag{5}$$
$$= a'' - a' \text{ taken on Fig. 2.}$$

The question is then to obtain by successive approximations, which are easily made, two values of U' and U'', symmetrical with regard to U_0, and such that the difference of the losses measured on the loss characteristic (Fig. 2) is equal to p.

Then:

$$x_p = \frac{U'' - U_0}{I\,\sqrt{3}} = \frac{U_0 - U'}{I\,\sqrt{3}} \tag{6}$$

Substituting this value of x_p in equation (3) gives U'', and this, when substituted in equation (2) determines $K\,r$. Now, since r is known, K is obtained.

Knowing the values of k and x_p, the loss at any load may be calculated. The magnetic loss voltage $O\,M$ for any running condition may be determined from the diagram of Fig. 5; and knowing this, the magnetic losses may be obtained from the loss curve, to which the $k\,r\,I^2$ losses are to be added and also the mechanical losses P_0.

5. In other words, readings of the power input are taken when the alternator is run as a synchronous motor for the V-curve test.

It is to be noted that this method, as in the case with the rotor removed, involves the disadvantage of being carried out at a low power factor. However, with certain precautions, this method can be carried out successfully, as the following tests indicate. If wattmeters gave correct readings at low power factor, this method could be extended to the calculation of the losses in any running condition, provided, of course, that the above assumptions be justified by tests.

Study of the curve of the losses as a function of current when running as a synchronous motor at no-load. The above assumptions could first be checked in the following manner: Simultaneously with the readings for the V curve, readings of the corresponding losses are taken, and then a curve of these losses is drawn in terms of the current. We have called this a comet curve because of its special shape. Readings of the losses are then taken for the same current I_1 on the two branches of the curve, corresponding to which, values of x_p and k are deducted according to the above method and from these values the comet curve is plotted. The

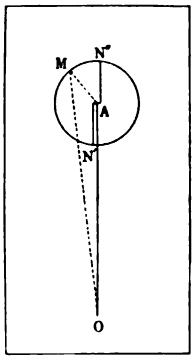

Fig. 5

coincidence of the calculated curve and that obtained from test will justify the assumptions.

This calculation is possible only when the equation of the no-load-loss characteristic is known. It is particularly simple in non-saturated machines where this curve is a quadratic parabola.

In this case it is possible to avoid the cut-and-try method by solving equation (5); $f\,(U)$ is then of the form, $\frac{U^2}{\rho}$. The analytical solution is given by the equation:

$$p = \frac{U''^2}{\rho} - \frac{U'^2}{\rho} \tag{7}$$

since:

$$(U''^2 - U'^2) = (U'' - U')\,(U'' + U')$$
$$U' + U'' = 2\,U_0 \tag{8a}$$
$$U'' - U' = 2\,x_p\,I_1\,\sqrt{3} \tag{8b}$$

Thence:

$$p = \frac{(U'' + U')\,(U'' - U')}{\rho} = \frac{4\,U_0\,x_p\,I_1\,\sqrt{3}}{\rho}$$

which gives:

$$x_p = \frac{p\,\rho}{4\,U_0\,I_1\,\sqrt{3}} \tag{9}$$

ρ can then be determined by setting up the following expression for the losses corresponding to the voltage U_0—see Fig. 2.

$$\frac{U_0^2}{\rho} = P_v - P_0 \text{ and } \rho = \frac{U_0^2}{P_v - P_0}$$

k is then deducted and thus it is possible to calculate the electric losses and to plot the comet curve for the various values of the current.

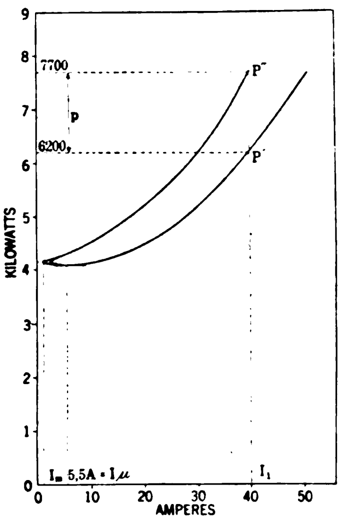

FIG. 6—COMET CURVE

Were it possible to assume the no-load loss characteristic to be a parabola of the second order, the above mentioned method could be employed to give a first approximation of the value of x_p, later to be revised by a cut-and-try process.

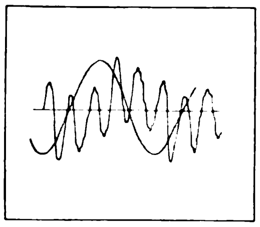

FIG. 7

Formulas (**8a**) and (**8b**), and the conclusions drawn therefrom, have been based on the assumption of zero power factor. This condition is fulfilled even for small values of current, and it is only for currents near the minimum of the V curve that the method indicated fails.

If it is assumed that the no-load-loss curve is a quadratic parabola, it is possible to calculate the comet curve for the exact value of the angle of phase; however, to give this study a practical instead of a theoretical aspect, we will not present this development here. The curve of Fig. 6 has thus been calculated, and for the current I, the corresponding losses are P'' and P'.

Even when variable power factor is taken into account near minimum current, the points of the comet curve do not correspond with those of the curve obtained from the tests. It is known that the wave form of minimum current of a synchronous motor is very distorted (Fig. 7). The minimum current read will be higher than that corresponding to the voltage and the power. This explains why the test results give the dotted part of the comet curve shown in Fig. 6.

The comet curve has a peculiar characteristic which may appear paradoxical at first. This feature is of no practical interest. However, it may confirm our hypothesis. It will be noticed on Fig. 6 that the minimum loss does not correspond to the minimum current. The losses decrease in a certain part of the curve when the current increases. This minimum loss occurs when the conditions are such that the increase of the electrical losses $k\,r\,I^2$ is less important than the corresponding decrease of the magnetic loss. Hence, this minimum occurs for a certain ratio between x_p and $k\,r$.

The existence of this minimum is easily explained analytically in the simple case of the quadratic parabola. Since this minimum can only occur in under-excited conditions, formula (4) reads as follows:

$$P' = P_0 + k\,r\,I^2 + \frac{(U_0 - x_p\,I\,\sqrt{3})^2}{\rho}$$

which gives:

$$p' = \left(P_0 + \frac{U_0^2}{\rho}\right) - \frac{2\,x_p\,U_0\,\sqrt{3}}{\rho}\,I + 3\left(\frac{x_p^2}{\rho} + k\,r\right) I^2$$

as the equation of the lower branch of the comet curve, on the assumption of zero power factor, which as stated, is permissible, even for small values of current.

This parabola gives a minimum corresponding to a current:

$$I_u = \frac{U_0}{\sqrt{3}}\;\frac{x_p}{(x_p^2 + k\,r\,\rho)} \tag{12}$$

and a power:

$$P_u = \left(P_0 + \frac{U_0^2}{\rho}\right) - \left\{\frac{U_0^2}{\rho}\right\}\left\{\frac{x_p}{x_p^2 + k\,r\,\rho}\right\} \tag{13}$$

$$P_u = \left(P_0 + \frac{U_0^2}{\rho}\right) - \frac{x_p}{\rho}\,U_0\,I_u\,\sqrt{3}$$

which, remembering that the term $P_0 + \dfrac{U_0^2}{\rho}$ represents the no-load loss P_v at the pressure U_0, therefore, can be written

$$P_u = P_v - \frac{x_p}{\rho}\,U_0\,I_u\,\sqrt{3} \tag{13a}$$

This minimum power has no physical existence unless the value of the minimum current I_m taken by the

motor be less than the current I_u corresponding to the minimum of the losses

$$I_m < I_u \qquad (14)$$

It can be shown that this corresponds to the condition

$$\frac{P_v}{P_v - P_0} k r < x_p \qquad (15)$$

or

$$\frac{\text{Total no-load losses}}{\text{No-load core losses}} k r < x_p$$

Experimental researches. A series of tests have been carried out on a 320 kv-a. 3000-volt, 61.6-ampere, 50-cycle, 26-pole synchronous motor. The results of these tests have been translated into the curves of Figs. 1, 2, 4, 6 and 8. The comet curve of Fig. 6 and the field curve of Fig. 4 have not been obtained at the normal voltage of 3000 but at 2000 volts, as the no-load loss characteristic at the latter voltage very nearly follows the law of the square, and also because the

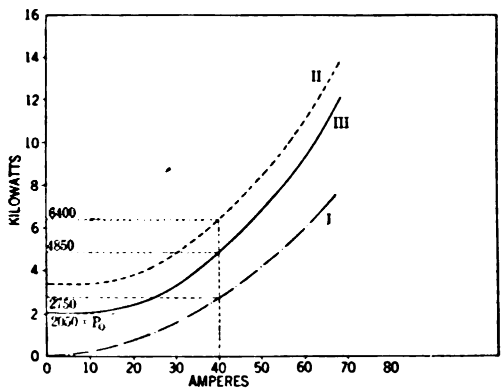

FIG. 8—CHARACTERISTICS OF ELECTRICAL LOSSES
I—Losses, measured, rotor removed
II—Short circuit losses

differences in the field curves are more pronounced when the alternator is not saturated.

As already explained, this characteristic has been obtained from the value of the power input with the machine running as a synchronous motor, at no-load and at the minimum current. The motor became unstable below 620 volts. Therefore, the dotted part of the curve had to be assumed in order to determine the mechanical losses; $P_0 = 2050$ watts. The total losses P_v on no-load at $U_0 = 2000$ volts are 4150 watts, which gives as the iron loss $4150 - 2050 = 2100$ watts.

ρ will be obtained from

$$2100 = \frac{2000^2}{\rho}$$

thence, $\rho = 1905$ ohms.

The iron losses at 2356 volts and 1644 volts are:
$4970 - 2050 = 2920$ watts and
$3470 - 2050 = 1420$ watts, respectively.

In order to determine whether the law of the square is satisfied, at 2356 volts we find

$$\frac{2356^2}{1905} = 2905 \text{ watts against } 2920 \text{ watts;}$$

and at 1644 volts

$$\frac{1644^2}{1905} = 1418 \text{ watts against } 1420 \text{ watts}$$

These results are practically identical. At 3000 volts, on the contrary, the curve considerably deviates from the quadratic parabola.

Let us now refer to the comet curve of Fig. 6. With the alternator running at no load as an over-excited synchronous motor, and carrying an armature current of 40 amperes, the power input was 7700 watts as compared with 6200 watts for the under-excited conditions.

Then $p = P'' - P' = 7700 - 6200 = 1500$ watts

Formula 9 gives for the reactance of loss,

$$x_p = \frac{p\,\rho}{4\,U_0 I_1 \sqrt{3}} = \frac{1500 \times 1905}{4 \times 2000 \times 40 \sqrt{3}} = 5.14 \text{ ohms.}$$

and for the inductive drop of loss,

$$x_p I_1 \sqrt{3} = 5.14 \times 40 \sqrt{3} = 356 \text{ volts}$$

The loss voltages are respectively:

$$U'' = U_0 + x_p I_1 \sqrt{3} = 2000 + 356 = 2356 \text{ volts}$$

$$U' = U_0 - x_p I_1 \sqrt{3} = 2000 - 356 = 1644 \text{ volts}$$

Equation (2)

$P'' = P_0 + f(U'') + 3 k r I^2$ becomes

$$7700 = 4970 + 3 k r I^2$$

Whence $3 k r I^2 = 2730$ watts.

The resistance r per phase is

$$r = 0.52 \text{ ohms}$$

which gives

$$k = \frac{2730}{3 \times 0.52 \times 40^2} = 1.094$$

or $k r = 0.569$ ohms

Thus, we know all the data required for the calculation of the comet curve. This has been traced on Fig. 6 and practically coincides with the curve obtained from the tests. The coincidence is particularly marked for the minimum P_u of the losses. The existence of this minimum is evidenced by the verification of the following inequality:

$$\frac{\text{Total no-load losses}}{\text{No-load iron losses}} k r < x_p$$

which gives in our case;

$$\frac{4150}{2100} \times 0.569 < 5.14$$
$$1.13 < 5.14$$

The corresponding current I_u for minimum input is, according to (12)

$$I_u = \frac{U_0}{\sqrt{3}} \times \frac{x_p}{x_p^2 + k\, r\, \rho} = \frac{2000}{\sqrt{3}} \times \frac{5.14}{5.14^2 + 0.569 \times 1905}$$

$I_u = 5.35$ amperes.

The minimum power P_u is, according to (**13a**)

$$P_u = P_v - \frac{x_p}{\rho} U_0 I \sqrt{3}$$

$$P_u = 4150 - \frac{5.14}{1905} 2000 \times 5.35 \sqrt{3}$$

$$P_u = 4100 \text{ watts}$$

this being 50 watts less than the total no-load losses.

The minimum current I_m measured was 2.1 amperes. This high value results from the distortion of the current wave (Fig. 7). If the current wave were a sine, the actual current should be:

$$\frac{4150}{2000\sqrt{3}} = 1.2 \text{ amperes}$$

The problem is now to determine, first the ratio of the reactance of loss x_p to the leakage reactance x and then the ratio of the actual losses to the losses given, either by the test with rotor removed or by the short-circuit test.

The ratio of reactances was obtained by a method proposed by the writer[6]. The rotor being removed, a rectangular coil was arranged on the stator core, two sides being parallel with the axis of the machines and the two other sides running along the ends of the core. This coil embraced one pole pitch and consisted of one or more wires.

The stator winding was then supplied with a current I_s of frequency f and readings were taken of the impressed voltage U_s, and also of the voltage u_s across the ends of the rectangular coil.

Let v be the number of turns of the coil, r_s and r_v respectively the resistances of the coil and the voltmeter across the terminals of the coil. The flux across the cylindrical space inside the stator is:

$$\Phi_e = \frac{u_s \times 10^8}{4.44\, f\, v} \left(1 + \frac{r_s}{r_v}\right) \text{Maxwell's} \qquad (\mathbf{16})$$

corresponding to a pressure at the terminals of a three-phase machine of

$$U_e = 2.13 \sqrt{3}\, f\, N\, \Phi_e\, 10^{-8} \text{ volts} \qquad (\mathbf{17})$$

N being the number of conductors in series per phase.

The reactance x due to the leakage of the stator is then:

$$x = \frac{U_s - U_e}{I_s \sqrt{3}} \qquad (\mathbf{18})$$

For a current $I_s = 67$ amperes, the following voltages have been obtained,

$$U_s = 861 \text{ volts}, \quad u_s = 0.441 \text{ volts}$$

at $f = 50$ cycles per second.

The coil was made up of but one wire making $v = 1$; r_s and r_v were

$$r_v = 4.7 \text{ ohms}, \; r_s = 0.17 \text{ ohms}$$

corresponding to

$$\frac{r_s}{r_v} = 0.036$$

Hence,

$$\Phi_e = \frac{0.441 \times 1.036 \times 10^8}{4.44 \times 50} = 0.207 \times 10^6$$

and for $N = 728$ conductors per phase,

$U_e = 2.13 \sqrt{3} \times 50 \times 728 \times 0.207 \times 10^{-2} = 278$ volts

Therefore,

$$x = \frac{861 - 278}{67\sqrt{3}} = 5.02 \text{ ohms}$$

which corresponds nearly to the value of 5.14 ohms found for x_p.

In this case it is permissible to take as the value of the inductive drop of leakage of the stator that of the inductive drop of loss.

While the above test was made at a variable current, readings of the stator losses were taken, (Curve *I*, Fig. 8) giving, for 40 amperes, a loss of 2750 watts, which is practically equal to the above loss,

$$3\, k\, r\, I^2 = 2730 \text{ watts}$$

The losses on short circuit were measured as follows: The machine was driven by a direct-current motor the power input of which was measured with the alternator running on short circuit. Curve *II*, Fig. 8, gives the input to this motor in terms of the current in the alternator.

For the calibration of the motor the alternator was run on no-load, at a variable voltage, the input to the d-c. motor also being measured. Curve *II*, Fig. 2, has thus been obtained. As Curve *I* on the same figure represents the actual power input to the machine under test, it is possible to obtain the exact losses of the direct-current motor. These are measured by the difference of the ordinates of the two curves.

It is thus possible to determine the curve of the short-circuit losses of the machine as shown by (Curve *III*, Fig. 8). For a current of 40 amperes, the total losses on short-circuit are 4850 watts, of which $P_0 =$ 2050 watts, should be subtracted leaving

$$4850 - 2050 = 2800 \text{ watts}$$

This does not differ greatly from the 2730 watts found above for $3\, k\, r\, I^2$.

Therefore, according to the prescribed rules, the no-load loss P_v, at the normal pressure U_0, should be added to the losses on short-circuit. This gives a total value of

$$4150 + 2800 = 6950 \text{ watts}$$

6. Edouard Roth, *Revue Générale de l'Electricité*, 7 February, XVII, p. 217.

as compared with the values 6200 and 6700 watts obtained when the machine is run at the same current as a synchronous motor, either over- or under-excited.

It should be noted that the method of the comet curve, the method with rotor removed and the short-circuit test give the same result for the electric losses. Further, we have seen that the inductive drop of leakage represents the voltage drop of loss.

NOTE. The tests which have been carried out are relatively simple, as they only involve running the machine at no load. The conditions under which they were made do not enable us to determine the losses that may exist on load at power factors other than zero. Presently another series of tests will be carried out that will enable us to determine the value of these losses for full load and to compare them with those found by the separate loss method.

As already mentioned in this article, it is desirable that other manufacturers make similar tests before definite conclusions are established.

THE FORCE BETWEEN MOVING CHARGES*

BY V. BUSH

The classic theory of circuits, as used by electrical engineers, is founded on the assumption that charge is invariant. The new forces which come into play when charges move, that is, when current flows, are expressed in terms of magnetic fields. According to this view the force between a pair of relatively moving charges is made up of two components, one along the line joining them which is always given by Coulomb's law, and a second perpendicular to this, depending upon the velocity, and expressed by means of magnetic fields. This classic concept involves necessarily a change of mass with velocity in order to account for observed results with high-speed electrons. Such a change of mass is also given by the theory of relativity.

There is an alternative theory of circuits, originally advanced by such men as Gauss and Weber, in which there is only one component of force, and in which the concept of the magnetic field is absent. It is entirely adequate to explain all the experimental results which have been obtained with complete electric circuits. For many years it has been practically abandoned, largely on account of the work of Maxwell. The present paper develops this alternative theory and applies it to the behavior of individual electrons in the belief that the alternative theory also deserves careful attention at this time.

In this alternative scheme mass is a constant, and charge is variant. The various circuit effects, such as the force between wires carrying current and induced voltages, are accounted for on this basis by reason of this variation of charge and without the agency of magnetic fields. Some of the possible objections to the idea are then treated.

When applied to relations inside the atom this alternative method of approach gives results similar to those given by restricted relativity and variant mass. The advance of the perihelion of an electron revolving about a positive nucleus coincides with that obtained by Sommerfeld by the use of Einstein's relativity, and applied to the fine structure of the hydrogen spectrum.

According to this present scheme, there is a critical radius in the free motion of an electron about a positive charge, and this appears significant in connection with our knowledge of the atomic nucleus.

*Abstracted from *Journ. Math. & Phys.* Massachusetts Institute of Technology, Vol. V, No. 3, March 1926.

CORRESPONDENCE

HIGHWAY LIGHTING

Editor, A. I. E. E., Journal:

The communication on page 354 of the April JOURNAL brings up again the old suggestion of street surface lighting by means of a sheet of light distributed from a source in such a way as to confine it below eye level. This suggestion has no doubt been considered by nearly every engineering specialist on street lighting and presents some very interesting features.

I was especially interested in it a number of years ago but found no opportunity for trying it out until 1917, when the Kensico Dam roadway offered an ideal situation. Mr. H. A. Tinson and Mr. C. A. B. Halvorson working with the engineers of the New York Board of Water Supply, produced an installation which was admirably suitable for those particular conditions.

The study of the problem, however, seemed to indicate rather definitely that such an arrangement would not be economically practical for ordinary highways.

Some of the objections to the low mounted units for general conditions are:

1. Relatively short spacing and therefore numerous lighting units are required.
2. The accurate light-controling equipment is high in first cost and relatively inefficient.
3. Glint effect and silhouetting, which are important in highway lighting, are more or less lost, so that the lighting is less effective for vision than the amount of light on the surface would indicate.

This method of lighting, therefore, does not seem particularly promising under present conditions.

The Kensico Dam installation is described in a paper by C. A. B. Halvorson and A. B. Oday, see *Transactions*, Illuminating Engineering Society, April 3, 1920, page 153, or *Electrical World*, February 14, 1920, page 371.

G. H. STICKNEY

Harrison, N. J.

A Method for Determining the Sign of the Smaller Wattmeter Reading in Balanced Three-Phase Power Measurements

By H. K. HUMPHREY[1]

Member, A. I. E. E.

WHEN three-phase (three-wire) power is measured by the two-wattmeter method, the smaller reading may be either positive or negative, so that the total power, which is the sum of the two wattmeter readings, may be obtained by adding the smaller reading to the larger in one case, and by subtracting it in another case. On balanced load this reading is positive, and must be added, when the power factor is greater than 50 per cent; it is negative and must be subtracted when the power factor is lower than 50 per cent. However, unless the power factor is known, it is necessary to make sure by some other means which is the correct sign for this smaller reading; failure to do so has sometimes led to curious if not serious error. For balanced load, there are in use several methods of determining the sign of this reading at the time of test. These require that either the connections or the load be altered and that additional data be taken. Often enough, however, this sign is questioned only after the test is completed and the apparatus scattered, and in this case it is apparent that a determination which depends upon a simple consideration of the usual instrument readings would be useful. Such a method is the one to be described. It is applicable only to balanced three-phase loads and sinusoidal wave forms, but in itself gives an indication of the extent to which results are affected by variation from these conditions.

The belief seems to be general that for any set of readings of line voltage, E_L, line current, I_L, and the two wattmeter readings, W_1 (larger) and W_2 (smaller), there are two possible conditions of power factor, one greater than 50 per cent in which W_2 is positive, and one lower than 50 per cent in which W_2 is negative. That is, for instance, if E_L is 200 volts, I_L, 31.1 amperes, W_1, 5.60 kw., and W_2 + 0.34 kw. (power factor 55 per cent), there would be expected for some lower power factor the readings; E_L, 200 volts, I_L, 31.1 amperes, W_1, 5.60 kw., W_2 − 0.34 kw. This is not the fact, however; there is no such possible set of readings on a balanced system with sine-wave voltage and current. The condition of load which would give a reading W_2 of − 0.34, with the same values of voltage and current would give a reading W_1 of 5.23 kw., not 5.60; or, for the same voltage, the load which would give 5.60 kw. for W_1 and − 0.34 kw. for W_2 would require 33.3 amperes, not 31.1. The accompanying curve, which shows each wattmeter reading, W_1 and W_2, separately for all values of power factor ($E_L I_L = 1.0$), will make this fact clear. The curves are obtained by plotting against cos ϕ the ratios $\frac{W_1}{E_L I_L}$ and $\frac{W_2}{E_L I_L}$ calculated from $W_1 = E_L I_L \cos(\phi - 30 \text{ deg.})$ and $W_2 = E_L I_L \cos(\phi + 30 \text{ deg.})$[2]

Stated in a somewhat different form, any particular pair of wattmeter readings (sign considered, of course) can be obtained for only one value of the product $E_L I_L$ or of volt-amperes ($v\sqrt{3}\,E_L I_L$); this value is not the same for positive W_2 as for negative, which may be shown as follows

The power is, of course, $W_1 + W_2$; the wattless volt-

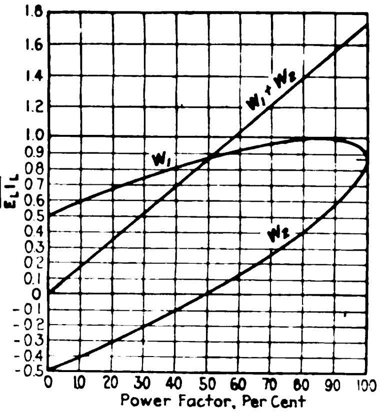

Fig. 1

amperes are $v\sqrt{3}(W_1 - W_2)$[3]. From these, the volt-amperes, VA, can be computed:

$$\begin{aligned} VA^2 &= (\text{watts})^2 + (\text{wattless volt-amperes})^2 \\ &= (W_1 + W_2)^2 + 3\,(W_1 - W_2)^2 \\ &= 4\,(W_1^2 + W_2^2 - W_1 W_2) \qquad (1) \end{aligned}$$

Equation (1) shows that the volt-amperes are always larger if W_2 is negative. But the volt-amperes can also be computed from

$$VA = v\sqrt{3}\,E_L I_L \text{ or } VA^2 = 3\,E_L^2 I_L^2 \qquad (2)$$

The values of VA (or of VA^2), computed from the data by (1) and by (2), will not check if the wrong sign has been used for W_2; but if the proper sign has been used, and if there is no disturbing factor such as unbalance, they will agree; failure to check for both assumptions as to sign of W_2 signifies an error in either test or computation, unbalanced load, or harmonics in voltage or current, and the degree of disagreement may be taken as a measure of the effect of these disturbing conditions.

1. Assistant Professor of Electrical Engineering, The Rice Institute, Houston, Texas.

2. See R. R. Lawrence, Principles of Alternating Currents, p. 331.

3. R. R. Lawrence, op. cit., p. 334.

One method of checking, then, is to compute the volt-amperes not only from the voltmeter and ammeter readings (2), but also from the wattmeter readings; (1), equation (1) should be used twice, once taking W_2 positive, the other time negative; unless disturbed by faulty readings, unbalance, or distorted wave-forms, one of the values computed from (1) will check the value obtained from (2), and the sign used for W_2 in the checking case is clearly the correct one. To return to the example previously given, for wattmeter readings W_1 5.60 kw. and W_2 + 0.34 kw., the kv-a. must be 10.87, while for $W_2 - 0.34$ the kv-a. must be 11.54. Since the kv-a. computed from $v\sqrt{3} \times 200 \times 31.1 \times 10^{-3} = 10.78$, it is clear that the positive sign is correct for W_2, and further, that meter inaccuracies, or careless reading, or unbalanced load conditions, or distorted voltage or current, collectively, are producing a discrepancy of less than 1 per cent.

Further examples of the use of this method are given in the table (to the left of the heavy dividing line). The data for these examples were selected from actual runs in which the power factor varied steadily from a low value to something well over 50 per cent, so that for each set of readings the sign of the smaller wattmeter reading was known without question; in each case, except the fifth, the particular reading for which the power factor was nearest 50 per cent, and for which, therefore, the method would most likely fail, was chosen.

A variation of the method which may be more convenient in some cases is the computation and comparison of power factors instead of volt-amperes. Power factor is commonly computed either by the ratio

$$P f = \frac{W_1 + W_2}{v\sqrt{3}\, E_L I_L}, \text{ or by taking the ratio } k = \frac{W_2}{W_1}$$

and finding the power factor on a curve plotted against k.[4] These two values of power factor will agree under the same conditions as the values of volt-amperes. The accompanying curves may be used for the same purpose and they seem even more simple. If the ratio $\frac{W_1}{E_L I_L}$ be computed, the power factor may be read at once from this curve; the other ratio, $\frac{W_2}{E_L I_L}$, should fall upon the other curve at the same power factor. It will be noted that the second ratio, $\frac{W_2}{E_L I_L}$, is used only as a check upon balance, etc.; it is not needed to determine the power factor. And, indeed, the curve itself is not needed to determine the sign of W_2, for the ratio $\frac{W_1}{E_L I_L}$ is always less than 0.866 $\left(= \frac{v\sqrt{3}}{2}\right)$ when W_2 is negative (power factor less than 50 per cent), and is always greater than 0.866 when W_2 is positive (power factor greater than 50 per cent), so that this ratio alone is sufficient unless a further check is desired. Using the data of the previous example,

$$\frac{W_1}{E_L I_L} = \frac{5600}{200 \times 31.1} = 0.900 > 0.866; \text{ therefore,}$$

W_2 is positive, and from the curve, the power factor is 55 per cent; the ratio $\frac{W_2}{E_L I_L} = \frac{+340}{200 \times 31.1} = 0.055$, which indicates a power factor of 54.5 per cent. Other examples of this use of the method are also given in the table; these are to the right of the heavy dividing line.

It is clear that the methods given are but variations of one. The more convenient should be used according to circumstances or personal preference; either one is a very easily applied check upon the readings, the connections, and the sign of the smaller wattmeter reading.

COMPUTATIONS FROM ACTUAL DATA, SHOWING METHODS OF DETERMINING SIGN OF W_2 AND CHECKING READINGS

E_L	I_L	W_1	W_2 (sign known)	$v\sqrt{3}\, E_L I_L$	Kv-a. from wm. taking $+W_2$	Kv-a. from wm. taking $-W_2$	sign of W_2	$\frac{W_1}{E_L I_L}$	sign of W_2	$\frac{W_2}{E_L I_L}$	Power factor from W_1	Power factor from W_2
201	23.4	3.76	−0.56	8.15	7.03	8.14	−	.799	−	.119	39.0	39.0
200	31.1	5.60	+0.34	10.78	10.87	11.54	+	.900	+	.055	55.0	54.5
215	18.6	3.46	−0.04	6.93	6.88	6.96	− *	.865	−	.010	50.0	49.3
213	20.6	4.06	+0.54	7.61	7.64	8.71	+	.925	+	.123	60.0	60.5
207	15.7	1.82	−1.44	5.64	3.31	5.65	−	.560	−	.443	7.0	6.5
217	18.8	3.56	+0.06	7.07	7.06	7.17	+	.872	+	.015	51.0	52.0

Sample calculation for first line: Column 5, $v\sqrt{3} \times 201 \times 23.4 \times 10^{-3} = 8.15$ kv-a.

Columns 6 & 7, $4 \times 3.76^2 = 56.55$

$4 \times 0.56^2 = 1.25$

Sum 57.80

For $+W_2$, subtract $4 \times 3.76 \times 0.56 = 8.42$

$57.80 - 8.42 = 49.38$; $v\sqrt{49.38} = 7.03$

For −, add 8.42: 66.22; $v\sqrt{66.22} = 8.14$

Column 8, since column 7, using $-W_2$, checks column 5, W_2 is negative

Column 10, Since $\frac{3760}{201 \times 23.4} = 0.799 < 0.866$, W_2 is negative

Columns 12 & 13, power factors read from curves at 0.799 and −0.119 respectively

*Note: The data in this line are such (W_2 about 1 per cent of W_1) that a certain determination of the sign of W_2 is difficult. While the method gives the correct result in this case, it could hardly be relied upon in general.

4. R. R. Lawrence, op. cit., p. 332.

Sectional Electric Drive for Paper Machines

BY R. N. NORRIS[1]

***Synopsis.**—This paper describes a system of electric control for sectionalized electric drive which makes use of a mechanical differential. Further, it discusses the drive of the constant-speed end of the paper machine and the general advantages of electrical sectional drive for paper mills. Some figures are given on the power consumption of several classes of mills. The type of drive described has been used for some time in Europe and Canada and it has now been successfully introduced in the United States.*

In this paper will be described a system of sectional electrical drive which utilizes a mechanical differential as the basis of its control. First, this particular type of system, called the Interlock System, will be described and this will be followed by comments on the drive of the constant-speed end of the paper machine, with statement of the advantages of sectional driving in general.

Like all other sectional electric drives the Interlock installation consists essentially of a d-c., compound-wound, interpole generator with an exciter, which exciter supplies the excitation current to the field circuit of the generator and also the field circuits of the several section motors.

It is essential that the generator and exciter be designed to give good regulation under varying load conditions and that voltage regulators be provided to maintain a steady voltage in order to compensate for variations in load or speed of the prime mover.

Fig. 1 is a schematic diagram and layout of a typical installation showing the section motors at the couch, press, dryers and calender sections of a newsprint machine. This illustration does not show the reel or winder sections, but the reel and additional calender sections or smoothing roll sections, etc., can be driven in a similar manner, and the sketch serves to show the arrangement of the drive in general.

Each section of the paper machine is driven by a compound-wound interpole d-c. motor, which may be either directly coupled to the paper machine in-driving shafts or coupled thereto through some form of gear unit—double helical, worm, chain, etc. Sometimes a very convenient arrangement is to use direct-coupled motors for the heavier powers at couch, dryer and calender sections, and geared units at the press sections.

Fig. 2 shows direct-coupled motors driving a 234-in., 1200-ft. per min. newsprint machine. The sectional drives are housed in a separate room, the in-driving shafts of the paper machine passing through the walls into the machine room proper.

Fig. 3 shows an all-geared arrangement of Interlock drive, and Fig. 4 shows the semi-geared arrangement referred to above. Fig. 5 is a line drawing of a direct-coupled motor and also shows control unit.

In large newsprint machines the dryer sections consisting as a rule, of 40 to 46 cast-iron cylinders, five or six feet in diameter and up to 240 in. face, are usually geared together and driven by motors driving through two pinions on to the same load.

However, the arrangement of the machine, whether direct-coupled, gear-driven, or, as here termed, semi-geared, is a matter of detail which may vary with the particular case in question.

As illustrated by Fig. 1, a d-c., adjustable-voltage generator, G, supplies the necessary power to the section motors, $A\,1$ to $A\,7$. This generator is separately excited, and the exciter also supplies the excitation

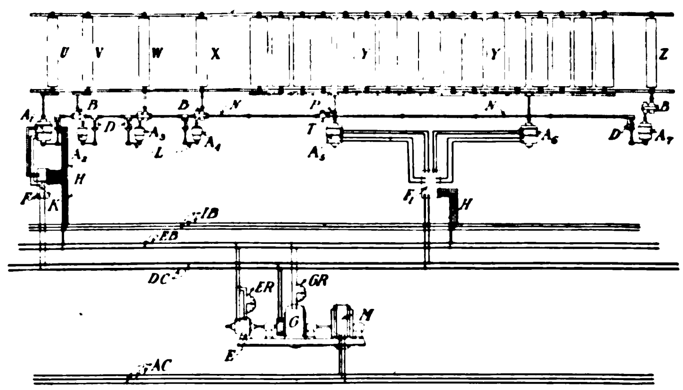

FIG. 1—SCHEMATIC DIAGRAM AND LAYOUT OF TYPICAL INSTALLATION

A.	Section motors	U.	Couch press
B.	Speed reduction gear	V.	1st press
D.	Differential regulator	W.	2nd press
E.	Exciter	X.	3rd press
F.	Motor starting panel	Y.	Dryer section
F.	Dryer starting panel	Z.	Calenders
G.	D-c. generator	DC.	Main d-c-bus, 500 or 250 volts
H.	Contact and field connections	EB.	Exciter bus, 250 volts
K.	Armature starting resistance	ER.	Exciter field rheostat
L.	Cone pulleys and belt for adjusting draw	GR.	Generator field rheostat
M.	Main synchronous motor	IB.	Interlock bus, 250 or 125 volts
N.	Master shaft	AC.	Main a-c. bus
P.	Chain drive		
T.	Bevel gears		

current to the field circuit of the several section motors.

$A1$ to $A7$ represent the various section motors, which, on the couch, and the two dryer sections, are direct coupled to the intake shafts. On the three press sections and the calender section, a single reduction herringbone gear is employed. For purposes of simplicity no main switchboard is shown in this illustration; however, a main switchboard is provided between the generator and exciter and the main busbars, $D\,C$, and exciter busbars, $E\,B$. On the couch section is shown one of the motor starting panels, F, with the

1. Managing Director, The Harland Engineering Co., of Canada.

Presented at the Regional Meeting of District No. 2 of the A. I. E. E., Cleveland, Ohio, March 19, 1926.

necessary connections from the field and armature circuits of the motor, and the differential regulator D; $F1$ is the starting panel for the dryer motors.

Speed adjustment within the desired range of the paper machine is obtained, in the case of large newsprint machines, entirely by variation of the generator voltage which is applied to the section motor armatures.

Fig. 2—Direct-Couples Motors Driving a 234-in.,1200-Ft. per Min. Newsprint Machine

In book-paper machines, or other machines requiring large speed ranges, this speed adjustment is obtained by a combination of generator voltage regulation as above and variation of the field strength of the section motors. The whole of this speed adjustment is obtained from a combined regulator which is operated by one handwheel or by remote-control, push-button operation.

The arrangement of the Interlock control system shown in Fig. 1 consists of a master shaft N, located in

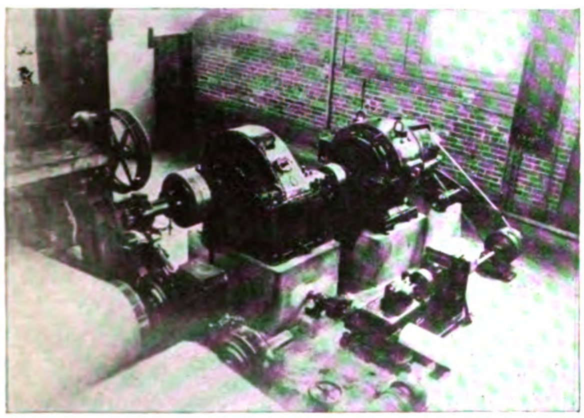

Fig. 3—Interlock Drive in Operation on Third Press Section of 234-in., Newsprint Machine, 600/1000 ft. per Min

any convenient place, and extending the entire length of the variable speed end of the paper machine. This master shaft transmits practically no power, as it is only a governor shaft. The power required to drive the master shaft is negligible, and the whole shaft, with the differential regulators but without the draw control belts in position, can very readily be turned by hand from any point of the shaft. At each section, the differential control gear, D, is inserted.

In Fig. 1 the shaft is shown passing underneath the reduction gear units, but it, of course, has no connection with these units and is simply shown in this position as being a convenient position for it.

It can be placed in any convenient position—under the floor if desired, with the regulator equipment sus-

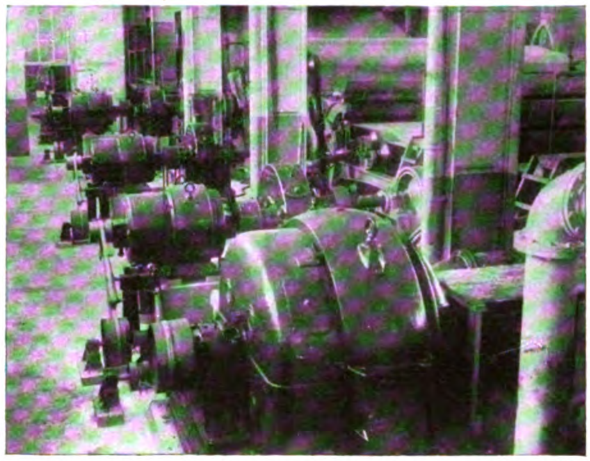

Fig. 4—Semi-Geared Arrangement of Interlock Drive

pended from the ceiling,—and if the master shaft is an insuperable difficulty either in the layout of the plant at the back of the paper machine or in reality in the mind of the prospective user, then it can be replaced by a synchronous generator and synchronous motor at each section; but in the author's opinion the shaft is the better drive from a point of simplicity and reliability and provides a more rigid and positive drive for the control units.

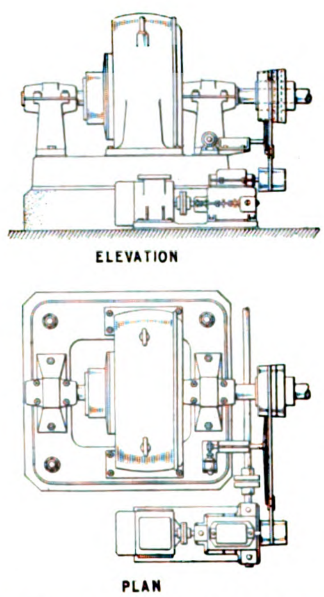

Fig. 5—Showing Direct-Coupled Motor and Control Unit

The master shaft can be driven by either a small, separate electric master motor or from one of the sections of the paper machine, preferably the dryer section, as shown in Fig. 1. This master shaft when driven from the dryer sections is driven by means of a small chain

drive or a small geared drive, whichever happens to be the more suitable for the layout in question.

A diagrammatic illustration of the differential-control apparatus, geared to the master shaft at each of the sections to be controlled is given in Fig. 6. This

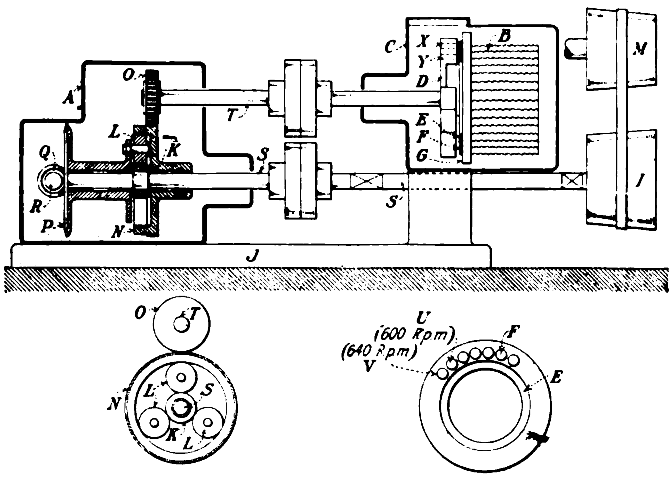

FIG. 6—DIAGRAMMATIC ILLUSTRATION OF DIFFERENTIAL CONTROL APPARATUS GEARED TO MASTER SHAFT AT EACH SECTION TO BE CONTROLLED

differential control consists of bevel gear, *P*, free to revolve on cone pulley shaft, *S*, and a bevel pinion, *Q*, which is mounted on the master shaft, *R*. Attached to the bevel wheel, *P*, are three planetory pinions, *L*, which mesh with the sun wheel, *K*, the last named being keyed to the cone-pulley shaft, *S*; the pinions, *L*, also mesh with the internal teeth of the annular ring, *N*, which turns freely on shaft, *S*. Around the outside of the annular ring, *N*, are teeth that engage with another spur wheel, *O*, mounted on shaft, *T*, this shaft being connected through a coupling to a shaft carrying the brush arm, *D*, in the automatic differential regulator *C*.

If the shaft, *S*, carrying the cone pulley, *I*, which is driven by the section motor, runs (in the opposite direction) at the same speed as the bevel gear, *Q*, located on the master shaft, then there will be no re-

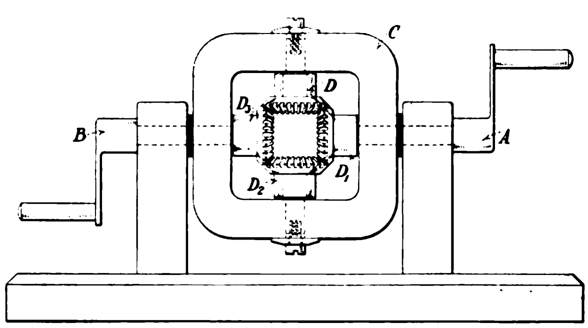

FIG. 7—BEVEL-GEAR DIFFERENTIAL

sultant movement of the annular ring, *N*; but however slightly these two may vary in angular position relative to each other, a correct and instantaneous response is given on the annular ring, *N*, and coincidentally on the wheel, *O*, which is driven by the annular ring. The bevel pinion, *Q*, is driven by the master shaft in each case, and the sun wheel, *K*, is driven from the cone pulley through the section motor itself, which must be controlled in each case. Therefore, any tendency of difference in angular relation between the master shaft and the motor to be controlled is instantly reflected on the annular ring.

An epicylic train of wheels is an elusive creature when it is desired to know exactly what takes place, and to more readily grasp the simple and effective nature of the control it is easy to look upon this as a bevel gear differential as Fig. 7. This consists of a small frame, *C*, with four small bevel gears, *D*, *D*1, *D*2, *D*3, all of the same size and having the same number of teeth. Gears, *D* and *D*2, turn on journals that are attached to the frame *C*; gear *D*1 is keyed to the shaft, at the other end of which is keyed the handle *B*; and gear *D*3 is keyed to a shaft, at the other end of which is keyed the handle, *B*; the frame *C* is free to turn on these two shafts. Suppose the frame to be held stationary and handle *A* to be turned clockwise; then, gears *D* and *D*2 will turn in opposite directions, and will cause gear, *D*3 to turn in a direction opposite to that of gear *D*1, which is keyed to the same shaft as the handle *A*. The two handles *A* and *B* will, therefore, turn in opposite directions at the same speed in revolutions per minute.

Now if the frame, *C*, be free to turn and handle, *A*

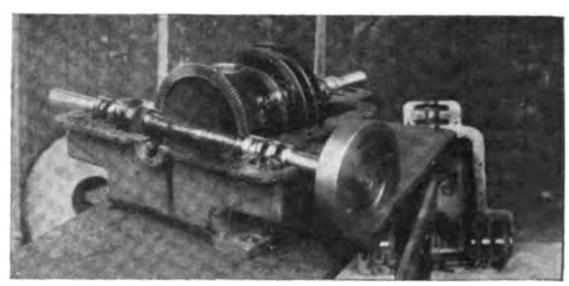

FIG. 8—EPICYCLIC INTERLOCK DIFFERENTIAL WITH COVER REMOVED

and *B*, together with gears, *D*1 and *D*3, are turned in opposite directions at the same speed, the frame *C* will remain stationary, the conditions then in so far as the revolutions of the gears are concerned, being exactly the same as they were when the frame was held stationary. If, on the contrary, while *A* makes 100 turns, *B* makes one turn more or less than this, *i. e.*, 99 or 101 turns, the frame, *C*, must make half a turn forwards or backwards, the same result that would be had if *D*1 were stationary and handle, *B*, made one turn.

The angular displacement has nothing to do with time; it depends only on the difference between the number of turns made by the gears, *D*1 and *D*3, regardless of whether this takes one minute or one year. Therefore, if in *any* period of time, gear *D*1 has an angular velocity of 1 deg. greater or less than gear *D*3, the frame *C* must be displaced ½ deg. from its initial position.

The Interlock system of control is merely the application of this principle to the regulation of the speed of the electric motor connecting a single field rheostat to the third member of the differential, which, in the epicyclic differential Fig. 6, is in the ring, *N*, and is so connected by gear, *O*, shaft, *T*, and coupling, *X*.

Fig. 8 shows the epicyclic Interlock differential with the cover removed, and Fig. 9 closed, and it gives a good idea of the robust construction. The gears all

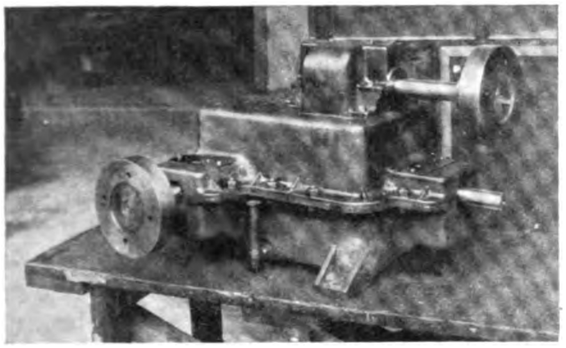

FIG. 9—EPICYCLIC INTERLOCK DIFFERENTIAL WITH COVER CLOSED

run in oil, and being enormously large in comparison to the power required, they will run indefinitely without wear. In fact, after four years' operation at 24 hours per day on a large Canadian newsprint installation, the gear teeth still show the signs of the hobbing cutters which milled them out of the solid.

The field regulator portion of the control contains a large number of resistance units which are cut in and out of circuit of the motor field, the circuit being completed through the brushes *X* and *Y* which travel over a number of contacts *F* and form a complete circuit through the brass ring contact *E*. In practise, the brush arm, *D*, quietly breathes between the two contacts, of which there are 80 to 100 on the regulator.

The accuracy with which the desired speed is required is so great that if there were a million contacts instead of 80, they would not suffice to have one for every flicker in speed; the brush would steadily breathe but the movement would still be between the contacts, one on each side of the desired speed. Referring to the lower right hand part of Fig. 6, suppose that one of these contacts *U* represent 600 rev. per min., on the motor, that the next contact, *V*, represent 640 rev. per min. and that a speed of exactly 620 rev. per min. on the motor were required; then the brush arm would be quietly breathing between the two contacts *U* and *V*, spending sufficient time on either contact to produce an average field that will give a perfectly steady motor speed of 620 rev. per min., the speed that was desired for the moment. Should this desired speed be 635 rev. per min. say, then the action is exactly the same as before, except that the arm spends a fraction more time on contact *V* than on contact *U*.

If the load varies on any motor, it will immediately tend to speed up or slow down, which will produce a tendency to change any angular variation between the two halves of the differential. The annular ring, *N*, will move and the rheostat arm, *D*, will take up this new position to suit the load in question.

The control is absolutely automatic and instantaneous for all conditions of load which may occur, and no hand adjustment of the motor field strength is required for any load change which does occur such as happens at the press sections, for instance, when the weights are changed, or at the couch section when the vacuum is altered.

If the machine operator desire to change the draw between sections of the paper machine, he has only to move the belt on the cone pulley, *I*, and cone pulley, *M*, Fig. 6, attached to the motor shaft; the motor is then trying to drive, *K*, at a speed that is different. This immediately sets in motion the annular ring *N*, which comes to rest again in a moment, after moving through a few degrees of arc, enough to alter the resistance in *C*; harmony is then once more established, and the motor, running at a different speed, as desired, is still driving the sun wheel, *K*, at exactly the same speed as that of the bevel pinion. The 1½-in. belt may be shifted on the cone pulleys by a hand-wheel or by remote control of a fractional h. p. motor that operates the belt-adjustment gear.

Starting up of the respective section motors is obtained usually by means of automatic push-button-operated contactor motor-starting panels. The push buttons can be located anywhere and are usually on the front of the paper machine at the respective sections, the panels themselves being arranged usually as a switchboard in a substation preferably alongside the

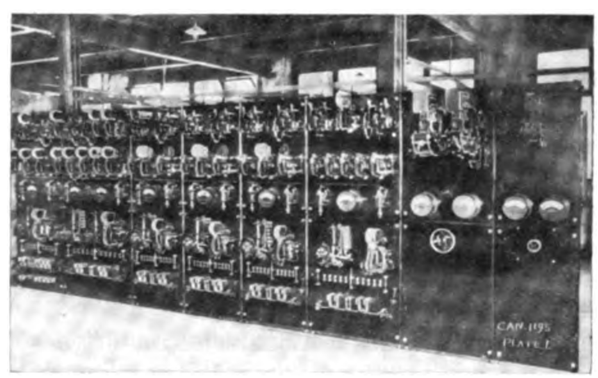

FIG. 10—TYPICAL SWITCHBOARD FOR AUTOMATIC PUSH-BUTTON OPERATED MOTOR STARTING PANEL

generator and main switchboard; Fig. 10 shows a typical switchboard of this nature.

The starting panels are provided with resistance units capable of giving very slow crawling speeds which are required when putting on new Fourdrinier wires or felts at the press sections or the dryer sections, and also for the purpose of inching round the various sections for inspection purposes.

Each section can be started, run at slow speeds, or stopped, independent of the other sections, without

interfering with any of the other sections. They will all continue to run at the predetermined speed. Should the master section shut down—whether it is the dryer sections, or a small master motor—all the other sections automatically still continue to run at the speed at which they were first operating.

Of course, for the time being, while the master section is standing, the Interlock is not in operation, but immediately the master section has again been brought to full speed the other sections automatically go into interlock.

These conditions are all made by the means of simple automatic devices.

Motors

All motors, whether for direct-coupled machines or for geared installations are totally enclosed and supplied with forced ventilation. This is a distinct advantage at the back of the paper machine, as behind the dryer sections high temperatures are met, and behind the wet end of the paper machine at the couch and press sections a great amount of splashing of water mixed with paper stock occurs which is not good for the windings of any electric motor. Furthermore, at times careless use of a hose by some operator may ruin a motor. All this is safe-guarded against by the use of totally enclosed machines.

This Interlock sectional electric drive which was developed by the Harland Engineering Company has been in successful use since 1914 when it was first installed in Scotland on a small machine having a wide speed range of ten-to-one. During the four or five years previous to this installation there were two sectional electric drives in operation in Great Britain. One of these was not altogether successful and was replaced by mechanical drive. The other was converted to the Interlock differential-control system and is the drive in Scotland referred to above. This equipment is still in operation. Since the installation of this equipment, constructional improvements in mechanical and electrical details have been made as a result of experience, but the principles of control and operation have not been changed.

Before passing from sectional electric drive reference will be made to the driving of the constant-speed end of the paper-machine, which seems liable to suffer from neglect owing perhaps to the tremendous interest that has been focused on its sister part.

The paper-machine drive has always been separated into two groups,—the constant speed part, and the variable speed end. The development of the sectional electric drive has provided for the latter, but there appears to be little movement as yet to study and change driving arrangements of the constant speed end. Where a separate driving unit is provided it is quite usual to have two generators and exciter, all driven together, consisting of a d-c. generator, its exciter (which also excites the sectional motor fields) for the variable speed end, and an alternator to provide a-c., three-phase supply to operate the constant speed end. This constant speed end may be driven by one motor, or it may be divided into groups, but no attempt seems to be made to adjust the running speed of its elements to suit the changing speed of the paper machine.

A little progress has already been made in one or two mills in so far that in a few cases the pumps, etc., are being driven by separate motors, thus eliminating belts as far as possible. For this purpose the d-c. motor has been employed, which has wherever possible been direct coupled to pumps, and which allows a moderate amount of speed control by shunt regulation, thus enabling the speed of the pump to be adjusted to suit the operating speed of the paper machine itself. For such a purpose, direct current clearly has an advantage, and the author believes will gradually be more widely adopted.

It is true that some portions on the constant speed part have been initially conceived and developed with a drive from a steam engine or a counter shaft in mind, and perhaps do not seem to be specially suited for direct coupling to a motor, but, doubtless with the development and more extended use of an individual drive on the constant speed end, designs which the business seems to demand will gradually be evolved. In such matters engineers do not usually lag far behind. With such an arrangement the speeds of the various pumps can be adjusted to suit the output required of them, which to a moderate extent varies with the speed of the paper machine. In this way economies in power can be attained and it is believed other advantages also will result. It will be evident that the control of this part of the machine will be more complete than is otherwise possible.

The following table gives averages of some hundreds of power readings taken from time to time on various machines. The first row covers readings on 14 machines of similar size in operation, and the second row, 6 machines. The others are averages on selected individual machines:

Width & Type of *M/c.*	Average Speed Ft. per min.	Electric H. P. Input to Motor per inch width of Machine per 100 Ft. per Min. Paper Speed									
		Couch	1st. Press	2nd. Press	3rd. Press	4th. Press	Dryers	1st. Cal.	2nd. Cal.	Exciter.	Total
23-4in. News	875	0.039	0.016	0.023	0.022	..	0.060	0.036		0.0057	0.2017
166-in. News	750	0.054	0.029	0.027	0.0	..	0.674	0.650		0.009	0.243
168-in. Kraft	675	0.039	0.027	0.020	0.017	..	0.041	0.036		0.008	0.188
148-in. Book	520	0.046	0.044	0.026	0.044	..	0.035	0.031	0.068	0.008	0.300
148-in. Tissue	230	0.017	0.041	0.017		..	0.047	0.043		0.006	0.171

From several readings obtained from machines having mechanical drives with single motor the average e. h. p. per inch of width for 100 ft. per min. is 0.35 e. h. p.

Then there is the very interesting side of the question relating to the effect of sectional driving on the thermodynamic efficiency (a) of the paper machine itself—(b) of the paper mill as a whole,—as a result of the saving in power effected by sectional driving.

From the power table just given, it will be seen that a 234-in. paper machine, operating at 1000 ft. per min. would require 472 e. h. p. A mechanically operated machine operating at the same speed would require about 819 e. h. p.

Assuming that the average output of paper from the machine is 125 tons per twenty-four hours, and that the average steam requirements for drying the paper are 3.75 lb. of steam per pound of paper, then we get a steam requirement in the drying cylinders of the paper machine, 38,900 lb. of steam per hour.

A steam turbine operating under normal conditions usually met with in a paper mill would have a water-rate of about 38 lb. of steam per e. h. p.-hr. allowing for generator efficiencies, so that by utilizing to the fullest extent the power in the steam required in reducing it from the normal pressure to the pressure required for drying in the paper machine cylinders we can obtain approximately 1000 e. h. p.

Now, if the paper machine is driven mechanically, the balance of horse power so obtainable (181. e. h. p.) would hardly justify the installation of an additional generator to supply the excess power to the constant-speed end of the machine, but the balance of power obtainable by using sectional drive, 528 e. h. p., is sufficient to justify this and is usually enough to drive the whole of the constant speed end of the paper machine. This renders the paper machine an individual unit, which has many advantages.

Sectional driving of paper machines has also had its effect upon building design by reducing the cost of basements and saving space.

The foregoing does not pretend to deal with the general advantages to be obtained in the use of sectional electric drive as compared with mechanical drive. These are becoming so generally well-known that it is only necessary to outline briefly a few of them—such as the elimination of belts and ropes, and their consequent very high up-keep costs; the saving of power as is shown on the power figures given above; the very much steadier speed control between sections of the paper machine which result in a better quality and production of paper from a given machine with a given quality of stock supplied to the machine.

Each section of the paper machine is made a separate unit and with electrical indicating instruments it is possible to detect faults which may arise on the paper machine itself which allows of investigation and probably rectification of the trouble before it becomes serious, whereas with mechanical drive very probably the first indication of trouble is when the trouble has become serious enough to necessitate expensive repairs.

The greater ease in handling the paper machine by the paper mill operators is very marked and needs to be experienced to be realized. The absence of ropes and belts on the back side of the machine makes the machine more accessible, which all helps in the upkeep and maintenance of the plant and reducing life hazard.

Due to the very even starting torque exerted by electric motors, particularly of the d-c. type, dryer gear life is increased as compared with the mechanical drive where power application of the dryer gears is usually by clutch or snatching of cone pulleys which puts sudden stress on the gears.

These notes have been put together on the assumption that they will be read to those who have some knowledge of paper machines and are interested in present and future operation and development. There is to my mind a great field in the United States for conversion of old mechanically driven machines to sectional drives and although I expect there are many paper makers who will disagree with me, I maintain that there are very many advantages to be obtained in doing this.

One, of course, still meets the man who says the mechanical drive is good enough and he is clearly right from the standard of his own point of view. Everybody knows that mechanical drives have made and will still make good paper. In the beginning it was the large powers and high speeds required by the large newsprint machines which forced forward this subject of sectional driving, although its actual development was accomplished before the advent of the large high-speed machine.

The steady increase in the size of newsprint machines finally made sectional driving a necessity.

When its reliability became established, it made wide machines and high-speed machines more readily available than formerly. Its advent also has apparently had an influence on the design of the paper machine itself as regards the widths and speeds at which it can be built.

The reliable nature of the drive in operation on newsprint machines has been proved and has demonstrated also that for the small book machines, etc., the same good results can be obtained: in fact, it is becoming more general, and nearly all new book machines are fitted with sectional drive. As stated before there is a big future for the conversion of existing machines to sectional drive.

In this connection it is interesting to consider that some form of sectional drive has been constantly the subject of research by independent peoples in different parts of the world; contemporary with the work which we were doing in Great Britain, other people were carrying on similar experiments on this Continent and in Europe. All these experiments, the author believes, were made quite independently of each other showing a widespread belief in the necessity and usefulness of sectional drive.

Can the Thermal Capacity of Electric Machines Be Made a Simple and Practical Element of Rating?

BY A. E. KENNELLY*

PREFACE

THE subject of this paper has been suggested to the U. S. Committee, by the Council of the I. E. C., as suitable for a report at this 1926 meeting, and has been assigned to the writer for preparation. The writer does not claim any authorization from the U. S. National Committee to present its views officially on the subject. He merely submits the paper as expressing personal opinions, aided, however, by the records and reports of a certain group of engineers who have given special attention to the thermal constants of electric machines, and who are mentioned in the following text.

BRIEF ANSWER AND PURPORT OF THE PAPER

It is believed that the thermal constants of electric machines in the variable regime, (especially their binary time constants), can, in many cases, be used in a very simple way for practical operating purposes. It is not, however, recommended that such thermal constants should be introduced into the rating of machines at the present time. It is, nevertheless, recommended that these thermal constants should be regarded as useful subsidiary information concerning machines, until such time as engineers may have become more generally familiar with their application and use. All machines do not seem equally subject to their useful application. Attention should be called to the practical service that the purchasing and operating engineer may derive from the thermal constants of machines. It seems likely that, at some future time, after the matter has been more thoroughly investigated by designers, manufacturers, testers, and operators of electric machinery, these thermal constants, including thermal capacity, may be found sufficiently important and reliable to be promoted from the present category of useful subsidiary information, to the category of rating constants of machines.

It should be pointed out that but little of the technical material in this paper is new. It is mainly collected here for convenience of reference.

Thermal Constants of Electric Machines may be divided for convenience into two classes, namely,

1. Steady-regime constants.
2. Variable-regime constants.

Class 1 may be considered to contain the following, for any machine or element of the same (such as field, armature, internal or external part of winding, stator rotor, commutator, bearing, etc.)

a. Hottest-spot maximum safe temperature.
b. Maximum accessible measurable temperature.
c. Ambient temperature, θ_a.
d. Instantaneous temperature rise of machine or element θ.
e. Instantaneous temperature, $\theta + \theta_a$.
f. Ultimate temperature rise under continuous rated load, Θ.

All of the above constants enter either directly or indirectly into the continuous rating of a machine from the thermal standpoint, and need no discussion here.

Class 2 may be considered to contain the following thermal constants for any machine or element:

A Ultimate temperature rise characteristic $\Theta - P$, under different sustained percentages of rated load.

B Time constant or constants of machine or element τ hours or minutes

C Thermal capacity of machine or element k watt-hours per deg. cent. temperature rise above stationary ambient.

D Specific thermal capacity of material in a machine or element—watt-hours per kg. and deg. cent.

E Dissipation constant of machine or element s watts per deg. cent. temperature rise.

The variable-regime thermal constants (*A*) to (*E*) are the main subjects of discussion in this report.

UTILITY OF VARIABLE-REGIME THERMAL CONSTANTS

Characteristic A. The most important of the class 2 here considered is probably *A*, the ultimate temperature rise characteristic $\Theta - P$. This is a characteristic curve connecting the ultimate temperature rise of the machine, presumably at its max. accessible temperature location, for different percentages of rated load. When drawn on logarithm paper, such a curve usually approximates to a straight line over a moderate percentage range of load. Thus, in Fig. 1, the particular machine supposed to be there designated develops an ultimate temperature rise of 40 deg. cent., in a specified element, at continuous rated load. It also develops 50 deg. cent. rise at 1.15 times rated load, and 76 deg. cent. at 1.5 times rated load, if the straight line characteristic *A O C* is adhered to over that range. This straight line rises 1.6 units of ordinates in one unit of abscissa length; so that this straight line represents a temperature rise increasing as the 1.6th power of the load, over the range it may be taken to cover.

An operating engineer, knowing the continuous rating of the machine, can ascertain with the aid of such a characteristic the temperature rise of the element considered, over a certain range of steady loads, from, say, 0.50 to 1.5 times rated load. The maker of the

*Honorary Secretary of the U. S. National Committee, I.E.C.

A report presented to the International Electrotechnical Convention at its U. S. Meeting in April 1926.

machine may not have made ultimate temperature rise measurements at different steady loads; and therefore may not be prepared to give this $\Theta - P$ characteristic. He will in many cases, however, have secured such a series of three or four different ultimate temperature rises, at different percentages of rated load, on some similar machine of the same dimensions and speed. The purchasing engineer may be able to obtain this auxiliary information from the maker, and so construct

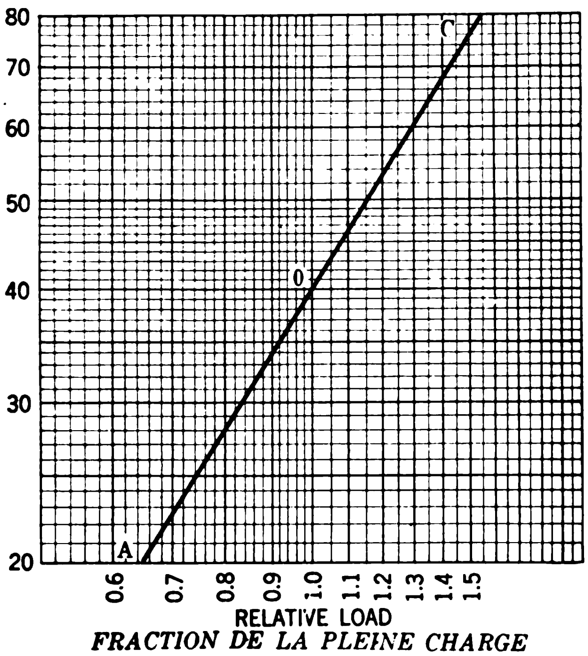

FIG. 1—APPROXIMATE STRAIGHT LINE RELATION BETWEEN ULTIMATE TEMPERATURE RISE AND STEADY LOAD FOR A PARTICULAR DYNAMO MACHINE

a $\Theta - P$ characteristic which is likely to be fairly reliable. The operating engineer may subsequently be able to check this characteristic from the observed behavior of the machine under some particular steady load or loads in service.

Time Constants B. It is well known* that when a machine passes from one steady load to another, at constant ambient temperature, the temperature rise of any element will change, in the simplest case, with time, according to a simple exponential curve or time-constant curve. Owing to complexity of thermal relations among the different elements of a machine, the temperature rise may depart materially from a simple exponential curve; but in many cases it conforms to such a curve sufficiently closely for practical purposes.

Two principal varieties of thermal time-constant present themselves:

1. The exponential time constant τ_ϵ, fundamental in the theory of such curves, but awkward to use.
2. The binary time constant τ_2, suitable for practical use.

In any exponential curve, the exponential time-constant τ_ϵ is that interval of time during which the temperature rise comes within $1/\epsilon$, or 1/2.718, or 36.8 per cent, of the ultimate rise. In a period of 2 τ_ϵ, the rise will come within $1/\epsilon^2$, or about 13 per cent, and in 3 τ_ϵ within $1/\epsilon^3$, or about 5 per cent, of the ultimate rise.

The binary time constant τ_2 is that interval of time during which the temperature rise comes within 1/2, or 50 per cent, of the ultimate rise. In a period of 2 τ_2, the rise will come within $1/2^2$, or 25 per cent, and in 3 τ_2 within $1/2^3$, or 12.5 per cent, of the ultimate rise.

Fig. 2, which is drawn on arith-log paper, shows the attainments and deficiencies at any number up to four exponential or binary time constants. These lines are straight. Thus after four exponential time constants, the attainment is about 0.982, or 98.2 per cent, while the deficiency is 0.018, or 1.8 per cent. Similarly, after the lapse of four binary time constants, the attainment is 0.9375 or 93.75 per cent and the deficiency $^1/_{16}$, or 0.0625 or 6.25 per cent. The two time constants are always connected by the relation

$$\tau_2 = 0.69315\,\tau_\epsilon \quad \text{or} \quad \tau_\epsilon = 1.4427\,\tau_2 \text{ hours} \qquad (1)$$

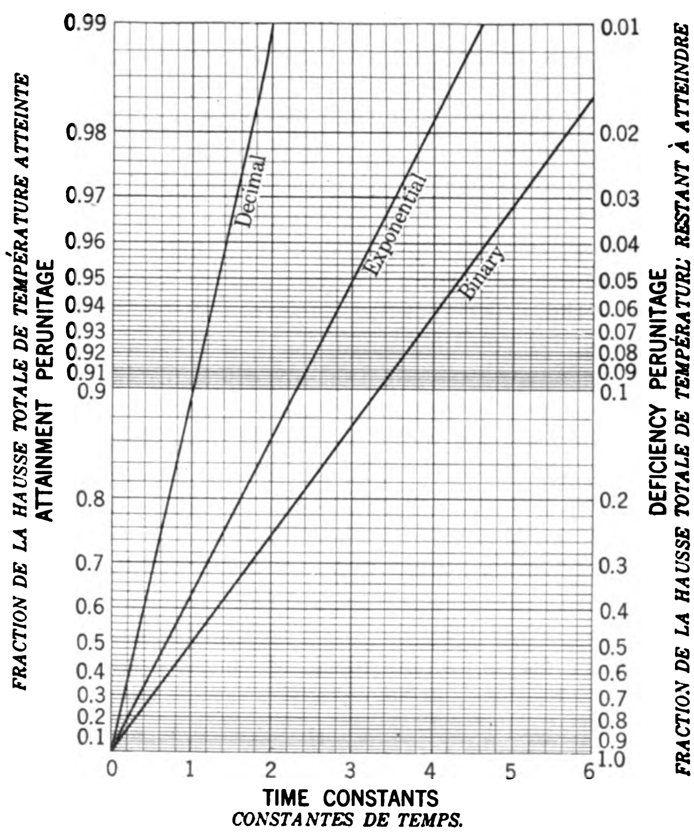

FIG. 2—ATTAINMENTS AND DEFICIENCIES IN TERMS OF THE DIFFERENT TIME CONSTANTS

so that if the exponential time constant is known, the binary constant is always approximately 70 per cent of it.

The binary time constant τ_2 of a modern rotary dynamo machine ordinarily lies between 10 minutes and 40 minutes, and does not vary greatly with the size or rating of the machine. If we take a mean value of say 25 minutes, and assume that the temperature rise of the machine element considered follows a

*Bibliography 1, 2, 5, 13, 14, 15, 17, 18.

time-constant curve, then when the load is suddenly changed from one steady value to another, the characteristic $\Theta - P$ curve enables the corresponding change in ultimate temperature rise to be predicted. Suppose that the change will be ultimately 30 deg. cent. Then in τ_2, or 25 minutes, the rise will be 15 deg. cent., in $2\,\tau_2$, or 50 minutes, it will be $15 + 7.5 = 22.5$ deg. cent., in $3\,\tau_2$, or 75 minutes, it will be $22.5 + 3.75 = 26.25$ deg. cent., and so on. After $6\,\tau_2$, or 150 minutes, the change will be for practical purposes complete.

An operating engineer may be able to utilize the time constant of a machine in an emergency. He may want to carry a temporary overload without overheating his machine. He knows that he can carry such an overload during a period of one time constant, without attaining more than half the temperature rise due ultimately to that load, provided that the element of the machine considered has this margin of temperature below the danger point, and that the curve of heating is exponential; also that no other element will rise more quickly.

Although rotary machines have binary time constants usually well below one hour, some transformers and particularly, air-cooled, oil-immersed transformers, have time constants of three or four hours. The period during which a temporary overload can be maintained with due precautions, in an emergency, is thus correspondingly increased with such transformers.

When the temperature rise of a machine or element is exponential, it becomes easy to predict the course of the changing temperature when the $\Theta - P$ characteristic and the binary time constant are given, if the load is changed abruptly from one long continued steady value to another. If the load is changed in a less simple way, so that one thermal transient is started before the preceding transient or transients have been substantially terminated, the predetermination of the corresponding temperature becomes more complex. As is well known to designers of traction motors, the resultant curve of θ against time is obtainable from the superposition of a plurality of single exponential curves.

Significance of the constants C, D and E. These variable-regime thermal constants are not at present of much use by themselves. They may, however, be useful conjointly, in arriving at an estimate of the time constant B. If the time constant can be predetermined with satisfactory precision, a $\theta - t$ test of temperature rise against time becomes unnecessary, provided that it is known that the curve is exponential, and that the ultimate rise is known from the $\Theta - P$ characteristic. The relations between B, C and E are given by the familiar formula:

$$\tau_\epsilon = k/s \qquad \text{hours (2)}$$

or

$$\tau_2 = 0.693\,k/s \qquad \text{hours (3)}$$

The value of k, or the C constant, may be computed theoretically from the weights of the different parts of a machine and their specific heats. In practise, certain empirical constants may have to be used, as in Appendix I. Consequently, a time constant that has been observed, is at present more reliable and satisfactory than a time constant that has been computed; although designers, guided by experience, place confidence in their predetermined time constants.

E. The dissipation constant s is defined by the formula

$$p = \Theta\, s \qquad \text{watts (4)}$$

where p is the power lost in the machine or element during the steady thermal state, after the ultimate rise Θ has been substantially attained. Knowing the power losses, and the ultimate temperature rise corresponding thereto, the constant s can thus be evaluated.

Tests for the Exponential Quality of $\theta - t$ Temperature Rise Curves

The time-constant of a machine can only be utilized to the degree of precision within which the temperature rise curve is exponential, according to the formula:

$$\frac{\Theta - \theta}{\Theta} = \epsilon^{-\frac{t}{\tau_\epsilon}} = 2^{-\frac{t}{\tau_2}} = 10^{-\frac{t}{\tau_{10}}} \qquad (5)$$

where $\dfrac{\Theta - \theta}{\Theta}$ is the *deficiency*, θ/Θ being the *attainment*. A temperature rise curve $\theta - t$ having been obtained by observation, it is always possible to determine, from inspection, whether the curve is in satisfactory agreement with (**5**); *i. e.*, whether it admits of time-constant application. It is first necessary that the ambient temperature during the test shall have been kept constant, or that the curve be first corrected accordingly, if it has slightly varied*. The ultimate temperature rise Θ, for the curve must also be forthcoming, either by noting that the test has been maintained for a time sufficient to develop substantially this ultimate rise, or by extrapolating from the curve as in Appendix II, or from preceding temperature-rise tests as recorded in a $\Theta - P$ characteristic.

The time during which the temperature rise θ changes from 0 to $\Theta/2$ deg. cent. is measured along the time axis of the curve. This should be the binary time constant τ_2. In another such time constant, the further temperature rise should be $\Theta/4$ degrees. In the third such time constant, the further rise should be $\Theta/8$, and so on. If these relations hold satisfactorily, the curve may be regarded as exponential, from an engineering standpoint. Strictly speaking, the theoretical requirements for exponential temperature rise are so severe, that they can probably never be fully complied with in any machine. Nevertheless, it is surprising how many machines develop satisfactory time-constant curves in their tests, although the time constant of one element, such as the field-winding, may be markedly

*Bibliography 17.

different from that of some other element, say the armature winding in the slots.

A second test, but much more severe, of the exponential quality of a $\theta - t$ curve, is to plot the deficiency $(\Theta - \theta)/\Theta$ on inverted arith-log paper. Thus Fig. 9 gives a $\theta - t$ curve for a certain 2000-kv-a. air-cooled transformer, the curve being drawn exponentially to fit the observations, according to the formula

$$(50.5 - \theta)/50.5 = \epsilon^{-\frac{t}{3.72}} = 2^{-\frac{t}{2.58}}$$

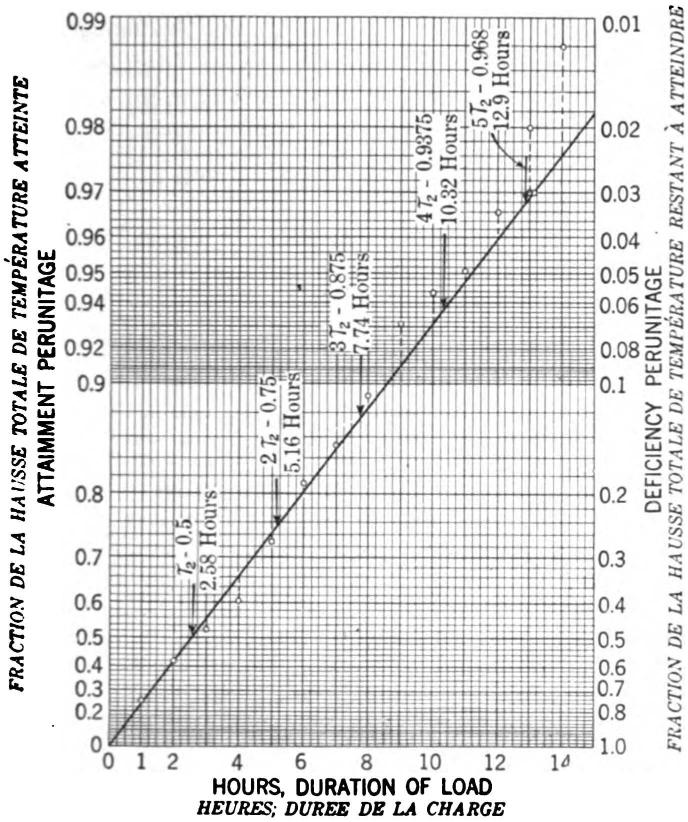

FIG. 3—TEMPERATURE-ELEVATION CURVE OF 2000-KV-A.

Transformer (Fig. 9), drawn on inverted arith-log paper. Straight line, computed exponential rise. Small circles, observed attainments and deficiencies of temperature elevation

It will be seen that the hourly observations conform to this curve satisfactorily. Fig. 3 gives the corresponding plot of the same observations on arith-log paper. The exponential curve is now a straight line; but the observations appear to depart from it much more widely, especially in the upper parts.

In cases where the temperature rise curve departs so far from an exponential law as not to admit of time-constant reckoning, it may sometimes be dealt with in a relatively simple manner by the use of two independent time-constants. Messrs. V. M. Montsinger* and W. H. Cooney† have shown that when, as in many modern air-cooled, oil-immersed transformers, the windings are thermally separated from the core, but the oil is thermally common to both, the temperature rise of the windings above the top layer of oil follows satisfactorily one exponential curve of say 3½ *minutes* binary time constant; whereas the top layer of oil in the transformer follows satisfactorily another exponential curve, of say 3½ *hours* binary time constant.

Prof. Karapetoff has recently given a theory of the temperature rise of a body containing two thermal elements in partial mutual communication.‡ The solution leads to two independent time constants, associated with two final temperature rises, two thermal capacities k_1, k_2 and dissipations s_1, s_2. By means of appropriate tests, these time-constants may be evaluated. Practical results with the method are not yet forthcoming.

EXPERIMENTAL DATA CONCERNING HEATING CURVES OF MACHINES

Figs. 4 and 5 are taken from curves published by Mr. C. M. Laffoon§ on large turbo-alternators, using imbedded temperature detectors in the armature winding. Fig. 4 shows the temperature rise of a 35 megavolt-ampere machine (35 mv-a.), under steady load, with the detectors in contact with the copper armature conductor and within the insulating cover. The curve is drawn exponentially to fit the observations and an ultimate rise of 24 deg. cent. The binary time

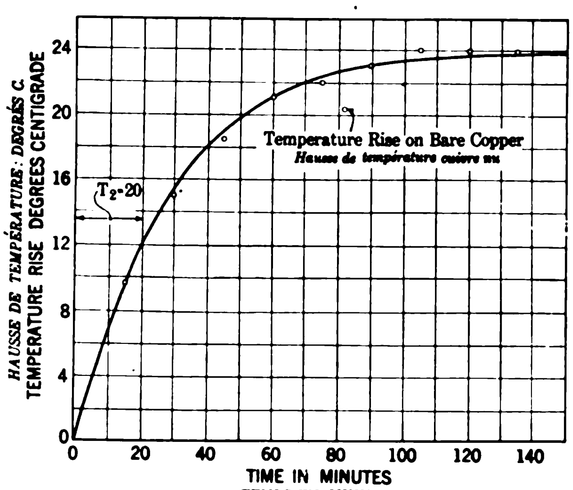

FIG. 4—TEMPERATURE RISE OF A 35,000-KV-A. THREE-PHASE TURBO GENERATOR OPERATING UNDER CONSTANT 75 PER CENT LOAD

Imbedded temperature detectors in contact with the copper winding. Curve computed exponentially to fit the small-circle observations. (C. M. Laffoon, Bibliography 18, Fig. 2).

constant is 20 minutes. The agreement of the observations with the curve is, in general, satisfactory. Fig. 5 shows similar results reported on a 25.9 mv-a. alternator armature using two different positions of imbedded detector; namely, one in contact, as before, with the copper winding, and the other between adjacent coils in the slots; so that an insulating cover separated the

*Bibliography 18, pages 649-651, also 7a.
†Bibliography 19.
‡Bibliography 23.
§Bibliography 18, pages 651, Figs. 2 and 3.

detector from the copper. In the upper curve, the agreement with observations is, in general, satisfactory, but there is a wide departure of the observed temperature rises from the exponential lower curve, during the first hour. This departure is attributable to the effects of the interposed layer of insulation between detector and copper. The time constant τ_2 of the upper curve is 26 minutes, and for the lower curve 38 minutes.

Fig. 6 gives three temperature rise curves reported by

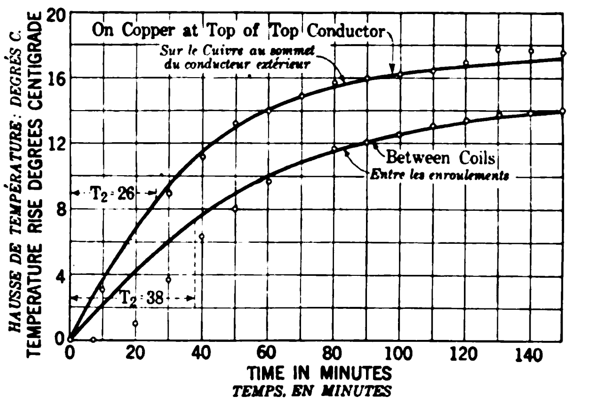

FIG. 5—TEMPERATURE RISE OF A 25,900-KV-A. THREE-PHASE TURBO GENERATOR OPERATING UNDER CONSTANT 75.3 PER CENT LOAD

Exponential curves to fit experimental data. Imbedded temperature detectors. Upper curve for detectors in contact with copper winding. Lower curve for detectors between coils, but outside insulation. (C. M. Laffoon, Bibliography 18, Fig. 3).

Mr. G. E. Luke* for a 35-h. p., d-c. railway motor. The temperature rises were obtained with imbedded thermocouples, and in the case of the armature, through slip rings. The observations conform well with the computed exponential curves. The binary time constant of

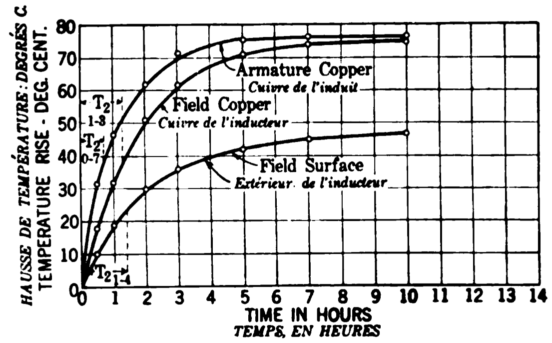

FIG. 6—TEMPERATURE-RISE CURVES OF A 35-H-P., D-C. RAILWAY MOTOR, 300 VOLTS, 35 AMPERES

Temperature by imbedded thermocouples (armature by slip rings). Curves are exponential to fit observations (G. E. Luke, Bibliography 18, Fig. 9).

the armature copper was 0.7 hour, that of the field copper, 1.3 hours, and of the field surface 1.4 hours. This shows that the location of the hottest-spot temperature in a machine during a temporary overload, may depend upon the time constants of the different elements.

In additional temperature rise tests reported by Mr. Luke, the agreement between the test observations and exponential curves was satisfactory in certain cases but unsatisfactory in others, depending upon the relative mutual dependence of the thermal elements in the structure of the machine.

Fig. 7 gives four temperature rise curves reported by M. O. E. Shirley taken in a series of special thermal tests on a 1100-kv-a., 3000-volt, three-phase synchronous motor. This machine was operated as a synchronous condenser, at substantially zero power factor, starting at ambient temperature, under steady excitation. The ambient temperature remained practically uniform throughout. The top curve represents the rotor field-winding temperature, from volt-ampere measurements. Until after the first hour, the observations conform satisfactorily well with the exponential curve of $\tau_2 = 34$

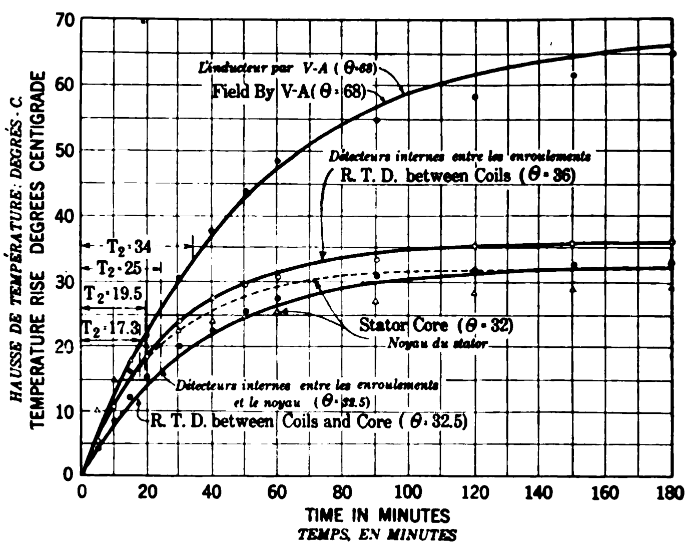

FIG. 7—TEMPERATURE-RISE CURVES FOR A 1100-KV-A., 3000-VOLT, THREE-PHASE SYNCHRONOUS MOTOR OPERATED AT APPROXIMATELY ZERO POWER FACTOR OR SYNCHRONOUS CONDENSER (O. E. SHIRLEY)

minutes. The maximum rise of this field winding exceeds the usual values on account of the over-excitation for zero power factor. The two R. T. D. curves refer to imbedded resistance temperature detectors. The upper of these curves refers to detectors between stator armature coils in the slots, and the lower to detectors placed between stator armature coils and stator core. Both of these curves are in satisfactory agreement with the observations. The former has a time constant of 19.5 minutes, and the latter 25 minutes. The stator core curve, derived from thermometer readings, is not in good agreement with the observations.

Air-cooled, Oil-immersed Transformers. Figs. 9, 10 and 11 give temperature rise curves reported by Mr. W. H. Cooney† from observations on large single-phase transformers tested under conditions of constant load. In these cases the time constant was predetermined by

*Bibliography 18, page 653, Fig. 9.

†Bibliography 19, Figs. 6, 8 and 10.

the method outlined in Appendix I. The curves are exponential with these respective time constants, and conform satisfactorily to the measured temperature rises. They refer to top-oil temperature rise above ambient air. The dissipation constant s in these

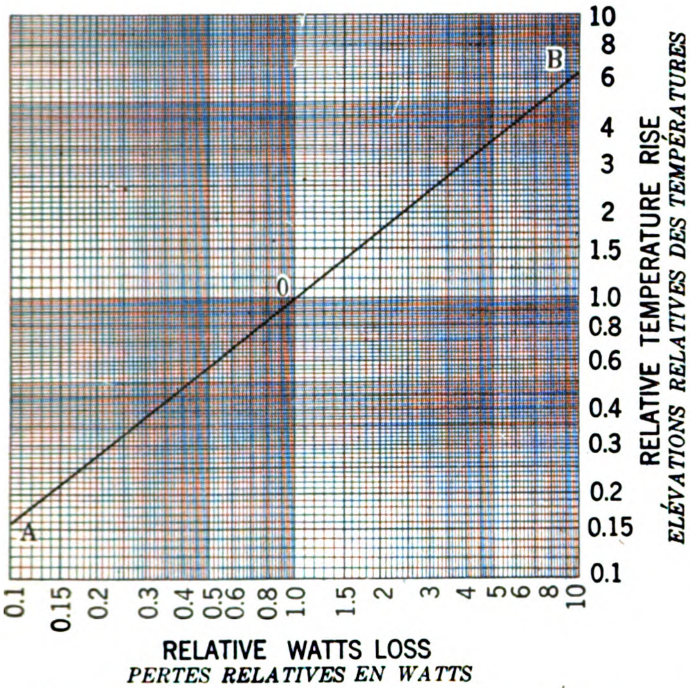

FIG. 8—APPROXIMATE STRAIGHT-LINE RELATION ON LOG PAPER BETWEEN RELATIVE TEMPERATURE ELEVATION OF TOP OIL AND RELATIVE LOSS OF POWER IN TRANSFORMER, REFERRED TO THE TEMPERATURE ELEVATION AT NORMAL RATED POWER LOSS

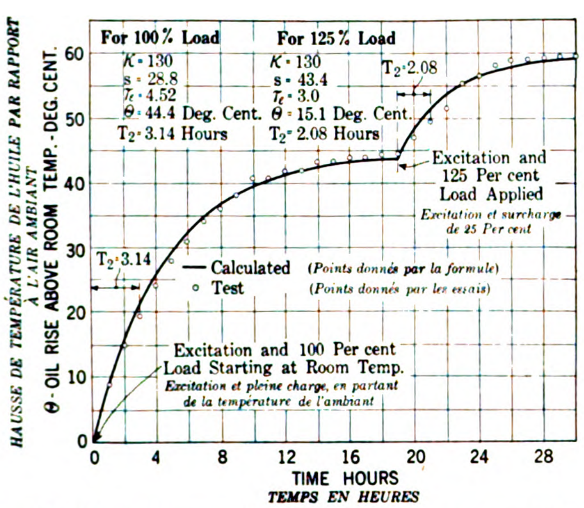

FIG. 9—TEMPERATURE RISE OF TOP OIL ABOVE AMBIENT AIR WITH TIME, IN A 75-KV-A. TRANSFORMER, 100 PER CENT LOAD AND EXCITATION APPLIED FOR 19 HOURS, FOLLOWED BY 125 PER CENT LOAD FOR 11 HOURS MORE

cases, appears not to have been constant over the temperature range. Fig. 8 gives the relation observed between temperature rise and relative watts loss, as drawn on log paper, for an exponent of 0.8. As a consequence of this variation in s, the time constant varies with the load on the transformer. Thus in Fig. 9 the first part of the curve, for 100 per cent load, during 19 hours, has $\tau_2 = 3.14$ hours, the ultimate temperature rise being 44.4 deg. cent. The second part of the curve, for 125 per cent load, during 11 hours, has $\tau_2 = 2.08$ hours, the ultimate additional temperature rise being 15.1 deg. cent., or 59.5 deg. cent. above ambient.

Fig. 10 gives a corresponding curve of temperature

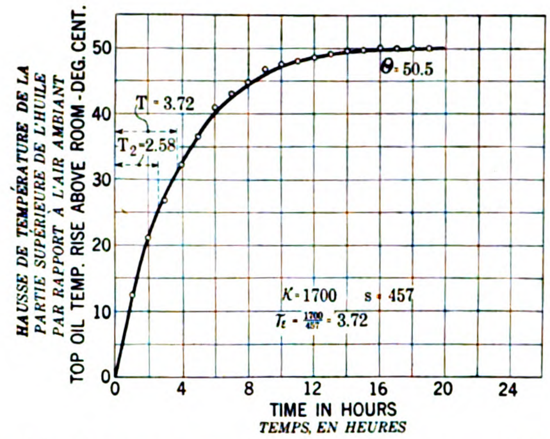

FIG. 10—TEMPERATURE RISE OF TOP OIL IN A 2000-KV-A. AIR-COOLED, OIL-IMMERSED TRANSFORMER STARTING UNDER NORMAL LOAD AND EXCITATION FROM AMBIENT ROOM TEMPERATURE

Exponential curve computed to fit observations. (W. H. Cooney, Bibliography 18, Fig. 8).

rise in a 2-mv-a. air-cooled transformer, operated for 19 hours under normal load conditions. The thermal capacity is given as 1700 watt-hours per deg. cent., and the dissipation constant 457 watts per deg. cent., so

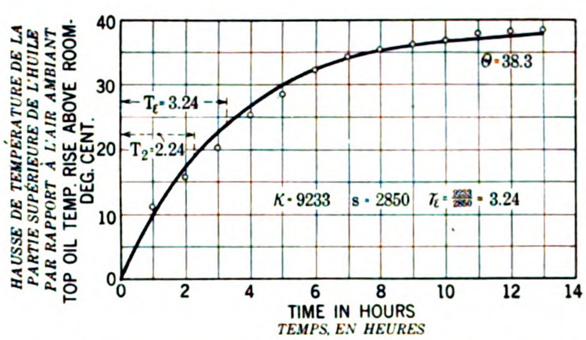

FIG. 11—TEMPERATURE RISE OF TOP OIL IN A 12,500-KV-A. AIR-COOLED, OIL-IMMERSED TRANSFORMER, STARTING UNDER NORMAL LOAD AND EXCITATION FROM AMBIENT ROOM TEMPERATURE

Exponential curve computed to fit observations. (W. H. Cooney, Bibliography, Fig. 10).

that the exponential time constant τ_ϵ is 3.72 hours, and the binary time constant 2.58.

The curves in Fig. 11 refer to the case of a 12.5-mv-a. transformer, with a thermal capacity of 9233 watt hours per deg. cent.

In all of the cases represented in Fig. 9, 10 and 11 the time constants were computed from the dimensions and weights of the transformer elements. The exponen-

tial curves were then drawn according to these time constants so as to show the conformity or departure of the observed temperatures from the curves.

Conclusions

The cases presented in Figs. 4 to 11 indicate that various examples of different types of machines follow temperature rise exponential curves, under steady load, within limits of precision sufficient for many practical purposes. On the other hand, there are various machines which, either in whole or in certain elements, depart materially from such curves. It is, therefore, unsafe to assume that any or every machine, taken at random, will follow an exponential temperature rise curve, unless either a test or record of the machine will establish the fact.

The binary time constant of a machine in association with its ultimate temperature rise characteristic curve, will enable the thermal behavior of the machine to be predicted in the variable regime, under change of steady load.

It is desirable to study the temperature-rise curves of all classes of machines, in order to diffuse a general knowledge of their behavior in the variable regime, this being useful information for the operating engineer.

Appendix I

Montsinger-Cooney Method of Estimating Thermal Capacity of Air-cooled Oil-immersed Transformers

Data for thermal capacity of transformer from top-oil to exterior ambient temperature.

Sp. heat of copper wire 0.0935

Sp. heat of steel core 0.115

Sp. heat of oil 0.47

Spec. thermal capacity of copper wire 0.109 watt-hr./kg. and deg. cent.

Spec. thermal capacity of steel core 0.134 watt-hr./kg. and deg. cent.

Spec. thermal capacity of oil 0.462 watt-hr./liter per deg. cent.

The ratio of mean oil temperature to top-oil temperature varies with the form and size of the oil tanks, but an average value is 0.86. Applying this ratio, the mean specific thermal capacity of the tank oil is $0.462 \times 0.86 = 0.397$, or in round numbers 0.4 watt-hr./liter deg. cent.

The weight of steel core in a transformer is commonly about 5.5 times that of the copper wire. Applying this ratio to the total metal in the transformer, the average specific thermal capacity of that metal is

$$\frac{0.109 \times 1 + 0.134 \times 5.5}{6.5} = 0.13 \text{ watt-hr./kg. and}$$

deg. cent.

Different parts of the oil tank attain different temperature elevations. Experience shows that a ratio of $2/3$ may be applied to the weight of steel in the tank in estimating, its specific thermal capacity.

The thermal capacity of the entire transformer from the top oil to the external ambient temperature is then

$$k = 0.13 \text{ (kg. copper + kg. core + } 2/3 \text{ kg. tank)} + 0.4 \text{ (liters oil)} \quad \text{watt-hr. per deg. cent.}$$

Data for thermal capacity of winding with respect to top oil:

$$k' = 0.109 \frac{S + s'}{2\,S'} \times \text{kg. bare copper wire} \quad \text{watt-hr./deg. cent.}$$

where S is the cross-section of the insulated wire and s' is the cross-section of the bare wire

This formula for k' takes account of the specific heat of the insulation of the wire as well as that of the wire itself.

Example of Time-Constant Computation

Data for 100 per cent load and excitation.

Top-oil steady temperature elevation, 40 deg. cent.

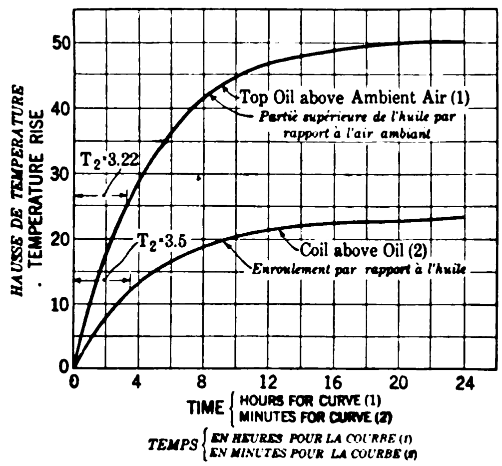

Fig. 12—Computed Temperature Elevation Time Curves for Transformer Having the Constants Analysed in Appendix I

Abscissas minutes for curve 2 coil rise above oil, and hours for curve 1 top oil above air

Winding steady temperature elevation, above top oil, 15 deg. cent.

Copper loss 9000 watts.

Core loss 6000 watts.

Weights, steel tank 2040 kg.

Steel core 1900 kg.

Copper 450 kg.

Volume of oil, 3410 liters.

Required the time constant for 125 per cent load and excitation, starting from ambient temperature.

Final copper loss $(1.25)^2 \times 9000 =$	14060 watts
" iron "	6000 "
Total, neglecting changes in resistance,	20060 watts

$$\Theta_0 \textit{ for top oil.} \quad \text{Relative losses } \frac{20060}{15000} = 1.337$$

From Fig. 1, oil rise $= 1.26 \times 40$ deg. cent. $= 50.4$ deg. cent.

$k_2 = 0.13\,(450 + 1900 + 2 \times 2040/3) + 0.4 \times 3410 = 1850$ watt hr./deg. cent.

$s_2 = 20060/50.4 = 398$ watts/deg. cent.

$$\tau_\epsilon = \frac{k_2}{s_2} = \frac{1850}{398} = 4.65 \text{ hours.}$$

$\tau_2 = 0.693 \times 4.65 = 3.22$ hours.

Θ for copper above top oil

$$15 \times (1.25)^2 = 23.5 \text{ deg. cent.}$$

$k_\epsilon' = 454 \times 0.109 = 49.5$ watt-hr./deg. cent.

$s' = 14060/23.5 = 508.3$ watts/deg. cent.

$$\tau_\epsilon = \frac{k'}{s'} = \frac{49.5}{508.3} = 0.083 \text{ hour} = 5.0 \text{ min.}$$

$\tau_2 = 0.693 \times 0.0826 = 0.057$ hour $= 3.5$ min.

The exponential curves for θ_0 and θ_c are given in Fig. 12, as computed from the above data, together with their binary constants, to two different scales of time, as abscissas.

The original data from which Appendix I has been prepared, will be found in Bibliography 18 and 19.

Appendix II

FORMULA FOR DERIVING THE ULTIMATE TEMPERATURE RISE FROM AN INCOMPLETE TEMPERATURE RISE—TIME CURVE ASSUMED TO BE EXPONENTIAL.*

$$\Theta = \frac{\theta_1}{2 - (\theta_2/\theta_1)} \quad \text{deg. cent.}$$

where θ_1 is the temperature rise at the end of t_1 hours, and θ_2 is the corresponding temperature rise at the end of $t_2 = 2\,t_1$ hours. It is assumed that $\theta = 0$ at the start, and that the ambient temperature remains constant throughout.

Thus if $\theta_2 = 1.5\,\theta_1$, it will follow that $\Theta = 2\,\theta_1$ and $t_1 = \tau_2$.

FORMULA FOR COMPUTING THE BINARY TIME CONSTANT FROM TWO ORDINATES OF AN EXPONENTIAL TEMPERATURE RISE CURVE TAKEN AT TWO SUCCESSIVE EQUAL INTERVALS OF TIME FROM THE START.

$$\tau_2 = \frac{0.30103\,t_1}{\log\left(\frac{\theta_1}{\theta_2 - \theta_1}\right)} \quad \text{hours}$$

where θ_1 is the temperature rise after t_1 hours, and θ_2 the corresponding temperature rise after $t_2 = 2\,t_1$ hours. Thus if $\theta_2 = 1.5\,\theta_1$ $\quad \tau_2 = t_1$

LIST OF SYMBOLS EMPLOYED

- ϵ = 2.71828 Napierian base.
- θ temp. rise above ambient (the latter assumed as constant) (deg. cent.)
- θ_1 temp. rise after time t_1 (deg. cent.)
- θ_2 temp. rise after time t_2 (deg. cent.)
- θ_a ambient temperature, (deg. cent.)
- Θ ultimate temp. rise above ambient, (deg. cent.)
- k thermal capacity of machine or element, (watt-hrs. per deg. cent.)
- s dissipation constant of machine or element (watts per deg. cent. rise above ambient).
- P output of a machine (watts)
- p power dissipated steadily in machine or element (watts)
- t time elapsed from start of temp. rise test (hours or mins.)
- τ_ϵ exponential time constant (hours or mins.)
- τ_2 binary time constant (hours or mins.)
- τ_{10} decimal time constant (hours or mins.)

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Temperature Rise and Losses in Solid Structural Steel

Exposed to the Magnetic Fields from A-C. Conductors

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Member, A. I. E. E.

and

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Non-member

Synopsis.—*Experimental investigations were made for the determination of the temperature rise and the losses occurring in structural steel members exposed to the fields from a-c. conductors. The work originated from the demand, among the designing engineers of an electrical manufacturing company, for practical data which would enable them to estimate, at least roughly, the temperature rise and the heat losses in the more common cases of structural steel members passing near the conductors. In the paper presented here, are given the results of the investigations in question. Examples are given illustrating the method of procedure in estimating temperature rise and losses in structural steel. The method of calculation applied is, in most cases, empirical. The major factors affecting temperature rise and losses are discussed on the basis of the test data. An understanding of these factors will often permit a designer to avoid iron heating without sacrifice of space or of economy. Thus a good part of the data presented applies to cases for which the temperature rise of the steel would ordinarily be considered not seriously objectionable.*

INTRODUCTION

In electric stations heavy a-c. conductors are often run in close proximity to steel structural members. It is well known that the steel members when exposed to a-c. magnetic fields will tend to heat on account of induced eddy currents and hysteresis losses. While a local temperature rise of a few degrees here and there in the steel will generally not be seriously objectionable, the iron losses must not reach an amount sufficient to raise materially the ambient temperature in the vicinity of the conductors themselves or in the vicinity of other electrical apparatus. Moreover undesirable expansion of the building steel and cracking of the concrete may sometimes result from excessive heating of the steel. It is even possible that, unless consideration is given to the iron losses, they may seriously add to the station losses.

While all of the above matters have been known, at least qualitatively, there has been but a scant amount of data available for designers to estimate the temperature rise and the losses in question.

OBJECT AND SCOPE OF PAPER

Since there has been an increasing demand for data on heating and losses in solid structural steel, especially in view of the more frequent use of the isolated-phase system of station layout, with its more wide-spread stray magnetic fields, an experimental investigation was made by an electrical manufacturing company to obtain, for their designers and engineers, practical data on the temperature and the losses in a number of the more common cases of structural steel members passing in the vicinity of heavy-current, a-c. conductors. Actual measurements of temperature rise and of losses on full-size steel members were made in the laboratory. Naturally only a limited variety of structural arrangements could be represented. Nor was it possible to set up a general or fundamental formula, for practical use, for the calculation of the temperature rise of solid iron members. Hence the application of

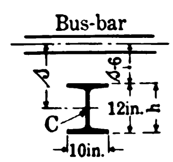

FIG. 1

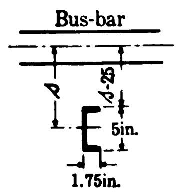

FIG. 2

FIGS. 1-2—TEST POSITIONS OF IRON MEMBERS (*I*-BEAM AND CHANNEL BEAM)

With respect to conductor crossing at right angles to the iron

the results obtained is primarily limited to the range of conditions covered by the tests. Nevertheless, it has been possible, by suitable choice of test conditions, to obtain a considerable amount of useful data, which

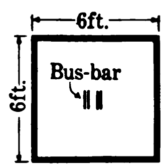

FIG. 3

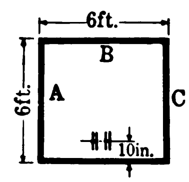

FIG. 4

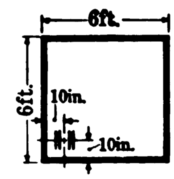

FIG. 5

FIGS. 3, 4, 5—TEST ARRANGEMENTS OF 6-FT. BY 6-FT. CLOSED CHANNEL IRON FRAME

With respect to a straight conductor passing through the frame at right angles to its plane

have been effectively applied for a year or more, in practical cases of station steel design and of conductor layout. The principal results obtained are summarized in the following paper. No recommendations are made, however, concerning the safe permissible temperature rise of the steel members or the maximum allowable losses.

*General Engineering Laboratory, General Electric Co.

Abridgment of paper presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

Method of Test

The iron structural members to be tested—in most cases full-size pieces—were placed in a variety of positions with respect to heavy-current test circuits. In a good many of the tests, isolated-phase construction was simulated by having the return conductors relatively remote from the samples under test, so that the simple case of one infinitely long, straight conductor, with the return conductor infinitely remote, was closely approached. In other tests, the resultant field at the

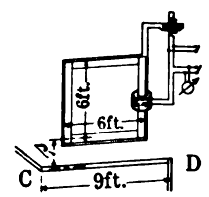

Fig. 6—Test Arrangement of "Electric Loop" Consisting of a 6-ft. by 6-ft. Channel Iron Frame

Conductor *C D* being in the plane of the frame

iron member under test, due to all conductors in the circuit, had to be considered. Moreover, in some circuit arrangements the adjacent-phase construction was deliberately imitated. The effects of conductor bends and loops on nearby iron members was also investigated. All tests were made at an ambient temperature of from 20 to 25 deg. cent.

For the I-beam, channel beam, switchboard pipe, round reinforcing rods and steel plates tested the resistivity ranged from 13.2 to 15.9 microhm-cm., and the maximum permeability from 1210 to 1800 at densi-

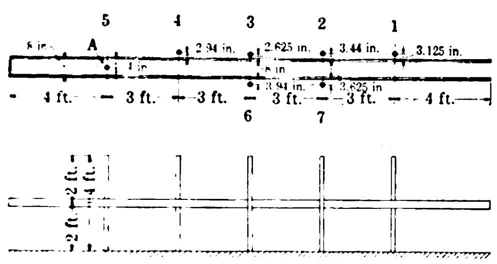

Fig. 7—Conductor and Iron Pipe Layout in Iron Heating Tests

With pipes passing outside of conductor group as well as between going and return conductors in adjacent-phase circuit

ties of from 6200 to 7800 gausses. In so far as structural steel members are concerned (having values of resistivity and permeability within the range of those given) approximate estimates of temperature rise may therefore be made on the basis of the test data given here (in accordance with the procedure outlined in the examples below), without further consideration of permeability and resistivity.

The temperature measurements were made with mercury thermometers attached with putty to the iron samples under test, or by thermocouples in the case of some of the smaller samples such as reinforcing rods.

In most cases the sustained final temperatures, or temperature rise, of the steel for constant loads were obtained.

The currents in the test circuit were of substantially sine-wave shape at frequencies of either 60, 40 or 25 cycles per sec. and were as high as 5800 r. m. s. amperes.

In a number of cases loss measurements were made. The method was to obtain the total input into the busbar system and to subtract therefrom the copper losses. A sensitive wattmeter of the reflecting dynamometer type was used whose current coil was connected to the line-current transformer and whose potential circuit was connected to two points of the busbar system embracing all the flux which produces losses. The copper losses were measured separately in the absence of the iron members. The measurement of a known loss (of the order of magnitude of the iron losses) produced

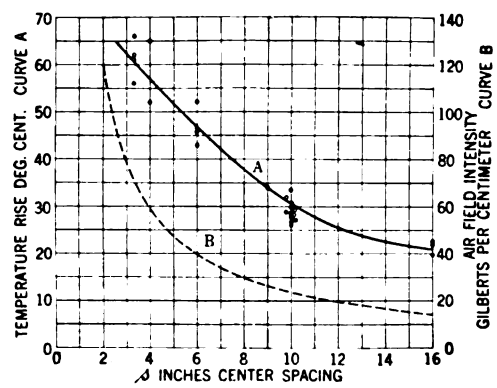

Fig. 8—Temperature Rise vs. Spacing (Curve A)

For long straight bare structural iron members crossing at right angles to a straight 3000-ampere, 60-cycle conductor, return conductors remote

Curve A: Final maximum temperature rise at iron hot spot for a constant conductor current

Curve B: Air field intensity vs. spacing for a single 3000-ampere straight long conductor

Center spacing measured from center of conductor to center of iron member

by a current induced in a short-circuited coil by the flux from the busbar circuit showed an over-all accuracy of loss measurements of better than 10 per cent.

Short-circuited copper windings of one or more turns were placed around the iron member in several cases so as to embrace the flux passing through the iron member and thus to reduce the iron loss. Measurements of the circulating current in the short-circuit windings were made for the purpose of obtaining a relation between iron heating (and losses) and the ampere turns in the short-circuited copper.

RESULTS OF TESTS

I. Straight Magnetic Members

Effect of Current on Temperature Rise

The final temperature rise at the surface of the steel member at the point nearest to the conductor, was found to vary as the 1.7th power (average value) of the conductor current for thick steel members (thicker than, say 1/8 in.) crossing at right angles to a conductor. The

value given is an average exponent derived from test results covering a current range from 1000 to 5800 amperes, center spacings between conductor and iron member from 2.5 to 16 in., and values of iron temperature rise from 10 to 175 deg. cent. Values of the exponent obtained from the various tests ranged from as high as 2 (for low values of maximum flux density and temperature rise) to 1.4 (for the highest values of temperature rise tested).

Temperature Rise at Different Spacings for Straight Iron Member Crossing at Right Angles to a Single Straight Conductor

The effect on temperature rise of spacing alone, in the absence of material effects of return conductors, is indicated in Fig. 8, for the case of a long, straight 3000-ampere, 60-cycle conductor crossing at right angles to a long, straight, horizontal, bare, solid, structural iron member. (It will be shown later that the shape and size of the iron member within certain limits, do not materially affect the hot-spot temperature rise for a given center spacing and current). All spacings are from center of conductor to the center of the iron member.

According to Fig. 8 it is seen that increasing the spacing from 6 to 10 in. reduced the maximum temperature rise of the iron 35 per cent, a further increase of spacing to a total of 16 in. gave a temperature rise about half that for the 6-in. spacing.

Effect of Frequency on Temperature Rise

Tests for temperature rise at 25, 40 and 60 cycles per sec. gave values of temperature rise roughly in the ratio of 1, 1.3, and 1.6, currents and center spacings being the same. The tests were made on 1¼-in. standard switchboard bare iron pipes and on bare ½-in. round and ½-in. square iron reinforcing rods.

Effects of Size, Shape, and Thickness on Temperature Rise

Various kinds of straight iron members crossing at right angles to a conductor, and not less than, say ⅛ in. thick and of cross-sectional dimensions (in a direction perpendicular to the conductor as dimension h in Fig. 1) up to 12 in. at *center spacings* from 10 in. to 16 in. from the conductor, had substantially equal values of temperature rise at any given busbar current, as indicated by tests of the following iron members: 12-in. by 10-in. I-beam, 5-in. by 1¾-in. channel beam, 4-in. by ⅜-in. by 8-ft. steel plate, 10-in. *I*-beam flange,* 1¼-in. switchboard steel pipe. See Fig. 9. In other words, the temperature rise under these conditions was *independent of the size, or cross-sectional area or shape for a given center spacing between conductor and iron,* regardless of the distance from the conductor to the nearest part of the iron. Variations of temperature rise within this rule were found to be not higher than 30 per cent and usually much less.

*Cut from the 12 in. I-beam already mentioned.

If the iron members have a thickness of the order of, or less than, two or three times the equivalent depth of flux penetration* (calculated for relatively thick members), or say less than ⅛ in., it will have a smaller temperature rise than thicker iron members because a smaller volume of iron per unit of surface will participate in the production of loss as indicated in Fig. 9.

Effect of Fields from Several Conductors on Temperature Rise of Iron

In a great many practical cases, there is more than one conductor contributing to the field at the hot spot of the iron. A number of such cases were tested and the following approximate rulings for iron heating were obtained when the "air-field intensity" along the axis of the iron member was taken into account. By "air field intensity" is meant the calculated resultant intensity, due to all conductors, in air assuming no magnetic bodies present, the intensity for the present

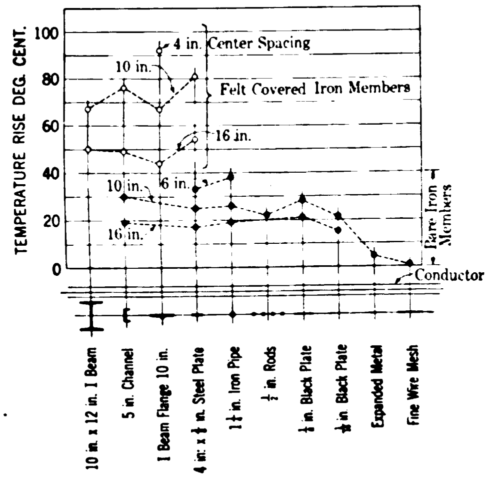

Fig. 9—Comparison of Values of Maximum Temperature Rise

For different iron members crossing at right angles to conductor
Iron members horizontal
Constant busbar current of 3000-amperes at 40 cycles per sec.
Figures on plot indicate center spacing between conductor and iron members

purpose being calculated along the line of the longitudinal center axis of the iron member at the section through the hot spot, *i. e.*, usually at the point where the axis is at the shortest distance from the nearest conductor. The relations pertaining to the effects of the magnetic fields from several conductors on temperature rise in solid iron are:

a. At any given center spacing from iron member to nearest conductor, the hot-spot temperature rise varied as the 1.4 to the 2.0 power (see Table I) of the air field intensity calculated for the center point of the cross section nearest to the conductor, as for instance, point C in Fig. 1—a relation similar to that already given for the current.

*Bibliography 2.

TABLE I

VALUES OF EXPONENT n, IN EQUATION (1) FOR CALCULATION OF TEMPERATURE RISE OF SOLID STRUCTURAL IRON MEMBERS CROSSING AT RIGHT ANGLES TO CONDUCTORS

H r. m. s. gilberts per cm. air field intensity.	n
20 or less	2.0
50	1.7
100	1.5
150	1.4

b. An approximate relation useful in a variety of cases for estimating the temperature rise of iron members exposed to fields from more than one conductor was found to be the following: at any given center spacing between an iron member and the conductor contributing the major component of the resultant field (usually this is the conductor passing nearest to the iron) the maximum hot-spot temperature rise, for any particular value of air field intensity (due to all conductors), at the center of the iron section through the hot spot, was independent of the arrangement of conductors—within certain limits.

A material departure from rule (b) was found, as would be expected, for those cases in which the different arrangements of conductors involved considerable changes in the distribution of the m. m. f. along the iron member (*i. e.*, on either side of the hot spot.) Thus for iron members outside the loop of Fig. 7, such as pipes No. 3 and 6, the experimental values of temperature rise were from 20 to 30 per cent less than those estimated from rulings *a* and *b* above, the reduction allowing for the fact that in the cases in question the m. m. f. and hence the iron losses fall off much more rapidly along the iron (*i. e.*, on one or on both sides of the hot spot) than the m. m. f. and the losses in a steel member crossing at right angles to *one* straight conductor only, center spacings being equal.

IRON MEMBERS RUNNING PARALLEL TO CONDUCTOR

A long and narrow steel member, such as an I-beam, a channel, or a pipe, will ordinarily heat much less (from 30-80 per cent less in the cases tested) when running parallel to the conductor than when crossing it at right angles, for the same spacings and currents. This is because the iron portion of the flux path around the conductor is a much smaller part of the complete flux path than in the case of a steel member crossing at right angles to the conductor. It will, therefore, often be advantageous from the standpoint of iron heating to lay out stations with the conductors parallel rather than at right angles to the iron members.

LOSSES IN STRAIGHT IRON MEMBERS CROSSING AT RIGHT ANGLES TO CONDUCTORS

A few loss measurements were made to indicate their general order of magnitude in a few cases, and their relation to the current magnitude, frequency, to the cross-sectional dimensions of the solid iron members, and to the spacing between iron and conductor. A complete investigation of losses to cover the wide field of the many customary structural layouts was, however, not made.

EFFECT OF FREQUENCY ON LOSSES

The relation between frequency and total loss in iron was investigated in the case of a closed iron ring 4-in. wide, ¼-in. thick and 20-in. average diameter. The results of the loss measurements, at 25, 40 and 60 cycles per sec., show that the loss varied roughly as the square root of the frequency.

EFFECT OF CURRENT ON LOSSES

Loss measurements at currents ranging from 1500 to 3000 amperes were made for a 10-in. by 12-in. steel I-beam, a 5-in. by 1¾-in. channel, a 4-in. by ⅜-in. steel plate, and a 1¼-in. standard switchboard iron pipe, when passing at right angles to a straight

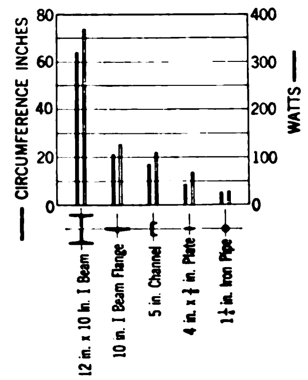

FIG. 10—COMPARISON OF TOTAL IRON LOSS WITH CROSS-SECTIONAL PERIMETER OF VARIOUS IRON MEMBERS CROSSING AT RIGHT ANGLES TO CONDUCTOR

Each iron member was tested separately
Center spacing between iron member and conductor 10 in.
Test current 3000 amperes at 40 cycles per sec.

conductor. The losses for the I-beam varied as the 1.8 to 1.9 power of the current, at constant spacing from the conductor. For other samples tested, this exponent was as low as 1.6

EFFECTS, ON LOSSES, OF CROSS-SECTIONAL AREA CIRCUMFERENCE AND SHAPE OF SOLID IRON MEMBERS

For iron members crossing at right angles to a conductor and not less than ⅛ inch thick and of cross-sectional dimensions (in a direction perpendicular to the conductor such as dimension h in Fig. 1) up to 12 in, at any given center spacing within the range from 6 to 16 in., the iron losses at any given current were actually found by test (see Figs. 10 and 11) to vary only with the circumference of the iron section and not with its area for the following iron members tested: 12-in. by 10-in. I-beam, 5-in. channel iron, 1¼-in. iron pipe, 4-in. by ⅜-in. steel plate, 10-in. I-beam flange.* Moreover, at any given spacing and conductor current, the loss for these iron members when crossing at right angles to a conductor was approximately proportional

to the circumference of the iron cross section, as indicated in Figs. 10 and 11. Deviations from this rule were less than 30 per cent (based on the average of the measured values) for the iron members tested. This result is in good agreement with the behavior of solid iron plates in respect to flux penetration and eddy-current loss, as worked out by previous investigators.†

Effect of Spacing

The relation between loss and spacing for straight iron members crossing at right angles to a straight conductor is indicated in Fig. 11. The curves show the average total measured loss per inch length of cross-sectional perimeter for center-spacings from 4 in. to

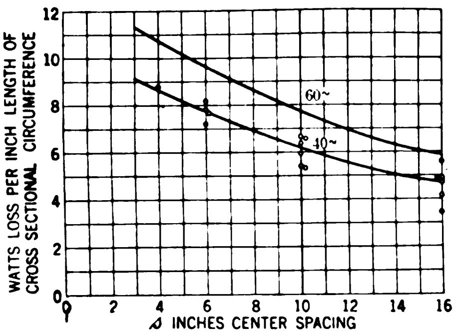

Fig. 11—Iron Loss per Inch Length of Iron Cross-Sectional Perimeter vs. Spacing

Test circuit closely approaching, as far as iron heating and losses are concerned, the arrangement of a single, long, straight conductor crossing at right angles to a straight long iron member. Busbar current 3000 amperes

Center spacing s measured from center of conductor to center of iron member

16 in. from a 3000-ampere conductor at 40 cycles and at 60 cycles.

II. Closed Iron Loops Around Conductor

Temperature Rise

To simulate *large frames of structural steel,* the circuit arrangements of Figs. 3, 4 and 5, with a 6-ft. by 6-ft. square frame of four 5-in. by 1¾-in. structural channel irons riveted or bolted together at the corners, were tested at busbar currents ranging from 1500 to 3000 amperes. The results of these tests showed that the temperature rise of iron beams in *large* rectangular magnetic frames surrounding a straight conductor and having sides larger than, say, 5 ft. may be calculated separately for each individual beam disregarding the other three sides of the frame, even if the conductor passes near the corner at a point as close as 8 in. from the nearest part of each of the two adjacent sides.

Small Frames. Both calculations and experimental observations indicate that small, closed uniform magnetic frames having sides of the order of, say, 2 ft. or less when surrounding a conductor must be expected to heat considerably more than a single straight iron member passing at right angles to a conductor, for equal spacings.

*Cut from the 12-in. I-beam already mentioned.

†Bibliography, 2, 5, 7.

Ducts of Iron Enclosing a Straight Conductor

In order to demonstrate experimentally that relatively high values of temperature rise and of loss may be obtained for sheet iron ducts completely enclosing an a-c. conductor, a horizontal 18-in. by 18-in. square iron duct of annealed iron sheets ⅛ in. thick was tested and gave a maximum temperature rise of 78 deg. cent. at the iron for a 3000-ampere, 40-cycle‡ busbar current, and an iron loss of 600 watts per foot of duct length.

Replacing the two horizontal iron sheets of the duct by non-magnetic sheets, but retaining the two iron side sheets, reduced the maximum temperature rise of the iron to 20 per cent; the total iron loss was reduced to about 10 per cent.

III. Closed Iron Frames Parallel to Conductor

The circulating current in a 6-ft. by 6-ft. channel iron frame as shown in Fig. 6 was of the order of 100 amperes when a straight 3000-ampere conductor was run parallel to one side of the frame and at 10 inches center spacing from the nearest channel iron, the conductor being outside the frame but in the same plane with it. The temperature rise of the iron was negligible. While the observed current in the 6-ft. by 6-ft. frame was small, considerably larger currents of, say, several hundred amperes may flow in heavy structural-iron frames of isolated-phase stations when the iron loops are large (say 15 or 20 ft. on a side) and especially when a heavy-current bus follows two sides of the frame§ or when the flux linking the iron loop is materially increased by the effects of other conductors. However, on account of the large surface over which the losses due to circulating currents in closed frames of large structural beams are distributed, their temperature rise will commonly be of minor consequence.

Copper Short-Circuit Rings

To Reduce Heating in Magnetic Members Crossing at Right Angles to Conductor. Copper loops around iron members crossing at right angles to heavy-current conductors may be used effectively to reduce the losses and temperature rise of the iron members; but when

‡60-cycle values of temperature rise and losses approximately 20-30 per cent higher.

§The circulating currents may be estimated for the more common types of frames if the magnitudes and relative phases of the currents in the nearby conductors, the dimensions of the frame and its position with respect to the conductors are known. The calculation in question involves determining the mutual inductance between the frame and the conductors, the self inductance and the skin-effect resistance of the frame. For skin-effect resistance calculations the reader is referred to Bibliography 2. From the loss, determined by the circulating current and the effective frame resistance, the order of magnitude of the temperature may be obtained from loss vs. temperature rise relations such as those given in Bibliography 12.

designed with too small a current-carrying capacity the copper loops may themselves seriously overheat.

In two typical cases, one with an iron girder beam 10 in. by 12 in., another with a 1¼-in. iron pipe, a copper sleeve or short-circuit winding having an ampere-turn capacity of 30 per cent of the busbar current reduced the iron losses and temperature rise to less than 10 per cent of their original values. In both cases the center spacing between the busbar and the iron member (crossing at right angles to the busbar) was of the order of from 6 to 10 inches, the busbar current ranging from 1500 to 3000 amperes.

EXAMPLES

Example 1. Estimate the hot-spot temperature rise of a square, vertical, bare channel-iron frame, having 6-ft. sides consisting of 5-in. by 1¾-in. bare channels, when a 3000 ampere, 60-cycle conductor passes at right angles through the plane of the frame at a point 10 in. above the center of the lower horizontal channel (Fig. 4), the frame being placed so that the channel section through the hot-spot is located as shown in Fig. 2 with respect to the conductor, s being 10 inches.

In estimating the hot-spot temperature rise it will be remembered that in large frames of this kind the maximum temperature is not affected by the presence of the three channel iron sides A B C; in other words the hot-spot temperature rise may be estimated by following the procedure given for single straight iron members.

Accordingly the first step is to obtain the reference temperature rise $T\,R_r$ from Fig. 8 for a straight horizontal iron member crossing at 10-in. center spacing from a long, straight 3000-ampere, 60-cycle conductor. Thus

$$T\,R_r = 31 \text{ deg. cent.}$$

and

$$H_r = 23.6 \text{ gilberts per cm.}$$

Calculating H, the air field intensity for $s = 10$ in. at the center of the channel section through the hot spot, the value

$$H = 24.8 \text{ gilberts per cm.}$$

is obtained, the excess of H over H_r being due to the effects of the return conductors in the circuit in question. Then the hot-spot temperature rise in the channel is found from*

$$\frac{T\,R}{T\,R_r} = \left(\frac{H}{H_r}\right)^n \qquad (1)$$

Where n in this case is 1.85, interpolated from Table I. Substituting the values

$$T\,R = 31\left(\frac{24.8}{23.6}\right)^{1.86} = 31 \times 1.095$$

Hence

$$T\,R = 34 \text{ deg. cent.}$$

*Based on relations (*a*) and (*b*) established above under the heading "Effect of Fields from Several Conductors on Temperature Rise of Iron."

i e., the desired final hot-spot temperature rise for a constant 3000-ampere current is estimated to be 34 deg. cent.

The nearest test condition to compare with this calculated result is a 40-cycle, 3000-ampere test with the frame of Fig. 4 and the same circuit, which test gave a 40-cycle, hot-spot temperature rise of 29.5 deg. cent. by thermometer. Estimating from the calculated 60-cycle temperature rise of 34 deg. cent., the corresponding 40-cycle temperature rise by the relation:

$$\frac{T\,R \text{ at 40 cycles}}{T\,R \text{ at 60 cycles}} = \frac{1.3}{1.6}$$

a 40-cycle value of $\dfrac{34}{1.23} = 28$ deg. cent. is calculated, which is in good agreement with the test value of 29.5 deg. cent.

Example 2. Estimate the loss in a structural 12-in. by 10-in. I-beam placed as shown in Fig. 1 with respect to a long straight conductor crossing at right angles to the beam. Let

s = 16 in.
I = 2600 amperes
f = 60 cycles per sec.
P = 64 in.

From Fig. 11, at $s = 16$ in.

$L_0 = 5.9$ watts per inch length of perimeter for a 3000 ampere reference current. Then the total loss at $I = 2600$ amperes is estimated from

$$L = P\,L_0\left(\frac{I}{I_r}\right)^n \qquad (2)$$

where $n = 1.75$, an average value. Hence

$$L = 64 \times 5.9 \times \left(\frac{2600}{3000}\right)^{1.78} = 295 \text{ watts}$$

Thus the total loss in the I-beam is estimated at 295 watts. The loss measured at 40 cycles per sec. with 2600 amperes was 230 watts, which is in good agreement with the estimated 40-cycle value of $\dfrac{295}{1.25} = 235$ watts.

SYMBOLS

f frequency, cycles per sec.

H r. m. s. gilberts per cm. in air, resultant air field intensity, due to all conductors, in the absence of iron members, calculated at the point occupied by the center of the iron cross section through the hot spot and in the direction of the longitudinal axis of the iron.

H_r r. m. s. gilberts per cm. reference air field intensity at spacing s inches from a long straight 3000-ampere conductor.

I r. m. s. amperes, conductor current for which iron heating or losses are desired.

I_r r. m. s. amperes, reference current of 3000 amperes flowing in a long straight conductor.
L watts total loss in solid iron member.
L_0 watts loss per inch length of perimeter P, for reference current I_r and spacing s.
n exponent of current or of air field intensity in temperature-rise calculations by equations (**1**) or (**2**).
ω $= 2\pi f$.
P inches perimeter of cross section of solid iron member.
ρ ohm-cm. resistivity of solid iron.
s inches, center spacing between iron member and nearby conductor.
TR deg. cent. hot-spot temperature rise at solid iron for current I and spacing s.
TR_r deg. cent. reference temperature rise at spacing s for current I_r.

SUMMARY

1. Results are given of measurements of temperature rise and of losses in structural steel I-beams, channels, pipes, plates, ducts and of temperature rise in rods, sheets and meshes when the iron members were exposed to the fields from 60-cycle, 40-cycle or 25-cycle conductors carrying currents as high as 5800 amperes. Experimental data were obtained to serve as a basis for designing copper sleeves to minimize heating and losses in structural-iron members crossing at right angles to conductors. Special tests were made on riveted and bolted steel frames placed within the field from a high-current circuit simulating isolated-phase construction. Empirical data and a simple procedure are given in the paper for estimating the temperature rise of straight steel members exposed to the magnetic fields from more than one conductor.

2. Iron members passing between going and return conductors in adjacent-phase layouts may reach very high temperatures; on the other hand, iron members passing at right angles to but outside of a group of going and return conductors will usually heat less than an iron member crossing a single conductor, when the current and minimum spacings are the same.

3. The temperature rise of structural iron beams in large rectangular magnetic frames surrounding a straight conductor (as in isolated-phase layouts) and having sides larger than, say, 5 ft. may be calculated separately for each individual beam disregarding the other three sides of the frame, even if the conductor passes near the corner at a point as close as 8 in. from the nearest part of each of the two adjacent sides. Small closed structural steel frames or ducts having sides of the order of two ft. or less, when surrounding a conductor, must however be expected to heat considerably more than a single straight iron member passing at right angles to a conductor, for equal spacings and currents.

4. A long and narrow steel member, such as an I-beam or a channel, will ordinarily heat much less when running parallel to a conductor than when crossing it at right angles, for the same spacings and currents. This is because in the parallel arrangement the iron portion of the flux path around the conductor is usually a much smaller part of the complete flux path than in the case of a steel member crossing at right angles to the conductor. It will, therefore, often be advantageous, from the standpoint of iron heating, to lay out stations with conductors parallel rather than at right angles to the iron members.

5. For various sizes of straight long solid structural iron members crossing ar right angles to a conductor and having a thickness not less than 1/8 in., when placed with respect to the conductor at any one center spacing within the range from, say, 6 to 16 in., the temperature rise was practically independent of the size, or cross-sectional area or shape of the iron member. In the same tests the losses of the various solid structural iron members not thinner than 1/8 in. were proportional to the perimeter of the iron cross section regardless of shape or volume. The iron members in question ranged in size from a 1¼ in. standard pipe to a 12 in. by 10 in. I-beam.

6. The values of temperature rise of structural iron members at the frequencies of 25, 40 and 60 cycles per sec. were roughly in the ratio of 1:1.3:1.6; *i.e.*, the 60-cycle temperature rise was 60 per cent higher than that at 25 cycles per sec.

7. The circulating current in a 6-ft. by 6-ft. channel iron frame was of the order of 100 amperes when a straight 3000-ampere conductor was run parallel to one side of the frame and at 10 inches center spacing from the nearest channel iron, the conductor being outside the frame but in the same plane with it. The temperature rise of the iron was negligible. While the observed current in the 6-ft. by 6-ft. frame was small, considerably larger currents of, say, several hundred amperes may flow in heavy structural-iron frames of isolated-phase stations when the iron loops are large (say 15 or 20 ft. on a side) and especially when a heavy-current bus follows two sides of the frame or when the flux linking the iron loop is materially increased by the effects of other conductors.

8. Short-circuited copper loops or bands around iron members crossing at right angles to heavy-current conductors may be effectively used to reduce the losses and temperature rise of the iron; but when designed with too small a current-carrying capacity, the copper loops themselves may seriously overheat. In two typical cases a copper sleeve, or short-circuit winding, having an ampere-turn capacity of 30 per cent of the busbar current reduced the iron losses and temperature rise to less than 10 per cent of their original values.

Acknowledgment. The authors are indebted to Mr. D. Basch for the use of iron-heating data obtained under his direction in a number of the earlier tests.

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NEW DISCOVERY MAY BROADEN ELECTRIC TRUCK FIELD

The recent discovery of a new element making possible much lighter storage batteries, as reported late in March from Vienna, Austria, will, when perfected for commercial use, broaden the transportation field now served by the storage battery truck. It is said that the new element is one-fifth the weight of lead and surpasses the lead accumulators now used in storage batteries in both capacity and power. That electricity is playing an important role in transportation is evidenced by the many installations of the electric truck for industrial plant hauling and city delivery service.

THE LONGITUDINAL FORCE IN CONDUCTORS

BY CARL HERING

The existence of a mechanical force in the direction of the axis of a conductor, the recognition of which the writer has been urging for many years, has been strenuously opposed by many (chiefly teachers and book writers) because it does not fit in with Maxwell's mathematical system, which recognizes only perpendicular forces. No one, however, has shown that it does not nor cannot exist, and it seems that its acceptance is now gaining, though slowly.

The following seems to convince opponents better than the writer's numerous other experimental proofs.* A loop of very flexible wire laid irregularly on a table, or floated on mercury, when insulated from it, will expand into a circle (or into a figure 8) when a strong current flows through it. The radial pressure of the flux inside of the loop is then balanced by a tensional force in the wire, quite analogously to these forces in a soap bubble or a toy balloon. This is the much disputed longitudinal or stretching force. This (as well as the radial force) is due to the mutual repulsion of the flux lines around the wire, and is an internal force or stress, due to its own flux; it should be carefully distinguished from the forces due to the flux from external circuits. Neither Maxwell nor Ampere seem to have known of the existence of any internal forces.

In the single, straight, conductor (one which is far removed from all others) the writer computed this force to be $i^2/200$ dynes, in which i is in amperes; hence it is very small. If certain newer theories are correct, it would follow that with 100 amperes in a single-turn circular circuit of 40 cm. diameter and 6 mm. diameter of wire, this force ought to be roughly about one gram, hence considerably greater, and the product of this force by the circumference of the circle, ought to be equal to the stored energy. This is a deduction and remains to be checked by tests, as this force has, apparently, never been measured before.

To enable passengers to see scenery at night, the Chicago Milwaukee and St. Paul Railway will, it is understood equip all observation cars on transcontinental trains with powerful adjustable floodlights.

Some 45 patents are said to be pending on a new process of taking and showing stereoscopic ("3-dimensional") moving pictures. A minimum screen width of 38 feet is required.

A blue glass recently concocted at the United States Bureau of Standards has the property of furnishing protection against ultra-violet rays. About half the lime in a soft soda-lime glass is replaced with cerium oxide, and sufficient cobalt oxide added to produce the desired color.

*TRANS. A. I. E. E., Vol. 42, 1923, p. 321.

Tests of Paper-Insulated High-Tension Cable

BY F. M. FARMER[1]
Fellow, A. I. E. E.

***Synopsis.**—The paper deals with those tests which are involved in specifications. The discussion is from the standpoint of the purpose and significance of the various standard tests which are made rather than that of the technic of the details of testing. A considerable number of data are given.*

The subjects treated are purpose and importance of tests of cable; insulation resistance test; high voltage test; dielectric loss and power factor test; "ionization" test; bending test; accelerated life test; preparation of samples for high-voltage tests and tests of components.

The possible significance of wide variation in some of the properties of cable is discussed. The relation found between time and voltage based on a large number of tests of both three conductor and single conductor cable is discussed at considerable length. A test for stability of the impregnating compound is described as is also a proposed standard load for dielectric-loss testing. Some data are given showing the effect of repeated bending on lead and how that effect is influenced by the tensile stress in the lead.

The paper concludes with a list of the ways by which, in the author's opinion, progress can be made in the improvement of the quality and the design of paper-insulated high-tension cable.

* * * * *

Introduction

Tests which are made on paper-insulated, high-tension cable may be divided into the three following general classes:

a. Research tests for the ultimate purpose of advancing this branch of the electrical industry by means of improvements in quality of materials and manufacturing processes, or improvements in cable design.

b. Tests on the commercial product at the factory to determine compliance with the manufacturer's standards or the purchaser's specifications.

c. Tests on cable after it is installed, including acceptance tests on new cable, periodic tests and fault location tests.

It is not feasible to cover even superficially all of these tests within the limits of one paper. It is, therefore, proposed principally to discuss those standard tests which are involved with specifications and certain other tests which, while not yet in specifications, aid in determining the quality of cable and the improvements which have been made therein. Furthermore, it is not proposed to discuss to any great extent the details of the technique of testing cable, but rather the purpose and significance of tests.

Purpose and Importance of Tests of Cable

Ostensibly tests in connection with the purchase and acceptance of cable are made for the purpose of determining whether or not the material complies with the specified requirements. The basic object, however, is to determine the suitability of the cable for the service to which it is to be applied. The specifications are, in effect, simply the engineer's method of describing cable which it is believed will be suitable for that service.

In no class of electrical apparatus does more reliance have to be placed on tests to determine suitability than in the case of cables. Insulation is a more or less important feature in all electrical apparatus but in high-tension cables it is *the* factor. The insulation in a high-tension transformer for example is, of course, of prime importance but the amount involved in the largest unit is insignificant compared to that in a cable line of average length. Consider for instance, the 66-kv. line of the Cleveland Electric Illuminating Company which consists of two three-phase circuits of three, single-conductor cables each. This line is about eight miles long and contains, therefore, about 50 miles of cable. The mean area of the insulation of this cable is about 123,000-sq. ft. or a little over 2.8 acres. While a few hundred sq. ft. of insulation are continuously under stress in the transformers at each end of this line there are nearly three acres of insulation buried in the ground, every square inch of which is expected to withstand continuously all day and every day a potential of 38 kilovolts.

Unfortunately we know far less about insulation than about any of the other essential classes of materials in electrical apparatus. In the case of cables, we impose particularly severe conditions because we effectually cover the insulation with a sheathing of lead so that no visual inspection whatever is possible and the sins of omission and commission, are thoroughly buried. We must, therefore, determine the suitability of this important part of a cable very largely by tests. Perhaps a better way of putting it would be to say that the best we can do is to make certain tests with the hope that, in the light of our present knowledge, they will eliminate cable which would be unsuitable for the intended service as prescribed by the specifications.

Insulation Resistance Test

The test for insulation resistance is one of the earliest made on electrical conductors. In the early days of the art when only low voltages were involved it served very satisfactorily as a means of detecting sections of wire or cable which would be likely to prove unsatisfactory in service. At such low voltages the inherent quality of the insulation did not have to be of a very high order and the principal things to be guarded against were mechanical defects and accidental injuries. The insulation

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resistance test served very well in weeding out wire or cable defective from these causes.

With the advent of higher voltages it was found that insulation resistance tests were of very limited usefulness in determining the inherent value of the insulation and that other tests were much more important in insuring a satisfactory product. It is now generally recognized that the number of megohm miles of a cable has little significance and no one can predict that a cable with high-insulation resistance will give better service than one with low resistance or vice versa.

While the actual value of the insulation resistance in megohm miles may not be significant, the *variation* in

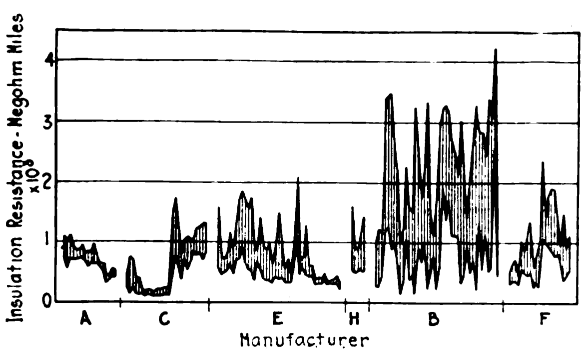


FIG. 1—INSULATION RESISTANCE OF 13-15-KV. CABLE INSPECTED DURING 1925

Upper line, maximum insulation resistance in each lot inspected
Lower line, corresponding minimum insulation resistance

the megohm miles between different sections of the same cable line, which are supposed to be identical in quality, may be very significant. The variation in the quality of high-tension cable is one of the greatest problems in the cable art for it is the weakest link in the chain that determines its strength and the problem of producing cable which is uniform from section to section or even foot to foot has yet to be solved. Obviously, cable having the least variation in quality is better than one the quality of which, although it may have a higher average value, varies over a wider range.

Fig. 1 has been prepared from insulation resistance measurements made in the course of the routine inspection of high-tension cable at six factories during 1925. The upper heavy line connects the values of maximum resistance found in each lot of cable and the lower heavy line connects minimum resistances. Each light vertical line connects the maximum and minimum values of resistance found in each lot submitted. The shorter the light vertical line is, the smaller is the variation in a single lot. The smoother the heavy lines are, the smaller is the variation between lots. It is evident that make "B" takes first place for variation while make "A" is conspicuously uniform, with "C" a close second.

Just what the practical significance of these differences in uniformity of insulation resistance is, we do not know. With respect to quality of the cable, these differences may mean much or they may mean little but it is submitted that until we have some means of measuring the quality of insulation more directly, we are justified in concluding that other things being equal, the cable with the smaller variation is the better.

HIGH-VOLTAGE TESTS

High-voltage tests of various kinds have long been considered the most important of all that are made on high-tension cable. They may be classified into (a) fixed or stated voltage tests, (b) momentary breakdown voltage tests and (c) time breakdown voltage tests.

(*a*) *Fixed Voltage Tests.* A fixed voltage test consists in the application of a prescribed voltage for a prescribed length of time to each reel of cable in the case of acceptance tests at the factory, or to an entire line of cable in the case of installed cable.

Volumes on the discussion of this subject of fixed voltage tests of insulation for all purposes, and cable in particular, have been printed. How high should the test voltage be and how long should it be applied to insure that the cable meets the desired standard without injuring the insulation? Which is the more effective, high voltage for a short time or a lower voltage for a longer time? These are questions which are still answered by opinions to a large extent. We do not as yet have all the facts definitely established which are essential to the formulation of the true answer.

What is the purpose of this particular voltage test? We encounter two serious obstacles when arriving at the suitability of a piece of cable. In the first place, the insulation is buried out of sight and in the second place, it is far from homogeneous. A member in a steel structure can be put in place with almost complete

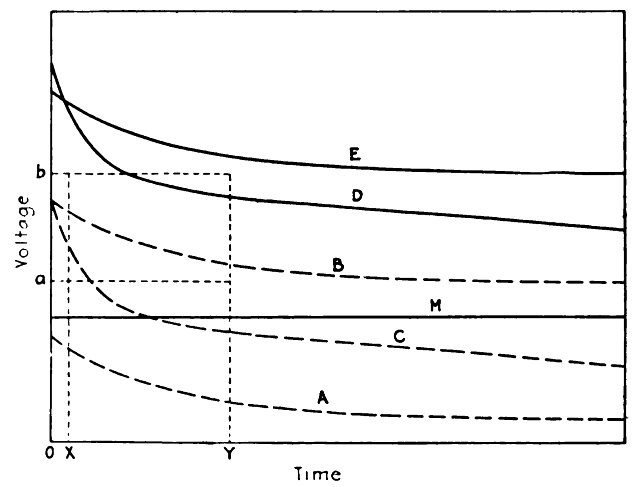


FIG. 3

confidence that it has 100 per cent reliability if it passes a visual inspection. But in the case of a length of cable we cannot judge by inspection whether it will serve the purpose intended nor can we depend absolutely upon a test to destruction of a specimen because of the lack of uniformity. We must "load" every foot of cable, that is, subject it to a voltage well above the

rated voltage—if we are to be assured of a reasonable "factor of safety."

The test should preferably accomplish two things,—eliminate cable the insulation of which is electrically weak because of accidental defects, and eliminate cable which is electrically weak because of the inherent low quality of insulation.

One way of visualizing the conditions with which we have to contend is indicated in Fig. 3. It is well established that the voltage which a given piece of insulation will withstand is greatly effected by the test conditions, one of the most important being the time of application of the voltage. Each portion of insulation has its own voltage-time characteristic which can be indicated in the general manner shown by the curves in the diagram.

Now, consider a section of cable with an accidental defect of a mechanical nature such as external damage to the insulation, registration of a large number of tapes, cracked or torn insulation, etc. The breakdown voltage of the section of cable will, of course, be that of the insulation at this point, and if the injury is serious, the breakdown voltage will be much below that of the rest of the section. Nevertheless, that spot has a time-voltage characteristic which we can indicate by curve A. But a moderate test voltage, a, even if applied only momentarily will cause puncture and therefore eliminate that section. If the defect is less extensive so that a lesser thickness of the insulation is effected, the curve may be something like B in which case, a test at a volts even if applied for y time, will not eliminate it. Nevertheless, its so-called permanent breakdown voltage, *i. e.*, the maximum voltage which it will withstand indefinitely is not sufficiently above the operating voltage, M, to provide the necessary factor of assurance. On the other hand, a test at b volts, even if only momentarily applied, would eliminate it.

Next, assume a spot which is inherently electrically weak due, for example, to incomplete saturation or overheating at a lead press mark. The insulation at that point may have a high momentary dielectric strength without a correspondingly high endurance strength due to high dielectric loss which causes failure in accordance with the thermal theory of Steinmetz and Wagner. The characteristic curve at this point might be of the shape indicated by curve C, in which case a test at a volts for a time x would not eliminate the section but a volts for y time would.

Normal cable may have a characteristic like curve E or curve D. The former is obviously the preferable type of curve. Both curves are higher than those for the other cases, consequently the test voltage should be adjusted to the normal cable and not to the abnormal cable only. The problem is then to determine the voltage which should be applied to insure as high a curve E as possible, and for as long a time as practicable in order to eliminate cable with too much of the characteristic indicated by D. This would be accomplished by applying b bolts for y time.

The practical question is then, what should the voltage be and for how long should it be applied? This question has been with us since the beginning of the industry and is likely to remain with us for some time to come. It is to be noted, however, that the trend in fixed voltage tests is very definitely upward both as to voltage and time. For instance, the A. I. E. E. rules adopted in 1911 prescribe double normal rated voltage for one minute. The standards of 1922 prescribe two and one-half times operating voltage for five minutes while those adopted August 6, 1925 prescribe three times the rated voltage plus 2 kv. for five minutes. The most recent specifications in wide use, namely, those of the Association of Edison Illuminating Companies, prescribe test voltages substantially in accord with the latest rules of the A. I. E. E. but the test period is fifteen minutes instead of five minutes. So, despite our lack of facts and figures, general knowledge and experience has gradually pushed up the test voltage and lengthened the time of application.

(*b*) *Short-time Breakdown Voltage Test.* The fixed voltage test will not of course tell us what factor of assurance we are getting. We try to get some light on that question by means of short-time breakdown voltage tests, *i. e.*, by testing short samples to destruction. The light we get, however, is rather feeble for after we have obtained the so-called momentary puncture voltage, we cannot coordinate it with the rated or operating voltage of the cable. This is due not only to the dielectric strength-time relation referred to in the preceding discussion, but to the variation in the material. The latter point could be taken care of by testing enough samples but any such procedure sufficiently extensive to truly represent the product would be quite impracticable. However, short-time tests do give us data which indicate the trend at least of the dielectric strength.

Table I shows a summary of a large number of tests made in 1923, 1924 and 1925 respectively on cable manufactured under the N. E. L. A. specifications. The results are reported in average volts per mil. Cables of all sizes and voltages are included, so that some common basis must be used.

TABLE I
DIELECTRIC STRENGTH OF CABLE

Year	No. of Tests	Average volts per mil at breakdown			Per Cent inc. in Average over 1923
		C-C	*C-S*	Average	
1923	260	291	283	287	..
1924	290	307	284	306	6.6
1925	106	354	357	355	23.7

"*C-C*" — between conductors.
"*C-S*" — between conductors and sheath.

It is evident that the dielectric strength of cables has been steadily increasing—being nearly 25 per cent greater on the average in 1925 than it was in 1923.

(c) *Long-Time Breakdown Tests.* The preceding discussion has indicated that one of the most important things which we would like to know is the *maximum* voltage which each length of cable will withstand indefinitely. The only way to get this information is by a series of tests to destruction by subjecting several samples of the same cable to different voltages continuously until failure occurs. Sufficient tests of this kind will give data from which a reasonable reliable answer to the above question can be made. Such tests are, however, very expensive as much time is required and also a considerable amount of costly cable. However, the significance and importance of such information is being recognized and it is felt that we have reached a step in the development of the art where this knowledge is essential to further intelligent progress. The cost of acquiring the necessary data is secondary in view of the importance of cables in the electrical industry and the large amounts of money being invested in them.

A considerable amount of this kind of testing is being done—some by the manufacturers and some by the utility companies, particularly the Commonwealth Edison Company of Chicago. Electrical Testing Laboratories are also doing a considerable amount of this class of cable testing and some of the data shown in the accompanying diagrams are made available through the courtesy of its clients, particularly the High-Tension Cable Committee of the Association of Edison Illuminating Companies.

The results of about 30 tests of three-conductor cable of various sizes and voltages are shown in Fig. 6 where the maximum stress gradient at the conductor

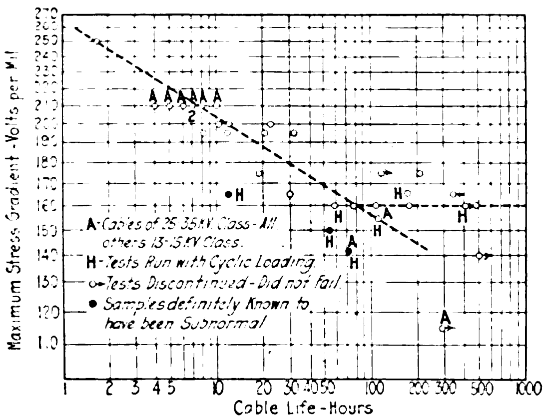


FIG. 6—CABLE TESTS (TIME-STRESS DIAGRAM) THREE-PHASE TESTS, THREE-CONDUCTOR CABLE

surface is plotted on logarithmic coordinates against time.

It will be noted that while the data are quite insufficient to justify anything like a final conclusion, they do suggest a more or less critical point in the life curve beyond which the cable will have indefinite life. That is, the broken line which is a reasonable mean of all of the points, suggests that, at a stress lower than about 150 or 160 volts per mil maximum stress gradient, the life will be indefinite (or at least will decrease at a very low rate) and that at higher stresses the life will vary inversely something like the seventh power of the maximum stress gradient. However, much more data are needed before this indication can be definitely established or disproved.

Fig. 7 shows some similar data, plotted in the same manner, which were obtained on 44 samples of single-conductor cable for very high voltages. If the points enclosed by the dotted line and which were obtained on specimens of two samples of cable that showed con-

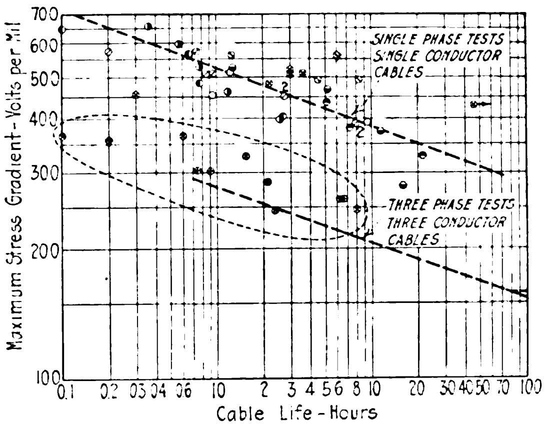


FIG. 7—CABLE LIFE TESTS (TIME-STRESS DIAGRAM)

Note: Points show single-conductor tests only. For three-phase test points see Fig. 12. Designations identify makes of cable tested

sistently much lower dielectric strength than the other samples that are omitted, a fairly definite straight line can be drawn, as indicated by the broken line.

Whether or not a critical point exists here also is not determinable because we have not as yet enough data, specially long-time data. However, it will be observed that the slope of the curve as plotted is the same as that for the three-conductor cable in Fig. 6. The left-hand portion of the latter curve extended backwards is shown in Fig. 7. In other words, the seventh power relation between the maximum stress gradients is again suggested.

DIELECTRIC LOSS AND POWER-FACTOR TEST

The practical significance of the dielectric losses in the insulation of cable was not fully appreciated until six or seven years ago when an epidemic of service failures led to the recognition of the dielectric loss type of failure. Bang and Louis[4] and other contributors to the TRANSACTIONS of the Institute have discussed the influence of dielectric loss on the carrying capacity of cables. Roper[5] has given concrete evidences of cable failures due to excessive dielectric loss. However, these losses have been so much reduced that they are no longer a serious element in cable operation. In the

4. *Influence of Dielectric Losses in the Rating of High-Tension Underground Cables*, A. F. Bang and H. C. Louis, TRANS. A. I. E. E., Vol. 36, 1917, p. 341.

5. *Dielectric Losses and Stresses in Relation to Cable Failures.* D. W. Roper, TRANS. A. I. E. E., Vol. 41, 1922, p. 547.

past four years, the average loss in 30-kv. cable dropped from about 1.6 to 0.6 watt per foot and for 13-kv. cable from about 0.9 to 0.2 watt per foot.

Power-factor measurements also provide another means of studying the problem of uniformity of cable to which reference has been made.

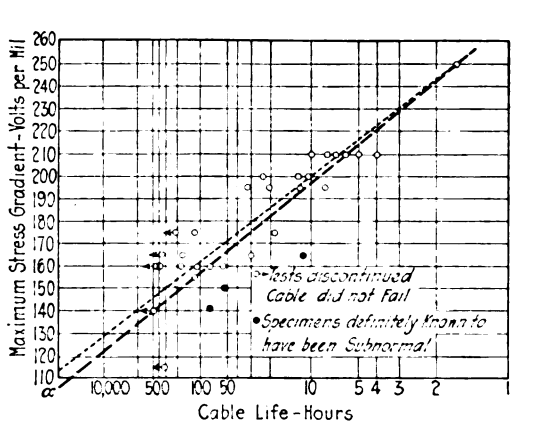


Fig. 9—Cable Life Tests (Time-Stress Diagram) Three-Phase Tests, Three-Conductor Cable

Fig. 11 shows some power-factor data for 13- to 15-kv., three-conductor cable made by various manufacturers during 1925, the upper line being values obtained at 80 deg. cent. and the lower line values at

TABLE II

City	Rated Kv. between phases	Thickness of insulation, inch	Stress Gradient volts per mil: Average	Stress Gradient volts per mil: Maximum	Remarks
Cleveland	66	30/32	41	79	In service
Philadelphia	75	30/32	46	82	Being installed
Philadelphia	75	26/32	53	89	On order
New York	132	23/32	106	160	Being manufactured
Chicago	132	23/32	106	160	Being manufactured

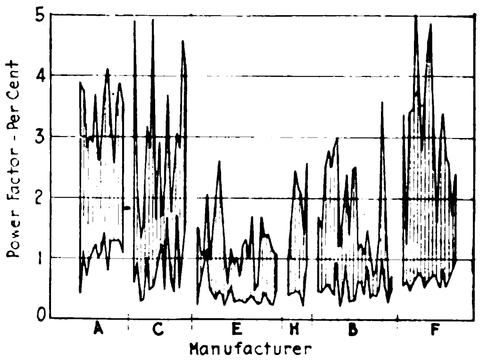


Fig. 11—Power Factor of 13-, 15-Kv. Cable, Inspected During 1925

Upper line—Power factor at rated voltage at 80 deg. cent.
Lower line—Power factor at rated voltage at 20 deg. cent.

20 deg. cent. It is evident the cable of manufacturer *A* was much more uniform in this respect at least than that of the others, particularly *C* and *F*. However, Make *E*, while not quite so uniform, was consistently much lower, with a minimum change between 80 deg. and 20 deg.

Several methods of making these measurements are in use and the suggestion has been made that one method should be adopted as a standard in order to eliminate some of the differences between different laboratories, but it is not believed that this is necessary or even desirable. What we need is not a standardization of one or more methods of making the measurement itself but a convenient *standard* load comparable in magnitude to the dielectric of a piece of cable.

Such a standard which gives promise of serving the purpose very well consists of three Leyden jars made of special glass, metal coated inside by silvering plus copper plating and outside with lead by the spraying process. The tubes are about two in. outside diameter, about 16 in. long and the glass is about $^{3}/_{32}$ in. thick. They are filled with oil and will withstand the application of 25 kv. continuously. With three-phase power factor at 25 deg. cent. of the particular set in the illustration is 0.22 per cent at 10 kv., 0.27 per cent at 25 kv. and 0.32 per cent at 50 kv. At 35 deg. cent., the corresponding power factor values are 0.24, 0.30 and 0.36 per cent.

"Ionization" Test

The work of many investigators in the field of insulation research has demonstrated that the less gas there is in the insulation the better it is as an insulator.

The so-called "ionization" test, a comparatively new one in the cable art, is intended to be a test of thoroughness of impregnation. We know that in a solid dielectric free from gas the loss will vary substantially as the square of the voltage and the power factor will be constant until the voltage approaches the rupturing value—barring, of course, temperature effects due to long application of the voltage. The theory of the "ionization" test is that, if air or gas is present, it will become ionized at a relatively low stress and the power factor will depart from a constant value as the voltage is increased, at a lower value than it would otherwise.

The "ionization" test, which is the present standard for specification purposes, is the determination of the change in power factor between an average stress of twenty volts per mil and one hundred volts per mil, respectively. The specifications issued by Association of Edison Illuminating Companies in November, 1924, prescribe that this change shall not exceed two per cent for a three-conductor cable or one per cent for a single-conductor cable.

The important question in connection with this test is, what is its real value? Will cable having a power-factor difference of two per cent for example, be better than one with a difference of four per cent and if so, in what respect and how much better will it be? Dr. Whitehead has shown[7] that insulating materials which were known to be poorly saturated had a high "ioni-

7. *Gaseous Ionization in Built-Up Insulation*, J. B. Whitehead, Trans. A. I. E. E., Vol. 42, 1923, p. 921, and Vol. 43, 1924, p. 116.

zation" test result and deteriorated rapidly under the application of voltage. However, we have no definite facts in the way of test data to show how much real gain is obtained in cables when this power-factor difference is two per cent instead of four per cent or one per cent instead of two per cent. Before reducing the permissible variation we should have definite knowledge on this point if such reduction involves increased manufacturing costs.

Bending Test

One of the most important tests in American cable practise is the bending test. It was introduced into cable specifications only five or six years ago but it has undoubtedly been an important factor in the marked improvement in workmanship and in the fabrication of the insulation of cables which has taken place. Excessive tearing was at first a common result in a bending test but now it is a rare occurrence. Furthermore, the insulation is tighter, more evenly applied and is practically free from wrinkles. Even in the case of cable with wood-pulp paper insulation, while there has been some improvement in the mechanical strength properties of wood-pulp paper, the improvements in fabrication processes have enabled such cable to pass this test—something that could not have been done two years ago.

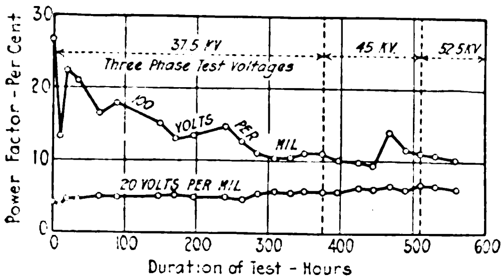


Fig. 16—Power Factor Variation with Time, Between Conductors

Combination No. 2. Rated voltage: 15,000
Insulation: paper, 14 x 10/32 in. *B C* and *B C L*
Conductors: 3-350,000-cir. mil sector

Table III shows in a striking manner the improvement that has been made in the ability of Manila paper-insulated cable to withstand this bending test, as measured by puncture tests. The figures given are grand averages of tests made on samples of cable of various sizes and voltages.

The last column shows what marked improvement has been made in the past three years—the effect of bending having dropped from 21 per cent to practically zero. In other words, present-day cable will withstand this severe bending test without any appreciable effect on the dielectric strength.

Tests of Components

Most cable specifications include some requirements, either general or specific, which necessitate certain tests to be made on most of the component parts of the cable. In addition, others not specifically required, are frequently made for the purpose of obtaining information.

Paper tests of paper removed from samples of cable are tested for composition of stock, tensile strength, tearing strength, folding endurance, dielectric strength and sometimes porosity or air resistance. Occasionally, also the dielectric constant is determined. Methods which are more or less standardized are usually employed for these tests but they will not be discussed here. It may be of interest, however, to note the general average value of some of the properties during the past three years, as shown in Table IV.

Tests of Compound. Few of the usual tests which are normally made on insulating materials can be applied to the compound in cables by the purchaser because the only way he can obtain sufficient quantities of a compound from the sample of cable is by extraction with benzol or other solvents.

A test that is frequently made is the determination of the approximate proportions of saponifiable and unsaponifiable constituents which are usually vegetable base and mineral base materials, respectively. It has been previously indicated that mineral base compounds have in general a much lower dielectric loss than vegetable base compounds but the latter has desirable viscosity and dielectric strength characteristics. A knowledge of the general composition of a compound is therefore useful as a check on the test results obtained on the cable itself.

TABLE IV
PROPERTIES OF CABLE PAPER (MANILA)

	Tensile Strength, lb. sq. in.*		Folding Endurance, No. double folds*		Tearing Strength, grams†		Dielectric Strength: Individual Tapes, Volts per mil		Dielectric Strength: Average Stress Gradient, Volts per mil‡	
Year	No. of Tests	Avg.	No. of Tests	Avg.	No. of Tests	Avg.	No. of Tests	Avg.	No. of Tests	Avg.
1923	150	7230	150	1010	150	180	..	..	260	287
1924	825	7350	825	724	825	179	56	589	290	306
1925(*A*)	273	8435	273	881	273	163	43	638	106	355
1925(*B*)	263	9250	263	620	263	170	78	649	40	369

*Parallel to strips.
†Across strips.
‡Repeated from Table III to show, as a matter of general interest the relation between the dielectric strength of single tapes and the dielectric strength of the total insulation (expressed in the same manner) as obtained in breakdown tests of samples of cable (before bending.)

A new test has recently been developed as the outcome of the unfortunate results which followed the change from vegetable base compounds to mineral base compounds in order to reduce dielectric losses which had

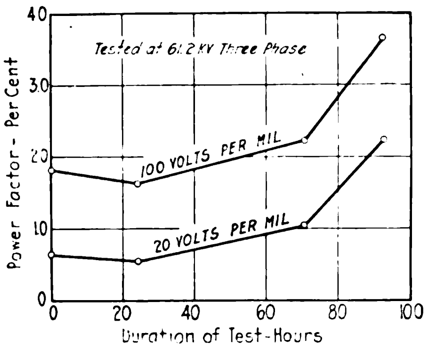
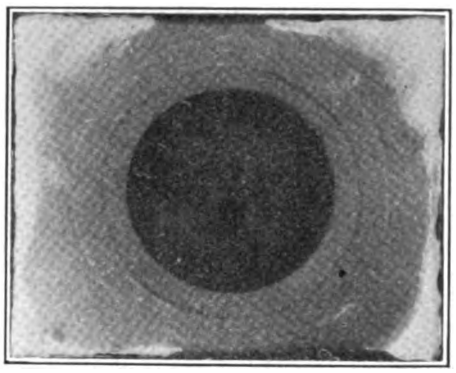
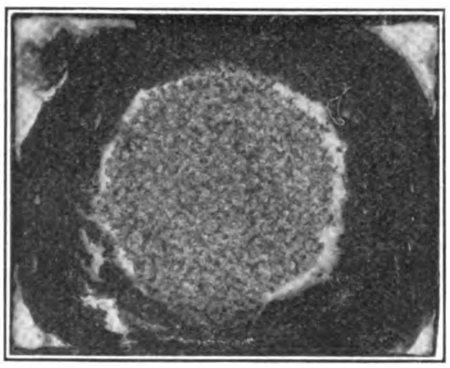


FIG. 19—POWER FACTOR VARIATION WITH TIME—BETWEEN CONDUCTORS

Combination No. 2. Rated voltage: 36,000
Insulation: paper, 33 x 25/64 in. *B C* and *B C L*
Conductors: 3-350,000 round



A



B

FIG. 26—WAX TEST

a. A specimen of petrolatum prepared for test
b. The same specimen after 48 hours at 600 volts per mil

been responsible for failures of the former type of cable. A few months service experience with the first high-voltage cables impregnated with mineral base compounds showed that an unknown, solid material, cellular in structure and extremely light, formed in the interstices of the insulation and failures too frequently followed in the course of time. It was evident, as is so often the case, that the elimination of one defect was being accompanied by the introduction of another.

In order to form this unknown material in any practical length of time, the compound must be subjected to stresses which are above the breakdown value. This is best done by placing the compound between concentric glass cylinders or between parallel glass plates. In the latter method as used at the Electrical Testing Laboratories, a film of the compound about three mils thick is placed between two lantern slide glasses on either side of which is a flat electrode to which the potential is applied. The upper electrode is removed at intervals and any change in the character of the film is noted.

Fig. 26 is a photograph of a test specimen before and after subjection to this test. Fig. 27 is a curve obtained with petrolatum which shows the time at which this unknown material, *X*, forms at various stresses—the stress being calculated from the measured dielectric constant of the glasses and the compound, the thickness

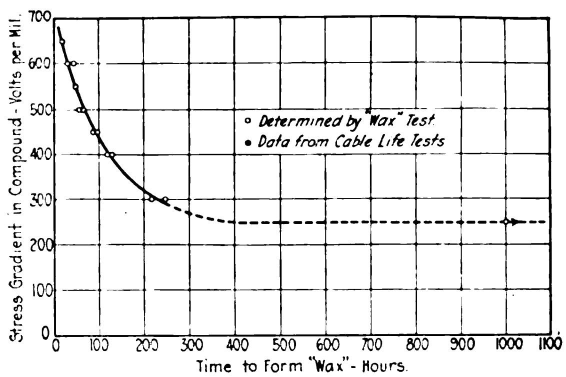


FIG. 27—WAX TESTS—TIME-STRESS DIAGRAM

of the glasses and the film, and the applied voltage. It seems reasonably safe to assume from the trend of the curve that in a sufficiently long time more or less *X* could be expected to form even at stresses existing in high tension cables in normal operation, that is, of the order of fifty to seventy-five volts per mil.

While the absence of any signs of disintegration in a compound when subjected to this test is not a guarantee that it will remain unchanged indefinitely in a cable,

TABLE V

Load lb.	Stress lb. per sq. in.	No. cycles of bending	Remarks
0	0	8710	First cracks noted
5	40	3400	First cracks noted
10	80	1900	First cracks noted
15	120	1000	First cracks noted
0	0	8100	First cracks noted
0	0	11000	Badly cracked
0	0	12000	Ready to break
10	80	2700	First cracks noted
10	80	3600	Badly cracked
10	80	4040	Broke

Note: First group of specimens from one piece of lead, other two from another piece.

it seems reasonable to assume that if 600 volts per mil for seventy-two hours at either room temperature or at 75 deg. cent. does not produce any change, the chances of disintegration taking place in service are rather remote.

Conclusions

The problem confronting the engineer responsible for an underground cable installation is the transmission of the most energy per dollar of annual cost, *i. e.*, per dollar of investment and per dollar expended in maintenance. The investment cost will depend not only upon the voltage employed, which presumably will have been selected after proper consideration of the economics of the situation and the local conditions, but also to some extent on the quality of the cable, for, the better the insulation, the less of it has to be used and the lower will be the cost. The maintenance cost, however, is largely a matter of quality although the cost of repairs due to inferior workmanship on splices, careless handling of cable during installation and other avoidable causes is not an insignificant item.

Every failure in a cable costs money in direct outlay for replacement of cable and for withdrawing the old cable and installing the new, in addition to splicing and other incidental expenses. There is the further effect of cable failures that cannot be evaluated, namely, the disturbance to the service, the continuity and dependability of which is such an important element in the "good-will" of an electric public utility.

The record of cable failures quoted above might be considered good and perhaps it is in comparison with the records of other electrical apparatus, particularly when the comparison is on the basis of the area of insulation involved. But it is the function of the engineer to make the record better and thereby reduce the maintenance cost in which cable failures form so large a part.

It is obvious that the greatest reduction in the number of cable failures is to be effected through improvement of the quality and through improvements in the design. Progress in both of these directions can be made in the following ways, all of which involve comprehensive and systematic testing of the kinds discussed in this paper:

(*1*) *Research by both manufacturers and users.* It is the manufacturers' problem to improve the quality of the materials which make up a cable. It is also their problem to improve manufacturing processes in order to produce cable which is not only better cable but which is more uniform. It is the users' problem to carry on investigations which will provide information that will permit more efficient operation based on facts rather than opinions and which will indicate the direction in which improvements are needed to meet the present and future requirements of the industry.

(*2*) *Thorough and systematic inspection and tests of cable when purchased.* While the immediate, primary purpose is to insure compliance with the contract, the greatest value of inspection and tests is likely to be the fact that it provides the means of obtaining definite, quantitative knowledge of the quality of cable. Such knowledge must be available before a reference point can be established and progress accurately measured.

(*3*) *Evaluation of cable.* The development of a satisfactory method of quantitatively evaluating cable through suitable weighing and combining the results of inspections and tests would provide a very useful incentive to progress.

(*4*) *Specifications.* Cable specifications must, of course, be based on current practise and consequently revisions of existing requirements must follow progress in the art. However, keeping specifications up to date so that they include advances as they are made does, in itself, contribute to the general progress through setting a high standard for *all* manufacturers and for *all* users rather than the *few*.

(*5*) *Periodic examination of cable in service.* Improvement in cables would unquestionably be greatly aided if we had more knowledge of what takes place in a cable which causes it to deteriorate and ultimately fail. Apparently all of the equipment on the system is given a more or less systematic inspection except the cable which is buried in the ground and forgotten until trouble develops. Samples should be removed when a convenient opportunity is afforded and examined and studied so that we can learn, if possible, what it is that determines the life of the cable and thus aid progress by indicating the direction of improvement both in the cable and in the specifications for the cable.

NEW TRAFFIC SIGNALS FOR CHICAGO

On February 7th, new traffic signal equipment went into service in the *Loop* district in Chicago at forty-nine street intersections. All this apparatus, equipped with three-light traffic signals at each corner, is served from underground circuits terminating at the City Hall where a central control board is located. This board provides an extremely flexible control, it being possible to vary the intervals between traffic halts at intersections along the same street. The ratio between periods on intersecting streets may likewise be varied. The control board was built under the specifications of the Department of Gas and Electricity.

New traffic-control equipment is also being installed outside the *Loop* district on eighty-seven intersections, some involving three streets. These signals are controlled by local panels which also permit flexible combinations of operation. Energy for the units outside the loop will be furnished by the Commonwealth Edison Company. Signals within the loop will be operated between 7:30 a. m. and 12:30 midnight.

Some Interconnected-System Operating Problems

BY FRANK G. BOYCE[1]

Member, A. I. E. E.

Synopsis—*This paper outlines the advantages and disadvantages of an interconnected system consisting of steam and hydroelectric stations. Investment costs are materially reduced because of less reserve capacity being required to insure continuous service. More efficient operation of generating units is possible and operating costs are reduced. Electrical disturbances are magnified and large generating stations must be located near the heaviest load centers so that the system may be split up to localize disturbances. A well-trained corps of load despatchers must be available and they must be fully informed of all conditions on the system which may affect operation.*

* * * * *

MUCH has been said and written of late regarding interconnected systems. In fact, "superpower" and "giant power" are almost as popular today as radio. Magazines and the daily news contain much information and misinformation on the subject.

The purpose of this paper is to bring out some of the economic and operating problems which must be kept in mind in the design and operation of an interconnected system of steam and hydroelectric generating plants and to show how these problems have been solved in some instances.

It must be kept in mind that while people in the metropolitan centers are accustomed to a very high quality of service, yet in the smaller towns and suburban sections the use of household appliances, electric refrigeration, electric cooking, water pumping and miscellaneous small motor uses are now quite common and are increasing at an amazing rate. These uses are demanding that the small towns and villages receive the same grade of service that the large cities have enjoyed and at the same time the investment must be kept sufficiently low so that this service can be furnished at a rate which will encourage the use of electrical energy and will compete with isolated plants.

The investment in generating equipment per kw. of installed capacity can usually be kept lower by interconnection, for it is possible to adequately safeguard service with a lower investment in reserve equipment, as reserve in any section of the network is available to supply demands in other sections and practise seems to indicate that sufficient reserve to replace the loss of the largest single generating unit is adequate.

Usually maintenance work can be so scheduled that it can be carried on in the hydroelectric plants during the period of minimum stream flow; likewise, work of this nature can be carried on in steam-generating plants during the period of maximum flow. This work can also be so arranged that only a predetermined amount of capacity on the entire system will be out of service at one time. By following the schedules given above, the greatest amount of the combined capacity of the entire system is kept available at all times which assists in keeping the amount of reserve capacity to a minimum.

1. Consumers Power Company, Jackson, Mich.

To be presented at the Regional Meeting of District No. 5 of the A. I. E. E., Madison, Wis., May 6-7, 1926.

Interconnection has made possible the greater use of automatic generating equipment, especially in the smaller hydroelectric plants. Very often the cost of maintaining operators at small hydro plants makes the cost per kw-hr. delivered from these plants so great that these plants become a liability. As systems grow in capacity, the smaller plant becomes less important with reference to the system demand, its principal value being the kw-hr. it can deliver to the system. In such a case, if the plants can be made sufficiently automatic to operate so as to obtain the most efficient use of the available water, their operation can be made profitable and others developed, provided the investment can be kept sufficiently low. It is thought that there is room for development along the lines of cheaper and simpler methods for accomplishing this. In some cases the small plant may be made semi-automatic, requiring only a simple means of opening the oil circuit breaker and shutting down the waterwheel. A number of such installations, some of them rather crude, have been in successful service for years.

Consideration should be given to the location of generating units at strategic points in the network with reference to the load centers. In some cases, generating units can be so located that a transfer of any large amount of power over a great distance will be unnecessary. In considering the location of generating units, some thought should be given to the sectionalizing of the system at times of serious trouble in one portion of the network. If this is done, the trouble will be confined to the smallest possible area. It is sometimes desirable to sectionalize the system when severe lightning storms occur over a portion of the network so that surges caused by lightning strokes will not be transmitted to other parts of the system.

The combination of steam and hydroelectric plants in one system allows the most effective use of the kw-hr. capacity of the hydroelectric plants and at the same time allows the operation of steam generating plants at their most efficient loads.

A greater number of hydroelectric units can be operated during heavy load periods, permitting the elevation of the storage reservoirs to be lowered slightly. During low-load periods a greater percentage of the system load can be carried by the steam generating units, allowing the hydroelectric reservoirs to return

to their normal elevation so that the hydroelectric generating plants are ready to repeat this cycle of operation at the return of the heavy load.

When a large number of plants are feeding into one network, all hydroelectric units can be operated at the most efficient gate openings at all times, thus obtaining the maximum kw-hr. output from the available water; likewise steam generating units can be operated at their most efficient loads. Changes in the system load can be taken care of by starting up or shutting down units.

Tests can be made which will determine the most efficient load at which boiler units will operate and as the system load requires, additional boilers can be fired or banked, or additional steam turbine units can be brought into service.

The efficiencies of steam generating plants are greatly increased by operation in conjunction with hydroelectric plants, because although the hydrostorage reservoirs may be small, yet the great flexibility of hydroelectric plants, due to storage reservoir capacities, permits the changing of loads on steam generating plants in blocks according to the most efficient load which can be carried on boiler and turbine units then in operation. The extent to which this can be carried out will be realized when it is pointed out that on a system having 10 steam generating plants ranging in capacity from 400 kw. to 40,000 kw. (some of these plants being rather old ones) a system of fuel economy for one year of approximately 21,000 B. t. u. was obtained, while if these plants were operated as isolated ones, the B. t. u. per kw-hr. would have been considerably higher.

It is also possible to obtain a greater kw-hr. output from hydroelectric plants operating as a part of one of these systems. As an example, one hydroelectric plant which has been operating for a number of years as part of an isolated system at a yearly output of 2,006,600 kw-hr. was recently made a part of a combined system and the output was increased to 2,797,900 kw-hr. per year.

It has been found that the efficiency of both hydroelectric generating plants and steam generating plants can be improved by dampening the governing mechanisms so that all of the plants will operate as base-load plants except with such capacity as is necessary to maintain system regulation. The governors on the hydroelectric units will be so set that they will be operating at the most efficient gate opening and at the same time governors on the steam generating units will be so arranged that they will be operating at their most efficient loads. This is made more certain on the steam generating units by the installation of what might be called a "load limiting device," which is attached to a General Electric turbine, as shown in Fig. 1. This device prevents the governor valve from opening beyond a certain amount, preventing the unit from carrying more than a predetermined amount of the system load. This does not in any way endanger the operation of the unit, for if the unit would be suddenly relieved of its load or should speed up for any other reason, the governor will function normally. This device can be so set that any predetermined amount of load will be carried by the unit, which amount can be changed very quickly by the operator. The hydroelectric units can be equipped with "load limiting devices" very similar to the above in order that these units can be set to operate at their most efficient gate openings.

The mechanical and electrical design of these plants can be much more simple than isolated plants. The electric equipment will usually consist of one bank of step-up transformers with its high-tension and low-tension circuit breakers. It will also contain one set of low-tension busbars with an oil circuit breaker for each generator and one bank of transformers to supply power for station auxiliaries.

In some cases it is feasible to omit the low-tension busbars and oil circuit breakers, installing a transformer bank for each generator with oil circuit breakers on the high-tension side of the transformers. These plants

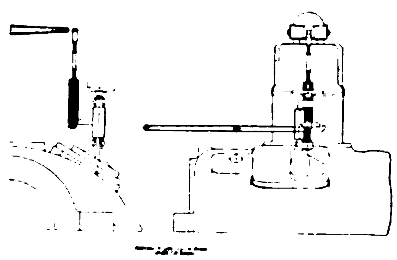


Fig. 1—Assembling of Load-Limiting Device Installed on 20,000-Kw. Turbine

require very modest expenditures for buildings as in most cases the transformers and in some cases the busbars and oil circuit breakers are installed outdoors.

The mechanical design is simplified by the elimination of many of the otherwise necessary duplicate station auxiliaries. The auxiliaries can in most cases be electric driven, obtaining their supply of power from the main busbars. If in an extreme case these auxiliaries should fail, a momentary interruption to the plant would probably result but would perhaps be unimportant, as the system load would be carried by reserve in the other plants until the plant which is in trouble is returned to service.

One item of very great importance in the mechanical design of hydroelectric plants is the facilities for spilling water, should the plant be suddenly relieved of its entire load. This is especially important in low-head plants where the storage capacity of the reservoirs is limited. Plants designed for interconnection are often connected to transmission systems by one bank of transformers or a single transmission line and do not supply a local power load, in which case an interruption to either of these removes all load from the plant. Arrangements must be made immediately to take care of stream flow.

One of the early methods used consists of a Tainter gate arranged to be raised by an electrically driven winch, operated by means of a crank in case of total interruption to power supply. This device was fairly satisfactory although in this climate it was found necessary to keep the gate free of ice, an operation requiring considerable manual labor. This type of gate was later improved upon by totally enclosing and installing steam coils inside the housing; thus, the gate could be held at a temperature that would keep it free from ice. This requires considerable fuel to maintain proper temperature.

There are a number of other methods in use, including the different types of conduit spillways in which the amount of water spilled is controlled by means of gate valves, butterfly valves or Broome gates. These methods are successful and have some advantages over the Tainter gates, aside from overcoming the ice problem.

As the length of transmission lines involved in a network and the connected capacity increases, the frequency and severity of disturbances is apt to increase. This should be kept in mind particularly when large metropolitan centers are concerned with large blocks of power concentrated in small areas. Insulation which is adequate for a system consisting of short low capacity lines will be entirely inadequate as the system grows. Thus, it is often found necessary to completely rebuild transmission lines and substations and install oil circuit breakers of greater rupturing capacity, replacing apparatus which was adequate in itself, before these units can be made a part of a larger transmission system.

A study of the proposed location of transmission lines with reference to the paths generally taken by storms is desirable in order that such lines can be so located that they will least be affected by these disturbances. Where more than one line is to be built between two points, it is often desirable to locate these lines on entirely separate rights-of-way so that all transmission lines will not be subjected to atmospheric disturbances at the same time.

In designing transmission lines, it must be remembered that materials used in their construction, such as steel, cement, porcelain, copper and aluminum, are exposed to the air, subject to all of the ravages of the elements—extremes of heat and cold, vibrations and strains caused by wind and heavy loading by sleet. It has been found that, especially in the northern climates, action of the weather has a deteriorating effect on the ordinary mixtures of clay and cement. The subjecting of these materials, with their different coefficients of expansion to the varying conditions of moisture and temperature, has caused unthought of failures requiring research and continuing improvement in design.

Periodic inspections of transmission lines by patrolling are advisable for a number of reasons, particularly in the more thickly settled districts. It has been found that patrols made on foot are most satisfactory. The frequency of patrolling depends largely upon the design and location of the particular line and also upon its importance.

With frequent regular inspections, the possibility of wire failures is considerably reduced, patrolmen often detecting burned spots on the wire caused by flashovers which later, particularly in the strain of the cold weather, will undoubtedly result in transmission line failures.

The elimination of tree conditions is another factor which should be given careful attention, proper pruning of trees is necessary and in some cases their removal is desirable. A close watch should also be kept for the possibility of people either erecting or moving buildings under the lines, as persons engaged in this work often do not realize the danger from high-tension wires. All such matters can be watched closely by the man who is constantly covering the line. The patrolman becomes more or less acquainted with all of the people living along the line and is able to impress upon them the possibility of danger from carrying on such work. This generally results in the patrolman being advised when matters of this kind are contemplated; thus arrangements can be made for a prearranged interruption of the line, if necessary, while the work is in progress.

In addition to the regular patrols of transmission lines, it is thought quite desirable to institute special patrols after a transmission line has been exposed to severe storms or when transmission lines have shown indications of trouble and have been returned to service without the fault being discovered.

On some systems it has been found desirable to carry on practically continuous testing of transmission-line insulators and in so far as the older insulators are concerned, this is still in most cases necessary.

Improvements which have been made by the manufacturer from lessons learned by experience in the field has produced an insulator which has an extremely low rate of deterioration for at least a period of from 10 to 12 years. While it is, of course, necessary to watch the insulators during this time, it is not thought so vital that they be continually tested.

Various kinds of tests have been in use but it now appears that the 60-cycle, high-voltage test is the most satisfactory.

In order to constantly improve the operation of generating plants and to increase the output of hydroelectric plants, an adequate system of station records must be maintained. Each station should be supplied with log books in which is recorded all operations which are carried out, also information relative to conditions leading up to each operation. Where operations are performed under instructions from foremen or supervisors, a notation should be made indicating from whom these instructions are received. These log books are

very useful in making studies of past operations and in showing how improvements can be made.

Rain gages should be maintained at each station in order that records of precipitation may be kept. These records are sometimes taken in cooperation with state authorities, in which case they become official government records. These records should be compared with run-off so that probable hydroelectric outputs can be estimated in advance. After heavy rains or in advance of spring floods, reservoirs can be so drawn down that the maximum amount of excess river flow will be utilized.

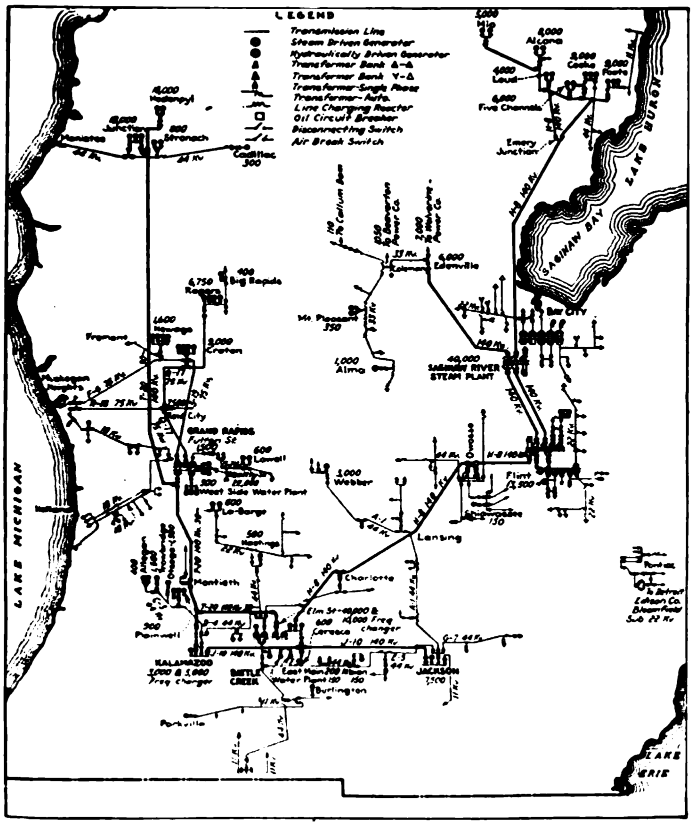


FIG. 2—MAP OF CONSUMERS POWER COMPANY SYSTEM

It is necessary that operators of these systems be constantly on the alert to detect any weaknesses which may be developing—thus faults may be detected before they have interfered with service. In order to accomplish this an adequate system of inspection and tests must be maintained.

Adequate means of communication between stations and the load despatching department is quite necessary for economical operation and in emergencies will assist, by locating faults and transmitting switching orders, in restoring service with the least delay.

An identification scheme for lines and switches will greatly facilitate transmission of orders and avoid mistakes. This scheme should consist of symbols which are not easily confused in discussion over telephone lines. This will avoid the possibility of incorrect operation of switches.

One of the very essential factors necessary for successful and economical operation is an adequate load despatching system. Such a department should be furnished with information showing efficiencies of both hydroelectric and steam generating units at different loads, delay of water between plants in series on the same river, rate of run-off from precipitation, relative storage above hydroelectric plants so that sufficient water can be passed from one plant to another on the same river and thus keep them all operating at the highest efficiency. The men must be kept acquainted with the loads to be carried and with any unusual conditions which will affect hour-to-hour operation. It is desirable to have these men acquainted with the condition of equipment in all the plants with reference to its ability to carry load; no apparatus affecting the capacity of any of the plants should be taken out of service without the advice of this department. Station operators should supply the load despatchers with frequent operating reports so that loads can be adjusted between plants and at the same time make sure that sufficient excess capacity is in service to take care of emergencies.

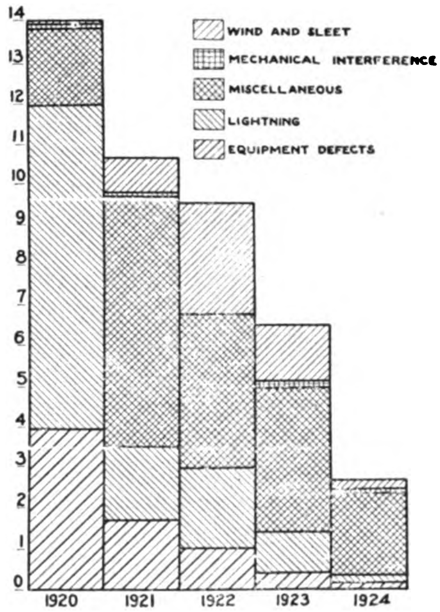


FIG. 3—CHART SHOWING COMPARATIVE REDUCTION OF TRANSMISSION-LINE INTERRUPTIONS

Some means is necessary to give the load despatcher a visual record of the position of switches. A method which has been used instead of the more elaborate electrically operated device is a small board consisting of a single-line diagram of the system laid out geographically, mounted on a thin wooden panel, backed by a bank of red lamps. Small holes of about 3/16-in. diameter are drilled through each switch location. Rubber plugs that can be readily pushed through and out of the holes with the point of a pencil are inserted in the holes to represent closed switches. The open

holes allow the red light to show through, representing open switches.

Each station should be provided with written instructions covering emergency operation of switches and lines—thus in case telephone communication is interrupted, operation can continue and interrupted service be restored.

The author has based many of his conclusions on the results of his experience with the system of the Consumers Power Company of Michigan, which has had to confront many of the problems to be considered. Fig. 2 is a map of this system showing 600 miles of 140-kv. transmission lines suspended in the form of a "U." There are 1100 miles of transmission lines from 22-kv. to 75-kv. in addition to the 140-kv. backbone connecting 44-steam and hydroelectric generating plants with distribution centers consisting of several moderate sized cities and a larger number of towns and villages. The west side is made up of 30-cycle equipment and the east side, 60-cycle, connected together at two points with 5000-kw. and 10,000-kw. frequency changers.

The extent to which these facilities can be made workable and the results which can be obtained are indicated to some extent by Fig. 3, showing the relative improvement of transmission-line operations with reference to interruptions to substation supply, involving lines of 22 kv. and above, including the transmission line itself and associated high-voltage apparatus in stations and substations. All interruptions are evaluated on a kv-a-mile-a-minute basis.

The causes are divided into five groups; Lightning, Wind and Sleet, Mechanical Interference, Equipment Defects and Miscellaneous. The mechanical interference group represents trouble due to foreign objects blowing into lines, automobiles and trucks leaving the road and striking poles and towers, and other similar troubles.

The miscellaneous group includes testing and inspection, interruptions necessary to take care of construction and maintenance work, unknown causes and mistakes. Prearranged interruptions to take care of construction and maintenance work represent about 90 per cent of this group. The continuing reduction in the interruptions from all causes shown by these graphs brings out clearly the improvement that is being made in both operation and design.

STREET LIGHTING BEGAN IN 1414

Street lighting began in 1414 when a city ordinance in London required every house and store owner on certain streets to hang out at least one horn-sided lantern at sunset. Paris, in 1558, led the world in municipal street lighting when it installed tall vases at important street corners in which pitch was burned each night with flickering, sooty results. These various crude outdoor lighting methods strove ineffectually for more than 450 years to achieve what the electric carbon and filament lamps have done in the last 40 years.

Discussion on Alternating-Current Analysis

ALTERNATING-CURRENT ANALYSIS[1]

(R. D. Mershon)

V. Bush (Communicated by letter): The total power in any network must evidently be supplied by the source. Similarly the algebraic sum of the separate reactive kv-a. in the separate branches must also be supplied from the source as excitation to the system. This applies to a system in which all voltages and currents are of the same frequency, irrespective of how the system may be interconnected. It is a very useful principle, and I have been using it with classes at the Massachusetts Institute of Technology in the form given by Dr. Mershon, since he first called it to my attention sometime ago.

Another way of looking at the matter is this. Again dealing only with a single frequency: the excitation or quadrature kv-a. which must be supplied is given by the amount of iron or air carrying flux, the permeability of the iron, and the flux density; and on the other hand, the amount of stressed air or dielectric, the dielectric constant, and the electric flux density. Specifically the net excitation, to be derived from rotating machinery, is given by the difference between the stored magnetic and electric energies, or

$$\int \left(\frac{B^2\, d\, v}{8\, \pi\, \mu} - \frac{E^2\, d\, v}{8\, \pi\, K} \right)$$

a volume integral. This is entirely independent of how the system is connected, the number of phases, and so on. In other words, if a certain weight of iron of known permeability is to be excited to a definite flux density, the excitation kv-a. requirement is the same no matter where the iron is placed or how related to the circuit. Also the contribution of the dielectric toward this excitation depends only on how much there is of it, its dielectric constant, and how high it is stressed.

It is a somewhat different matter when we consider the iron to be of varying permeability. There are then always harmonics introduced either in voltage or current, but not necessarily in both. It would seem that the amount of these harmonics should, in some fundamental way, depend upon the amount of iron present, its hysteresis loop and its maximum flux density, independent of the circuit connections. However, such a general principle is not available, largely because there is no ready way of specifying what is meant by the amount of harmonics present in the network. If such a conception could be arrived at in useful manner it would enable us to treat the harmonics produced by transformer banks with somewhat the same facility that the present principle affords for the computation of the apparent power of the network.

H. H. Race (Communicated by letter): In the recent paper on "Alternating Current Analysis" presented by Mr. Mershon he claims that the material he covered had not previously appeared in print. This has been taught for years as an elementary method for the solution of such problems and may be found in several much-used Electrical Engineering text-books.

My first reaction to Mr. Mershon's paper was to wonder why he should present the old long-hand method for the solution of such circuits, why he should prefer to use long expressions involving squares and roots in preference to representing vectors and operators by complex numbers.

Then I asked myself the opposite question, what advantages would result from the solution of such circuits using complex numbers. There are at least three:

(*a*) *The use of complex numbers allows the solution to be carried through in short symbolic equations.* The advantage of this would be much more apparent if Mr. Mershon had chosen circuits having more combinations of series and parallel circuits than he has shown. His equations are very unwieldy and would become much more so if the circuit were made more complicated.

1. A. I. E. E. Journal, January 1925, p. 43.

In symbolic form the total current in Fig. 3 may be obtained as follows:

$$i = \frac{e}{Z_{total}} = \frac{e}{Z_{12} + Z_{23}} = \frac{e}{\dfrac{1}{Y_1 + Y_2} + \dfrac{1}{Y_3 + Y_4}}$$

where Z and Y represent respectively the complex expressions for the impedance and the admittance of the branches denoted by their subscripts.

Compare this with equation (19) and we see that his C is the equivalent impedance of the whole circuit, although he does not call it such. If one were to solve the symbolic equation above, the actual computations necessary would be the same as those required for the solution of equation (19) but how much easier it is to obtain an expression for the current by the symbolic method.

(*b*) *A solution expressed in simple symbolic equations makes much more apparent the steps involved when one person is trying to understand the work of another.* This is important, else what is the use of engineering literature.

(*c*) *The use of complex numbers by engineers should be encouraged rather than discouraged* because so many problems are easily solved by their use, which are exceedingly laborious, if possible at all, using the long-hand method. For example, consider circuits having distributed constants.

Discussion at Midwinter Convention

TRANSMISSION SYSTEMS WITH OVER-COMPOUNDED VOLTAGES[1]

(Dwight)

New York, N. Y., Feburary 8, 1926

L. F. Woodruff: One of the chief problems encountered in the calculating of the most advantageous amount and phase of compounding for the generator-end voltage of a transmission line is the determination of the settings required to locate the receiver power circle center at a predetermined point. This problem is more involved than that of finding the center of the circle for given regulator settings, and while it is possible of explicit solution, such a solution is so cumbersome and involved that it is practically useless. Yet the logical approach to the problem is to try different circles of load power until the one is found which affords most economical operation, considering line and transformer losses, synchronous reactor losses and costs, voltage rise on the line, and stability. Then, having located the circle from economic considerations, the problem becomes that of finding the regulator settings required to make this the operating circle of the system.

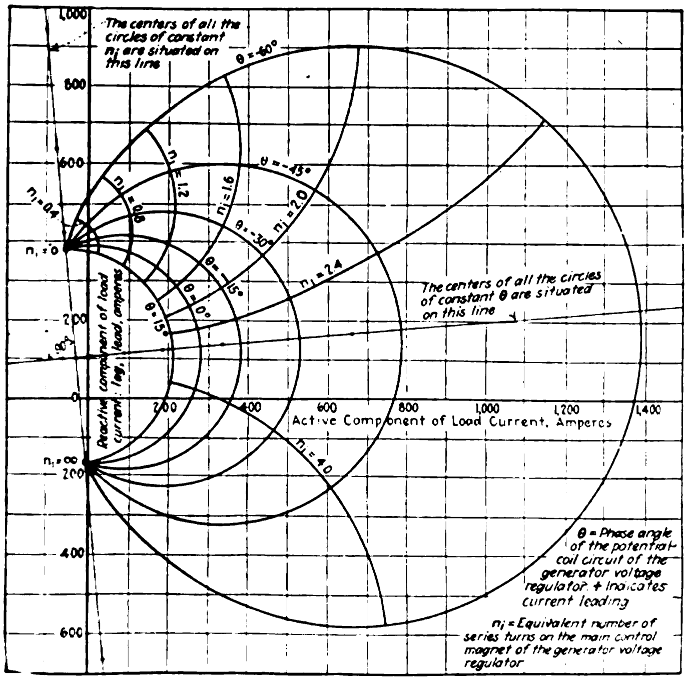


Fig. 1—Chart Showing Amount and Phase of Compounding at Generator End Required to Locate the Center of the Load Current or Power Circle at Any Desired Point. Load Voltage is Constant

Mapping of Power Coordinate Plane to Show Effect of Various Degrees of Compounding. I have found that the best method of solving this last problem is to draw on the load-power coordinate scale curves which map out the region in which the center is to be located in terms of parameters which indicate the amount of compounding. Certain features of these curves render their calculation and construction very much simpler than is at first apparent.

Fig. 1 herewith shows the amount of compounding required to locate the center of the load-power circle at any desired point, for a transmission circuit consisting of a 250-mi. line with terminal transformers. This figure has already been published[2], and the details of line, transformer and regulator constants may be found in the original references. In connection with it now I wish to point out these facts:

1. The center of the load-power circle, with constant load voltage and with generator voltage compounded, may be located anywhere on the chart.
2. For a given amount of compounding, the location of the center depends largely on the phase of the compounding.

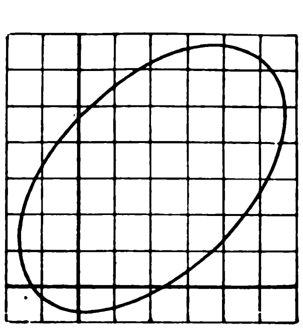


Fig. 2—Original Ellipse Diagram of Power at Load End of Line with Voltage Componded at Both Ends

3. The curves of constant amounts of compounding, but various phase angles, comprise a family of circles whose centers, for a constant load voltage, all lie on a straight line passing through the center of the circle diagram for ordinary constant-voltage operation, and another point in the third quadrant corresponding to theoretically infinite compounding. The curves of constant phase angle, but varying amounts of compounding, comprise another family of circles passing through the two points just mentioned. The phase of the compounding can be adjusted by putting a reactance and resistance in series with the potential coil of a voltage regulator, instead of only a resistance, and while this has not been done in practise, it offers opportunity of improvements in line control.

1. A. I. E. E. Journal, January, 1926, p. 25.

2. L. F. Woodruff. Regulator Settings for Long Lines, *Elec. Wld.* 1924. Also, Principles of Electric Power Transmission (Wiley), 1925.

Voltages at Both Ends Compounded—Load Power Ellipse Transformed to Circle. Since graphical methods are so advantageous in shortening or eliminating calculation, and since the main advantage of circle diagrams over others which could present the same information lies in their easy preparation, a method of transforming the "ellipse diagram" which Professor Dwight derived, into a circle diagram, should be of some interest and value.

Fig. 2 represents an ellipse diagram plotted on rectangular axes. To transform this to a circle diagram, let one of the scales be such as to make the major axis of the ellipse lie along the 45 deg. line, unless it already conforms to this condition.

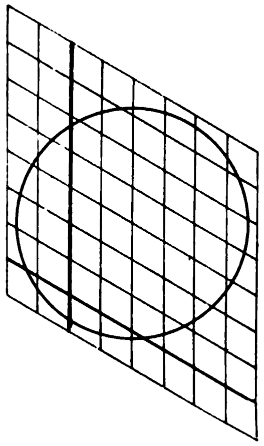


Fig. 3—Ellipse Diagram of Load Power Transformed to a Circle Diagram by Skewing the Axes

If the original angle of this axis with the horizontal is θ degrees, the change to 45 deg. may be accomplished by using a vertical scale equal to the horizontal scale multiplied by tan θ. Now suppose the major and minor axes of the new ellipse to be of lengths A and B respectively. By skewing the axes as shown in Fig. 3, so that the angle between them in the first quadrant is 2 $\tan^{-1}\left(\frac{A}{B}\right)$, the ellipse is transformed into a perfect circle, and so may be drawn at once with a compass.

CURRENT LIMITING REACTORS WITH FIRE-PROOF INSULATION ON THE CONDUCTOR[1]

(Kierstead)

New York, N. Y., February 9, 1926

V. M. Montsinger: The general tendency today is to make all electrical apparatus as fool-proof as possible. This is especially true of apparatus applied to protect other apparatus. In other words when the safety of other apparatus worth many thousands of dollars is dependent upon the proper functioning of a reactor it becomes doubly important to make the reactor as nearly perfect as possible. Mr. Kierstead's paper shows a marked advance in the art of making a dependable current-limiting reactor.

I well remember some of the early designs a few years ago, which were built by spacing bare copper cables by means of wooden supports notched to hold the conductors in place. Obviously a reactor having its turns supported by a combustible material, like wood, would not stand a very high temperature on short circuit, certainly not over 150 to 175 deg. cent. It was soon realized that a reactor of this design would not meet the severe conditions demanded of it. When the cast-in concrete type was developed and perfected it was thought that the problem of building a perfect reactor was solved.

But it was not long before someone left a bolt or a nut near a reactor and when a short circuit came on, the loose metal was drawn into the reactor by the magnetic forces set up, and the reactor failed to perform its function. A new problem had appeared which must be solved. This problem was not an easy one to solve because it was a difficult matter to obtain an insulation with sufficient toughness to resist the cutting or bruising action of a bolt hurled against it and at the same time to withstand a temperature of 300 to 400 deg. cent. without becoming charred. Some of the early forms of asbestos insulation were not satisfactory because they contained an appreciable amount of cotton, which soon burned out and weakened the fabric. Mr. Kierstead's efforts have succeeded in obtaining practically a 100 per cent asbestos insulation which is entirely satisfactory and we now have once again a reactor which appears to be practically perfect.

It is to be hoped that operating engineers who are dependent upon these reactors to protect large and expensive apparatus will appreciate Mr. Kierstead's efforts in producing a product so nearly proof against failures.

S. I. Oesterreicher: While I am in hearty agreement with many of Mr. Kierstead's statements regarding the insulation of current-limiting reactor conductors, still I regret very much not being able to give him full credit for his interesting conclusions.

As far as covering of reactor conductors is concerned, originality belongs to Mr. Philip Torchio and Mr. H. R. Woodrow. As far back as 1912, these two gentlemen designed and put in service current-limiting reactors in which the conductors were insulated partly with asbestos and partly with a rubberized tape.

Due to the increased generator rating and voltage of the circuit on which some of these first reactors were installed, they became obsolete and we had occasion to dismantle and inspect them.

On some of them the insulation after about 12 years of service was not impaired in the least and would have been good for many more years of service.

There is no question in my mind about the necessity of covering the reactor conductor with an insulation if reliability is sought. I believe that under normal operating conditions, if foreign materials are dropped or drawn into a bare conductor of a reactor, the effect will be far more serious than Mr. Kierstead states. If reactor turns or layers are short-circuited within the reactor, they act as secondaries in a transformer and the currents in the two circuits are inversely in proportion to the number of turns in these circuits. Therefore, the heating due to the increased currents in the short-circuited sections will make itself manifest in a very short time and greatly to the detriment of the reactor.

Mr. Kierstead attaches great importance to the absolute fire-proof quality of the insulation upon the reactor conductor. He gives data of tests carried up to 350 deg. cent. without any distress of the asbestos insulation.

However, the limitation of an arrangement as Mr. Kierstead describes it is not the absolute fire-proof construction but the fact that the temperature coefficients of expansion between copper and concrete are so greatly different and the temperature stresses caused by the copper in the concrete so out of proportion that cracking of the concrete starts long before any shortcomings of the insulation becomes dangerous.

We have in operation throughout the country over 2500 reactors with all kinds of fibrous insulations and do not seem to have trouble on account of the kind of insulation over the conductor.

I do agree with the statement that the insulation should be mechanically strong to be able to withstand injury. From time to time, we have received complaints from one or another of our clients that suddenly a reactor started to rattle. Investigation proved that in practically all cases the trouble was due to foreign bodies becoming lodged in the reactors.

Thus, it would seem that as long as the reactor conductor insulation has ample dielectric and mechanical strength it is only a convenience of design or cost as to what kind should be used.

A. E. Kennelly: In connection with Mr. Kierstead's paper, it may be worth while to point out what is certainly known although not perhaps very generally known, that in a uniform magnetic field, parallel lines of magnetic force so to speak, a small

1. A. I. E. E. Journal, February, 1926, p. 137.

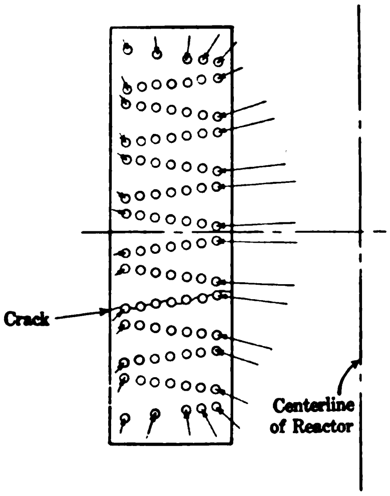
sphere of iron or steel is not subjected to any mechanical pull. That is contrary to popular belief on that subject. If a small sphere of steel is supported in a uniform magnetic field, no matter how strong the field, it will pull one way as much as the other. But if the magnetic field, instead of being uniform, is divergent in one direction, or convergent in the other, then the ball of iron or steel inserted in the field will be pulled in the direction of convergence and the pull is proportional to the flux density and to convergence. Mathematically it may be expressed as proportional to $B \cdot \frac{dB}{dc}$

W. W. Lewis: Reactors as well as other apparatus have their share of failures; some of these in the past have been due to mechanical weakness, others have been attributed to high voltage and others to so-called foreign metallic material.

The theory of foreign material has been amply substantiated in practise. In one installation 9 reactor failures occurred. Inspection after the first and last of these disclosed nails lying across some of the turns. In two other cases the reactors had been previously damaged. In the five other cases no definite cause was found for the failure. After the first failure, however, a quantity of bolts, nuts, washers and nails was cleaned out of the reactors. It may well be that some of these articles were missed in the inspection as indicated by the nail found after the last failure.

It seems obvious that live conductors so closely spaced as in reactors, are a menace to operation if left uninsulated and Mr. Kierstead is to be commended for removing this source of trouble.

F. H. Kierstead: Mr. Oesterreicher is correct in his statement that when the conductor is raised to 350 deg. cent. the concrete may crack, but his inference that failure of the reactor follows this cracking is not correct. The magnetic field of the reactor exerts a force on the winding that is transmitted as a compressive force on the concrete which forces the cracked surface closer together as is indicated in the illustration shown



SECTION THROUGH A REACTOR, SHOWING HOW THE MAGNETIC FORCE EXERTS A COMPRESSIVE STRESS UPON THE CONCRETE

herewith. Because of this fact the reactor continues to perform its function just as well after the concrete has cracked as before. The principle involved here is very much the same as that in a reenforced concrete building. The concrete of a building cracks due to expansion and contraction but it causes no concern because its compressive strength is not impaired by the cracks while the steel reenforcing resists the tension forces. The two cases are similar except that in the reactor the forces are all compressive and thus the reenforcing steel is not required.

These statements have been verified by twelve years of experience with this type of reactor in service.

TEMPERATURE RISE AND LOSSES IN STRUCTURAL-STEEL MEMBERS EXPOSED TO THE FIELDS FROM A-C. CONDUCTORS[1]

(SCHURIG AND KUEHNI)

NEW YORK, N. Y., FEBRUARY 9, 1926.

H. C. Forbes: Engineers who have been concerned with the layout of isolated-phase generating stations will be especially interested in the paper of Mr. Schurig and Mr. Kuehni. In general, this type of station construction is likely to lead to a condition such that heavy currents will be flowing through a bus bar which may be in fairly close proximity to the steel work of the station while the return circuit for this current is comparatively remote.

Some tests were made by The New York Edison Company to determine how serious the heating might be under these conditions and to ascertain what measures might be taken to reduce it. The results of these tests are too voluminous to be presented in their entirety, but it may be of interest to discuss some of them and to note the agreement with those given in the paper.

The structure tested was a rectangular steel loop about 6 in. by 10 in. Tests were made with the current-carrying conductor passing through the closed loop and then were repeated with one side of the loop removed and finally with the conductor passing at right angles to a single member of the loop.

It was found that with the conductor approximately 30 ft. from the steel work, the loss in the case of the single member was about 60 per cent of the loss under similar conditions with the loop completely closed. If the steel loop were larger, this difference would undoubtedly become less pronounced and for the construction used in most generating stations, the losses and resultant heating would be largely independent of whether or not the steel work formed a closed loop around the conductor. The temperature rise in the members would depend chiefly upon the proximity of the conductor, and the value of the current flowing.

Most of our tests were made at 60 cycles, but a few comparative tests were made at both 25 and 60 cycles. These gave a ratio of temperature rise of about 1.7 which I would consider a very good check on the value of 1.6 as given in the paper, particularly in view of the limited number of our own tests covering this point.

It was realized that the losses might be reduced by putting short-circuited copper turns around the steel members and tests showed that such a loop, when placed around the steel member at the point nearest the conductor, reduced the losses by 40 per cent in the case of a single steel member at right angles to the conductor and 60 per cent in the case of the closed steel frame. The use of more short-circuited loops than one at the point nearest to the conductor gave but little further reduction in the losses.

It appears from the tests which have been made that some caution should be observed in station design to avoid heating in the steel work and the paper which has been presented will serve as a very valuable guide. However, if care is taken to place conductors which are to carry heavy currents, say from 2500 to 4000 amperes at a distance of 2.5 ft. or more from the steel work, the heating will not ordinarily be serious and it is doubtful if the use of short-circuited copper loops would be justified.

A. E. Kennelly: We know that such physical conditions as described in this paper are very complicated and that it is very difficult to find a simple formula to cover a great range of such multitudinous conditions, but the practical way in which the results are tabulated and indicated seems of great value.

O. R. Schurig: I agree with Mr. Forbes that for spacings

1. Abridgment, A. I. E. E. JOURNAL, May, 1926, p. 446.

as large as 2.5 ft. between conductor and iron members crossing the conductor the temperature rise in the iron may be expected to be only a few degrees for currents of the order of 3000 or 4000 amperes even if the return conductors are quite remote as in isolated-phase construction. That follows from the curves shown in the paper and there is good agreement on this point as well as on the others brought out by Mr. Forbes. Also let me say that it would help a great deal if data obtained by the operating companies could be published in the discussion of this paper or in separate papers. Doubtless a good deal of the work we did could have been saved if the data and experience of other investigators had been available. We certainly hope such information will be published.

We agree with Professor Kennelly that the calculations from the dimensions and physical constants are very complicated and probably not practical at the present stage. However, efforts would doubtless be productive of good results in the course of time. This problem may be a good one for some of the college research laboratories

NO-LOAD COPPER EDDY-CURRENT LOSSES[1]

(SPOONER)

NEW YORK, N. Y., FEBRUARY 9, 1926

W. J. Foster: I am interested in this paper on the eddy-currents that exist in the copper on open circuit. A very easy way of determining these losses is to make a core-loss test before the machine is wound. Sometimes it interferes with production if a commercial machine is used. Occasionally it happens that a test has to be made at the factory on a machine which is to be shipped that involves knocking it down. In such a case, the core loss can be run off with the machine completely assembled, then after the winding is removed from the armature, it can be repeated.

I notice the author shows reasons why eddy losses exist in the slot, the cross fluxes changing as the rotor advances, etc. There are also conditions at the head of the armature due to the fringing of the flux that are responsible for some losses.

I remember in the case of a few machines many years ago learning something about how to sectionalize conductors by making use of different windings in the same machine, and finding quite a difference in the open-circuit core loss. Possibly others have had similar experiences.

In the matter of determining the losses, as Mr. Dawson and Mr. Barns have described, I believe their method to be about the only feasible method for certain large enclosed machines. However, we must look out for a number of things;—such as the specific gravity of the air. There is the matter of radiation. If it is a very high-speed machine, occupying small space, probably we can entirely neglect the heat that passes off by radiation, but in the case of slower-speed machines that occupy large space and have very large surfaces, some allowance should be made.

P. L. Alger (communicated after adjournment): It has been my opinion for some time that a large part of the observed core loss in a squirrel-cage induction motor is due to circulating currents in the squirrel-cage bars caused by the pulsations of flux in the rotor teeth. These pulsations are due to the variations of reluctance caused by the stator teeth, and are especially large when open slots are used in the stator. Also, these pulsations in the rotor teeth are very large when the ratio of rotor to stator teeth much exceeds unity, they are negligible when the ratio of slots is nearly equal to one, and they are fairly large when the ratio is considerably less than unity, but greater than one-half.

As I understand it, Mr. Spooner now suggests that the loss due to these pulsations of flux in the rotor teeth is not so much due to the circulating currents induced in the winding as to the eddy-current losses produced by the flux forced across the slots as a result of saturation of the teeth. Of course, the flux across the rotor slots is the same when a given number of ampere-turns are present, whether due to current in the rotor bars, or due to saturation in the rotor teeth, other things being equal. Thus, whether the pulsation of reluctance, due to the stator teeth, is counterbalanced by eddy currents and saturation ampere-turns produced in the teeth, as is the case with an open-circuited rotor winding, or is counterbalanced by the ampere-turns of a current induced in the squirrel-cage bars, the same eddy-current loss in the copper should result. But, in the former case, the ampere-turns in the rotor teeth are produced as a result of flux pulsations in the teeth, and these pulsations must be quite large to make many ampere-turns due to saturation. And, in the other case, the ampere-turns in the squirrel-cage winding can be produced by only a small change in flux, corresponding to the voltage required to supply the impedance drop of the winding. Therefore, in the former case, the flux pulsations in the rotor are large, the ampere-turn pulsations in the rotor teeth are not large, and the reflected pulsations of flux in the stator teeth are small; while, in the latter case, the flux pulsations in the rotor teeth are small, the ampere-turn pulsations in the rotor winding are large, and the reflected flux pulsations in the stator teeth are large.

From all this, in the case of a squirrel-cage motor with straight slots and considerably more squirrel-cage bars than stator slots, there can be a very small loss of the type described by Mr. Spooner, as the saturation ampere-turns in the rotor teeth are nearly constant, except for a slip-frequency variation. Therefore, in such cases, one ought to be able to calculate the tooth-frequency core loss as the sum of the pole-face loss, the copper loss in the rotor bars due to the induced currents based on the high-frequency bar resistance, and the flux pulsation loss produced in the stator as a result of the induced rotor currents. Hence, I came to the conclusion that Mr. Spooner's theory does not account for the losses in the ordinary squirrel-cage induction motor with straight slots, and, if he obtains numerical agreement between his calculations and test results, this agreement must be due in some measure to chance.

The foregoing remarks are not intended as a criticism of the paper, but as giving a line of reasoning parallel to Mr. Spooner's which should bring from him some interesting additional ideas. As far as slip-ring induction motors and direct-current machines are concerned, I think Mr. Spooner's theory should give a sound basis for core-loss calculations. It is interesting in this connection to note that, on the basis of Mr. Spooner's ideas, by using a high-grade steel in a d-c. machine, a greater core loss may be obtained than with a low-grade steel, as the extra saturation ampere-turns may cause more losses in the winding than are due to the saving in iron loss itself. On this basis, by subdividing the winding to avoid eddy currents, it should be possible to use a better grade of steel, with the result that a double gain in losses can be secured.

T. Spooner: Referring to Mr. Foster's remarks, we have tested a number of experimental and commercial machines, both d-c. and a-c., according to the method suggested by him, namely, with the windings in position in the slots and with the windings removed. The differences in losses caused by the eddy currents in the copper began to be appreciable at about 70 kilolines per sq. in. mean-tooth induction for induction motors and at about 120 kilolines per sq. in. for salient-pole machines. Often the test losses check the calculated losses quite closely, but sometimes there are rather wide differences. For small-diameter machines where there is considerable tooth taper, it is sometimes difficult to estimate accurately the slot leakage fluxes. This is perhaps one of the chief causes of the observed discrepancies.

We have made no investigation of losses caused by leakage fluxes in the neighborhood of the end windings.

1. A. I. E. E. JOURNAL, March, 1926, p. 264.

Because of the following considerations, I am unable to agree with Mr. Alger's line of reasoning in connection with the eddy-current losses in the rotor bars of squirrel-cage induction motors. In other words, I am still convinced that there exist eddy-current losses in the squirrel-cage bars, after connecting the end rings, which are equal to or greater than those which exist with the bars open-circuited.

Suppose we consider two adjacent teeth, No. 1 tooth having a smaller air-gap reluctance than No. 2 tooth at a given instant. Now, with the bars open-circuited, flux will flow across the slot through the bar from tooth No. 2 to tooth No. 1, giving radial and tangential components of leakage flux. If now the bars are short-circuited, sufficient current will flow in them to bring the mean flux in tooth No. 2 nearly up to that in No. 1. Since the fluxes in the two teeth are practically equal but the air-gap for one of these is less than for the other, the m. m. f. acting on tooth No. 2 must be greater than that acting on No. 1. In other words, the current in the bars will decrease the m. m. f. acting on tooth No. 1 and increase the m. m. f. acting on tooth No. 2. The tangential slot-leakage flux should therefore be increased toward the top of the slot and decreased toward the bottom, the total remaining about constant. At the same time the radial slot leakage flux will be decreased on the side toward tooth No. 1 and increased toward tooth No. 2.

High-frequency circulating currents in squirrel-cage windings, assuming an effective resistance as calculated by Field's formula, do not, in the cases which I have observed, account for the increased losses due to the presence of the copper bars unless the pulsation losses in the stator teeth due to the high-frequency circulating currents in the rotor windings are much greater than those which existed in the rotor teeth before closing the squirrel-cage windings. This seems improbable since the pulsation losses with closed squirrel-cage windings show no tendency toward decreasing as the induction increases due to tooth saturation, as would be the case if they were due to high-frequency iron losses in the stator teeth.

Mr. Alger's point concerning the danger of using high-silicon steel for the cores of machines operating at high-tooth inductions is well taken. Since at high inductions the permeability of 4 per cent silicon steel may be from ½ to 1/3 of that of low-silicon steel, the slot-leakage fluxes will be greatly increased for the former. Since the eddy-current losses increase as the square of the slot-leakage fluxes, the substitution of high- for low-silicon steel may increase very considerably the copper eddy losses. The remedy is, of course, a greater subdivision of the copper, as suggested by Mr. Alger.

HEAVISIDE'S PROOF OF HIS EXPANSION THEOREM[1]

(M. S. Vallarta)

New York, N. Y., February 11, 1926

J. J. Smith: I should like to refer to the paragraph third from the end of Mr. Vallarta's paper in which he states that Heaviside gave another alternative proof of his Expansion Formula. This is given in Heaviside's Electrical Papers, Vol. II, p. 226, in a footnote. As this seems to be another very important way of proving the expansion theorem, I shall take the liberty of quoting it in full, as follows:

Let

$$C = \frac{f(p_0)}{\phi(p_0)} E \tag{1}$$

be the differential equation connecting C with E where p_0 stands for d/dt and $\phi(p) = 0$ is the determinantal equation of the system, that is, $\phi(p)$ may be either the characteristic function in fully developed form, or the same multiplied by any function which does not conflict with its use in the determinantal equation. Then we have by the algebraical theorem:

$$\frac{1}{\phi(p_0)} = \sum \frac{1}{(p_0 - p)\,\phi'} \tag{2}$$

where ϕ' means $d\phi/dp$, and the summation includes all the roots of $\phi(p) = 0$. Therefore, by (1), using (2) and integrating:

$$C = f(p_0) \sum \frac{E}{(p_0 - p)\,\phi'} = E f(p_0) \sum \frac{e^{pt} - 1}{p\,\phi'} \tag{3}$$

E being zero before and constant after $t = 0$. But also by (2):

$$\frac{1}{\phi_0} = \sum \frac{1}{-p\,\phi'} \tag{4}$$

where ϕ_0 means ϕ with $p_0 = 0$, so that (3) becomes:

$$C = E f(p_0) \frac{1}{\phi_0} + E f(p_0) \sum \frac{e^{pt}}{p\,\phi'} \tag{5}$$

Now, perform the operations indicated by $f(p_0)$ and we get:

$$C = E \frac{f_0}{\phi_0} + E \sum \frac{f(p)}{p\,\phi'} e^{pt} \tag{6}$$

where f_0 means f with $p_0 = 0$. (See also the investigation at the end of the (later) paper on "Resistance and Conductance Operators.")

(6) is the form of the expansion theorem given by Heaviside in his Electromagnetic Theory, Vol. II, p. 135, a modified form of which is given on p. 127.

On going through the second volume of the Electromagnetic Theory, it is, I think, fairly evident that Heaviside used the above conception of the expansion theorem quite freely. For instance, on p. 88 he solves the problem of voltage applied at one end ($x = 0$) to a cable of length l which is grounded at the other ($x = l$) and for which the well-known formula is:

$$V = \frac{\sinh q\,(l - x)}{\sinh q\,l} E$$

By expanding

$$\frac{q\,l}{\sinh q\,l} = 1 - \frac{2}{1 + \left(\frac{\pi}{q\,l}\right)^2} + \frac{2}{1 + \left(\frac{2\,\pi}{q\,l}\right)^2} - \frac{2}{1 + \left(\frac{3\,\pi}{q\,l}\right)^2} \cdots$$

where

$$q = \sqrt{C\,R\,\frac{d}{d\,t}}$$

and then identifying

$$\frac{1}{1 + \dfrac{n^2\,\pi^2}{R\,C\,l^2\,\dfrac{d}{d\,t}}} \text{ with } e^{-\frac{n^2\pi^2 t}{RSl^2}}$$

the solution of the problem is readily obtained.

If his work in this example is carefully followed out it will be found that he is doing nothing but developing the various steps in the expansion theorem given in the footnote in his Electrical Papers, p. 226.

There are two fundamental concepts back of this derivation which it may be interesting to examine. Writing (1) in the form:

$$\left(A_n \frac{d^n}{d\,t^n} + A_{n-1} \frac{d^{n-1}}{d\,t^{n-1}} + \ldots\ldots + A_1 \frac{d}{d\,t} + A_0\right) C = f(p_0)\,E \tag{7}$$

where the actual value of $\phi(p_0)$ is inserted, it may be seen that this is a linear differential equation of the nth order for C. Now it is known that the general solution of this equation is:

$$C = B_1\,e^{p_1 t} + B_2\,e^{p_2 t} + \ldots\ldots + B_n\,e^{p_n t} + \frac{f(p_0)_{\,p_0 = 0}\,E}{A_0} \tag{8}$$

1. A. I. E. E. Journal, April, 1926, p. 383.

where $p_1, p_2 \ldots\ldots p_n$ are the roots of the equation

$$A_n p^n + A_{n-1} p^{n-1} + \ldots\ldots + A_1 p + A_0 = 0$$

Each term $e^{p_r t}$ is a solution of the equation

$$\left(\frac{d}{dt} - p_r\right) y = 0$$

We are thus lead to expect that the solution of a linear differential equation of the nth order can be made to depend upon the solution of n linear equations of the first order, and if a comparison is made of equations (1) and (3) it will be seen that the equation of the nth order in (1) has been transformed into n equations of the first order in (3) by means of a partial fraction expansion.

The second point to notice is that nowhere in the above proof does Heaviside use the property $C = 0$ when $t = 0$. What he does postulate is that E is zero before and constant after $t = 0$. It is under this hypothesis that in order to find the value of $\frac{1}{p_0 - p}$ he assumes it to be say y, then

$$(p_0 - p)\; y = E$$

Or

$$\left(\frac{d}{dt} - p\right) y = E$$

giving

$$y = i_0\, e^{+p(t - t_0)} + \frac{E\,(e^{pt} - 1)}{p}$$

Now in all practical problems the real part of p is negative, corresponding to circuits with resistance in which energy is dissipated; hence, whatever current may have existed at the instant $t_0 < 0$, where the actual value of t_0 may be made as large as we please, it will have become negligible by the time $t = 0$. Hence, the effect produced by the applied voltage E is contained wholly in the second term, giving

$$y = 0 \qquad t < 0$$

$$y = \frac{E\,(e^{pt} - 1)}{p} \qquad t > 0$$

Or, if we wish to put it another way, the y caused by E applied at $t = 0$ is given by this term, and the $i_0\, e^{p(t - t_0)}$ part is due to another cause. This is not the way in which Heaviside makes this particular step but the results are the same.

Whatever way we chose to look at it, the facts are that by using this substitution in (3) as shown, and completing the solution as in (6), we get the solution of (1), corresponding to the system (assumed to be a dissipative one) represented by (1) being at rest, and having been at rest for a very long time prior to $t = 0$. We have thus used the one condition

$$E = 0 \qquad t < 0$$

$$E = E \text{ constant} \qquad t > 0$$

to supplant the n terminal conditions which would be normally required to determine the constants in the solution of (1) or (7). The economy in such a reduction of terminal conditions should be apparent. The economy becomes more apparent when applied to problems in long transmission lines where an infinite number of terminal conditions arise in certain methods of obtaining the solution.

I presume the reason Mr. Vallarta did not discuss Heaviside's second derivation referred to above is that it involves so-called operational mathematics, and operational methods have been looked upon with disfavor by mathematicians for many years as being lacking in rigor, which may or may not be true. I like to think, however, that between the operational mathematics and the conventional pure mathematics there must be some common ground on which they can both meet together by a little give-and-take on both sides. I have published two papers in the *Journal* of the Franklin Institute with this end in view, one in June, 1923, and the other as a serial in October, November and December, 1925. In these papers the ideas given above are developed more fully. The interesting part, however, is that although Heaviside, as far as I am aware, uses his expansion theorem only in continuous systems for one coordinate in addition to the time, such an attempted development of a common ground between pure and operational mathematics has lead to a method of solution for two- and three-dimensional problems such as occur in the flow of heat, and in addition to the solution of potential problems in electrostatics in which no time factor appears. These results come from simple extensions of the development of the expansion theorem given above, which then becomes a particular expansion theorem in a great class of expansion theorems. Reference must be made to my paper for details. However, with Mr Vallarta I join in a plea for greater study of the works of Heaviside and for the development of both his ideas and the concepts of pure mathematics to the point where they will both merge into one as I have not the slightest doubt they should.

M. S. Vallarta: In his valuable discussion Mr. J. J. Smith has already given Heaviside's second proof of the Expansion Theorem, to be found in the second volume of his "Electrical Papers" (l. c. footnote 19 of the writer's paper.) The writer did not feel that a complete account of this second method of proof was necessary partly because it has already been discussed rather thoroughly elsewhere (see for example reference 9 in the writer's paper), but mostly because it is not quite so illuminating, or important from a physical standpoint, as the first method of proof based on the conjugate theorem.

Mr. Smith raises an interesting question when he speaks of operational calculus and its relation to the Expansion Theorem. As shown in the paper, operational methods are not required to establish the Expansion Theorem in the case of no null and no repeated roots of the determinantal equation, but the use of such methods really simplifies matters considerably in this exceptional case. For purposes of technical applications, however, the writer feels that both may properly be kept separate. That operational calculus can be rigorized if the proper tools and methods of attack are used has been shown by Wiener ("The Operational Calculus" forthcoming in the *Mathematische Annalen*) and Carson (see the Bell Technical *Journal* for 1925 and 1926). Once operational calculus is rightly understood it may be applied confidently not only to engineering problems, but also to problems in pure mathematical physics where less powerful methods break down completely. As a most advanced example of this type of problems, reference is made to a paper by Born and Wiener, (*Journal* of Mathematics and Physics of M. I. T., Vol. 5, p. 84, Feb. 1926) to quote but a single example.

The great importance of the conjugate theorem has been very recently recognized by K. W. Wagner ("Der Satz von der wechselseitigen Energie" *Elektrische Nachrichten-Technik*, Vol. 2, p. 376, Nov. 1925) who also gave in this article Heaviside's first method of proof of the Expansion Theorem. This and the writer's paper were written approximately at the same time (Wagner's paper was received for publication on Nov. 9, 1925; the author's paper on Dec. 1, 1925). The present writer is glad to add this interesting reference to the list already given in the paper.

THE USE OF VIBRATION INSTRUMENTS ON ELECTRICAL MACHINERY[1]

(Ormondroyd)

New York, N. Y., February 11, 1926

W. B. Creagmile: Mr. Ormondroyd has mentioned a vibrating-reed type of instrument with one reed. The common use of vibrating-reed instruments having a series of tuned reeds along a marked scale, to measure revolutions per minute

1. A. I. E. E. Journal, April, 1926, p. 330.

and a-c. frequency, is not mentioned in the paper. The reeds of the tachometer pick up mechanical vibration from the machine to which the instrument is attached. In the frequency meter, the reeds are set in vibration by alternating current flowing through an electromagnet placed in series with resistance across the mains.

The amplitude of vibration of any reed is dependent upon the amount of vibration of the machine to which the tachometer is attached, or the voltage of the line to which the frequency meter is connected. However, speed or frequency is not read by observing the amplitude of vibration of any particular reed, but by noting which reed is in vibration. Hence, we may say that the indications of speed and frequency given by the vibrating-reed tachometer and vibrating-reed frequency meter are entirely independent of the exact amount of vibration of the machine under test or of voltage of the a-c. line.

J. Ormondroyd: On the second page of the paper, the first sentence in the section on "The Vibrating Reed" makes brief mention of the two common uses of "tuned" reeds. Since the reed tachometers and electrical frequency meters are not used primarily to study vibration, no further mention is made of them.

The amplitude of motion at the end of a reed in a Frahm tachometer can be represented by equation (15) if

$$M = M + \frac{m}{4}$$

as in equation (16). This equation shows that the amplitude on any reed will be proportional to the impressed amplitude. But it also depends on the dynamic magnification which is a function of the frequency. Fig. 11c shows the relationship between reed-vibration amplitude and impressed vibration.

The reed which happens to be at or near resonance with the impressed frequency will have its motion magnified beyond all proportion to the magnification which the other reeds experience. The magnification at resonance is inversely proportional to the damping factor C as can be seen in Fig. 11c where the effect of two different values of C is shown. Putting $\frac{\omega}{\omega_c} = 1$, in equation (15) this is shown very clearly.

The speed or frequency is read by observing which reed has the greatest amplitude. The neighboring reeds usually show some smaller amplitude while the more distant reeds have no apparent motion.

In a sense the indications of speed are independent of the exact amount of the impressed vibration. This statement breaks down at the limit where the exact amount becomes zero. If turbine manufacturers could reach their ideal of perfectly balanced spindles and field-rotors the reed tachometers would become useless.

RATING OF HEATING ELEMENTS FOR ELECTRIC FURNACES[1]

(Keene and Luke)

New York, N. Y., February 11, 1926

G. E. Luke: The equations for heat loss as given in this paper are only approximate. The heat liberated by convection varies to some extent with the position of the resistor. Its variation with temperature rise to the 1.20 power is only empirically true, but it seems to hold over a rather wide range of size and temperature. Fortunately, the rate of loss by convection is a small percentage of the total so that it does not have to be so accurately known. The accuracy of the Stefan-Boltzmann equation for radiation depends upon the correctness of the coefficient of emissivity (e). This value (e) is not constant but changes somewhat with temperature. For practical purposes it can be considered as a constant without great error.

1. A. I. E. E. Journal, March, 1926, p. 222.

Although considerable data are published regarding the rate of heat transfer from high-temperature conductors, yet few are available as to the reduction in this loss due to the proximity of other parallel conductors. At first the method of calculation as shown on Fig. 3 was used. It was recognized that this method was not rigidly correct since the intensity of the heat radiation from a point on a plane surface in any direction is proportional to the cosine of the angle that direction makes with the perpendicular. Nevertheless the approximate method gave results within 2 to 3 per cent of the true loss as determined experimentally.

It is hoped that this paper will show the fallacy of designing resistors according to the constant-current-density method or the constant-surface-loss method. Figs. 5 and 6 show that the possible rating depends largely upon the resistor arrangement.

OPERATING PERFORMANCE OF A PETERSEN EARTH COIL-II[1]

(Oliver and Eberhardt)

New York, N. Y., February 9, 1926

L. P. Ferris: I wish to ask what was the condition of the coil as regards tuning during the period covered by this paper? Was it the same or different from the tuning employed during the period covered by the authors' previous paper on this subject? If the coil remained in the condition of tuning mentioned in the previous paper, overtuned by some 23 per cent., perhaps that will explain to some extent why the coil failed to prevent the tripping of the line switch in some of those fifteen cases listed in Table I. Under this detuned condition, the coil does not limit the fault current to as low a value as it would if it were tuned more exactly. With 23 per cent. overtuning (*i. e.*, with 1207 ohms reactance), the measurements reported in Mr. Lewis' paper of 1923 indicate a fault current of about 4.8 amperes, whereas the same paper gives measured currents of approximately 2.4 amperes for the coil setting nearest resonance (982 ohms). It is conceivable that, under some fault conditions, the arc might be maintained if the current were not reduced below the first figure, but would be extinguished if the current were limited to the smaller value corresponding to exact tuning. Perhaps Messrs. Oliver and Eberhardt could say how large a factor this detuning might be in accounting for some of these fifteen cases? As brought out in the discussion of the earlier papers, it would seem desirable if the coil were operated slightly detuned, that it be operated somewhat undertuned rather than overtuned, although the direction in which it deviates from the exact tuning would not seem to affect its ability to quench an arc.

W. W. Lewis: In this country the trend of operation away from the isolated neutral and toward the grounded neutral has limited the field of the Petersen coil. Nevertheless, the report of Messrs. Oliver and Eberhardt is valuable in clearly pointing out what can be done with this device under suitable circuit conditions.

In Europe, the tendency has been to design the reactor with an iron core to operate normally off resonance, but to be pulled into resonance by saturation when one conductor becomes grounded. As an alternative, the reactance is designed to be outside a certain band on each side of the resonance condition at all times. Both of these designs are intended to prevent certain overvoltage troubles anticipated when the three poles of an oil circuit breaker do not operate simultaneously. The modified devices have found much favor and have been very successful.

W. W. Eberhardt: I shall answer Mr. Ferris' question by stating that the coil, during the period reported in this paper, was overtuned approximately 23 per cent. Towards the end of the operating period, the coil was slightly undertuned but that was after the end of the lightning season and no operating experience was obtained with the undertuned setting.

1. A. I. E. E. Journal, March 1926, p. 227

ILLUMINATION ITEMS

By the Committee on Production and Application of Light

IN ITS INFANCY

Street lighting has been a problem ever since men began to herd together in cities. At first the problem was solved by each citizen who ventured out at night carrying a lantern or hiring a link boy to carry a torch before him.

This didn't amount to much as protection from highwaymen, although it did help some in getting over, around, or through the mud puddles. During that period the easiest and most popular solution of the street lighting problem was to stay at home after dark.

By and by came oil lamps stuck on poles to help out the hand lanterns. Then gas lamps took the place of oil, and so by degrees we come to our modern age of electric lighting.

It is well within the truth to say that even in America street lighting is still in a primitive stage. We have of course our "White Way" in every city of any importance, but once outside this area the streets are often dismal and dangerous after dark. The average community seems to spend just enough on street lighting to make the darkness more confusing. There is a popular notion that street illumination costs much money, but the latest investigation shows that per capita cost is only about 75 cents a year.

Scientific and adequate street lighting is a social question of paramount importance in the modern world.

First of all we have the fact of vastly accelerated out-of-door movement among all classes of people. Shut in by day, the masses and classes alike are impelled to stir abroad at night. In the theatre and shopping district, it has become the recognized practise to make the streets as light as day. What the community fails to furnish, the stores and places of amusement make up as part of their sales and advertising budget.

Among many others there are three reasons why every city, town, and many country roads, must, from now on, be properly lighted.

First the safety, happiness and comfort of all the people demand it. Second, the enormous increase in power transportation brings us to the point where traffic growth must cease unless folks can see where they are going. This refers to pedestrians quite as much as to those in automobiles, busses and street cars. Third, according to an ancient scripture, where the carcass is, the birds will gather together. With the streets thronged at night at the centers, it means that the home streets, roads and byways will all have belated travelers at night. This brings the hold-up man and other criminals to their harvest. Good street-lighting is second only to a good police force as a crime deterrent. Men love darkness rather than light when their deeds are evil. Crime diminishes as light increases.

Recognizing the great social value of good street-lighting, the scientific and engineering resources of the leading lighting laboratories have been directed towards a solution of this problem with extraordinary success. We have the lamps and the electric energy and we know how to use both to the best advantage in street-lighting. When the people wake up to the necessity of proper street lighting, half the job will have been done.—*Light*, March 1926.

NATURAL LIGHTING

Primitive man, during many ages, found daylight ample and satisfying to all his needs. His simple arts were carried on in the open and if the glare of the mid-day sun was objectionable he sought the shade of the trees. As arts and society became more complex, housing became necessary, and this created the problem of providing adequate indoor lighting. Artificial sources were developed and electric lighting has now reached such a stage of perfection that the cost of natural, as compared with that of artificial light, has become a matter of considerable interest.

Nevertheless, natural light still has its place in industries and homes, and it will still continue to hold this place for the following reasons:

1. It is ample. In our latitude the direct solar thermal energy at noon on a clear day is close to 100 kilowatts per square dekameter, (slightly more than 1000 square feet) or sufficient to maintain 2500 forty-watt lamps, if we could utilize it, which, in the future, someone may learn to do.
2. It never fails. The sun is always shining.
3. It is the kind of light to which the human eye is best adapted, and that which artificial light tries to imitate.

An objection to natural light is that it varies in intensity. Dr. Abbot's studies indicate a variation of about one per cent on each side of the mean in recent years. This is masked, however, by a variation of $\pm$ 3.5 per cent due to the varying distance of the earth from the sun. Furthermore, the percentage of solar energy transmitted by the earth's atmosphere varies from day to day and from hour to hour, even when there are no clouds. With clouds completely covering the sky, the diffused solar energy received on a horizontal surface is about one-fourth what it is in the absence of clouds. However, even in cloudy weather, natural lighting is ample for out-door operations except during rainfall, when most out-door work ceases. In the process of evolution the human eye has learned to adapt itself without discomfort to the intense light at midday in summer and to the feeble light of twilight, or a range of intensity from 10,000 to 30 foot-candles.—*Trans. I. E. S.*

The monument erected on the site of the original laboratory of Thomas A. Edison, at Menlo Park, N. J., will hereafter be flood-lighted so as to be visible from the trains of the Pennsylvania Railroad as well as from the Lincoln Highway.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Regional Meeting at Niagara Falls May 26-28

A program of unusual interest has been arranged for the Regional Meeting which will be held at the Niagara Hotel, Niagara Falls, N. Y., May 26-28, under the direction of the Northeastern District of the Institute. The technical sessions will include a symposium on measurement of dielectric power factor, papers on transmission, tests of hydroelectric units, rectifiers, transformer design, polarization of radio waves, armature reactance, magnetic-flux measurements, current transformers, supervisory control, fire protection for generators, etc. A list of the technical papers was published in the JOURNAL for April 1926, page 391, and a complete program will be distributed by mail prior to the meeting.

One paper not included in previous announcements but to be presented at the meeting is that of T Spooner on "Current Transformers with Nickel-Iron Cores;" also there will be a short talk on *The Calibration of Lichtenberg Figures* by K. B. McEachron of the General Electric Company.

For this meeting, a number of delightful entertainment features have been arranged. There will be a boat trip on Lake Ontario, with dancing on boat; also a scenic and inspection trip through the Gorge, and a special illumination of the Falls, a convention dinner, and two attractive lectures.

Ladies are cordially invited and special arrangements have been made for their enjoyment.

The steamer trip on Lake Ontario will be made on Wednesday evening, May 26. The boat will be boarded at Lewiston and a delightful trip under a full moon is promised. Music will be furnished by a good orchestra and dancing may be enjoyed by all who desire it.

A trip to the Niagara Gorge will be made on Thursday afternoon when the marvelous rapids and whirlpool may be seen. Stops will be made at points of scenic interest and at the power plants on both sides of the ravine, and there will be guides ready to take groups through the plants.

On Thursday evening, the Convention dinner will be held in the Niagara Hotel and a number of Institute officers will speak briefly, including President M. I. Pupin, E. D. Adams, C. C. Chesney, Guiseppe Faccioli, H. M. Hobart and others.

Following the dinner a lecture, with interesting demonstrations on "Modern Reproduction of Sound," will be delivered by L. T. Robinson.

The special illumination of Niagara Falls, which is planned for Thursday night, will be a spectacle of great beauty. The Falls will be bathed in light of changing forms and colors.

A piano recital by Vladimir Karapetoff, together with an interesting interpretation of the music played, is planned for Friday evening as one of the enjoyable events of the meeting.

The first exhibition of the new film of the Niagara Falls Power Company will be given if possible Friday evening in connection with a lecture on the possible future power and scenic developments at the Falls, by George S. Anderson of the Niagara Falls Power Co.

Reduced Railroad Fares

Reduced railroad rates, under the certificate plan, have been granted and every visitor who comes to the meeting by train should get a certificate, if not for his own benefit at least to help others who will want to take advantage of the reduced fare.

Under this plan, every visitor should request a certificate from his local ticket agent when purchasing his ticket to Niagara Falls. If 250 certificates are turned in at the meeting, return tickets over the same route may be had at half-fare rates. There are certain restrictions regarding dates, extra-fare trains, etc.; this information should be obtained from local ticket agents.

Everyone who travels by rail to the meeting *should get a certificate*, whether or not he intends to use it, for as above stated by obtaining a certificate he will help make up the 250 which are necessary to make the reduced fare available to those who wish to take advantage of it.

The Niagara meeting has been planned by the Coordinating Committee of the Northeastern District consisting of H. B. Smith, Chairman, Vice-President in the Northeastern District; A. C. Stevens, Secretary; J. R. Craighead, E. D. Dickinson, J. A. Johnson, A. E. Soderholm and A. W. Underhill, Jr. Local arrangements are being made by a committee of which J. A. Johnson is Chairman.

Madison Regional Meeting May 6-7

Arrangements are completed for the Regional Meeting of the Great Lakes District, to be held in Madison, Wis., at the Hotel Loraine, May 6-7. The program contains technical papers on the subjects of rural electric service, high-voltage cables, interconnected systems, research between colleges and industries and radio receiving circuits. A convention dinner and inspection trips are also scheduled. A complete program was published in the April issue of the Institute's JOURNAL, page 390.

Student Convention at M. I. T. May 7

Plans are practically complete for the Student Convention of the First District of the Institute to be held at Massachusetts Institute of Technology, Cambridge, Mass., on May 7. The tentative program is as follows: In the morning, there will be three or four student papers and discussions. At noon there will

be a luncheon and Counsellor's meeting. In the afternoon inspection trips will be made to Edgar Station, Simplex Wire and Cable Company, a machine-switching telephone exchange and the M. I. T. Laboratories.

A joint banquet with the Boston Section will be held in the evening. Dr. M. I. Pupin, President of the A. I. E. E., will speak on "Science and Engineering." The other speaker of the evening will be Mr. R. E. Doherty, of the General Electric Company.

Stanley A. Tucker, Chairman of the Yale Branch, will preside at the morning session. Prof. H. B. Smith, Vice-President in the First District, will act as toastmaster at the banquet in the evening and is sponsoring the meeting of the Counsellors.

A student committee, of which Stuart John is Chairman, is arranging the meeting with the assistance of Vice-President H. B. Smith and J. W. Kidder, R. D. Booth, W. H. Colburn, H. W. Timbie and H. B. Dwight, all of the Boston Section.

Annual Convention, June 21-25 at White Sulphur Springs

The forty-second Annual Convention, which will be held at *The Greenbrier*, White Sulphur Springs, West Virginia, June 21-25, will be very interesting and enjoyable technically and socially.

In the technical program there will be papers on such subjects as magnetization, remotely-controlled substations, high-speed circuit breakers, electric transients, machine windings, regenerative braking, non-harmonic alternating currents, theory of synchronous machines, heat transfer in machines, etc.

The reports of Institute's Technical Committees will form a major part of the technical sessions. These should be of interest to all, as they are written to describe advances in design and practise in the various fields of electricity.

As a feature of general interest it is planned to have addresses by representatives of the American Engineering Council and the American Engineering Standards Committee. The objects and activities of these organizations will be explained, as well as their relation to the Institute and other electrical organizations.

White Sulphur Springs is an exceptionally attractive location for the Convention and *The Greenbrier* is a magnificent hotel, possessing every comfort and convenience. Among the attractions will be golf, tennis, horseback riding, motoring, sulphur baths, a swimming pool, not to mention the beautiful scenery of the place. All afternoons will be free for recreation.

A complete program will be published in the June issue of the Journal.

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, April 9, 1926.

Present: President M. I. Pupin, New York, Past-President Farley Osgood, New York, Vice-Presidents Harold B. Smith, Worcester, Mass.; A. G. Pierce, Cleveland; Managers H. M. Hobart, Schenectady, N. Y.; G. L. Knight, Brooklyn, N. Y.; W. K. Vanderpoel, New York; John B. Whitehead, Baltimore; E. B. Merriam, Schenectady, N. Y.; H. A. Kidder, New York; National Treasurer George A. Hamilton, Elizabeth, N. J.; National Secretary F. L. Hutchinson, New York.

The minutes of the Directors' meeting of February 9, were approved as previously circulated.

The Board ratified the action of the Executive Committee, under date of March 19, in approving applications for student enrolment, election to membership, and transfer from one grade to another.

Reports were presented of meetings of the Board of Examiners held March 8 and April 9, and actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken on pending applications: 30 Students were ordered enrolled, 207 applicants were elected to the grade of Associate, 1 applicant was elected to the grade of Member, 1 applicant was elected to the grade of Fellow, 16 applicants were transferred to the grade of Member, 1 applicant was transferred to the grade of Fellow.

The Board ratified the approval by the Finance Committee for payment, of monthly bills amounting to $25,024.05.

Upon recommendation, approved by the Finance Committee, the Board voted to authorize the payment of traveling expenses, at the rate of ten cents per mile one way, of District Secretaries to the Section Delegates Conference at the Annual Convention, each year.

Upon request from the Pittsburgh Section, the Board authorized the extension of the territory of the Pittsburgh Section to include Marion and Harrison Counties, West Virginia.

The Board granted a request of the Portland, Seattle, and Spokane Sections for a readjustment of their boundaries to include territory not previously included in any Section.

Upon the approval of the Committee on Student Branches, the establishment of a Student Branch at Washington and Lee University, Lexington, Virginia, was authorized.

A proposed Uniform Electrical Ordinance and Uniform Statute, recommended by the Electrical Manufacturers Council, was considered and endorsed.

The Secretary announced the receipt of the trust fund for the Lamme Medal, bequeathed to the Institute by the late Benjamin G. Lamme, amounting to $5160 ($6000 less the inheritance tax); the formulation of a plan of procedure for making the award and the preparation of the design for the medal was referred to the Committee on Award of Institute Prizes for consideration and report to the Board of Directors.

The Board voted a gold medal award, in addition to the $100 previously authorized, in connection with the national "Best Paper Prize" recently established, to commence with the year 1926. The matter of design of this medal was referred to the Committee on Award of Institute Prizes.

In accordance with Section 33 of the constitution, the Board ratified the appointment by the President of the Tellers Committee, to report upon the ballots received in connection with the 1926 election of Institute officers, as follows: Messrs. S. P. Grace (Chairman), W. E. Coover, E. S. Holcombe, R. R. Kime, E. F. Thrall, E. F. Watson, and John T. Wells.

The Board confirmed the appointment by the President of Dr. Cary T. Hutchinson to succeed Dr. A. E. Kennelly as an Institute representative on the Engineering Division, National Research Council, and of Mr. Farley Osgood as an Institute representative on the Committee on Electric Power Houses, National Fire Protection Association.

Consideration was given to a request from American Engineering Council, and from the Denver Section of the Institute, that the Board of Directors go on record in approving Federal Bill H. R. 9397 to provide for inventory of water resources in the United States, and the Board voted its endorsement of the bill.

An invitation from the American Academy of Political and Social Science to be represented at the annual meeting, in Philadelphia, May 14-15, of that organization, was accepted, and the President was authorized to appoint delegates to this meeting.

The resignation of Mr. H. P. Gibbs as Local Honorary Secretary of the Institute for India, on account of leaving India, was presented, and upon the recommendation of Mr. Gibbs, Mr. F. W. Willis was appointed to succeed Mr. Gibbs as Local Honorary Secretary for India.

The Board accepted an invitation to appoint three representatives to attend the unveiling of the bust of Eli Whitney at the Hall of Fame, New York University, May 12, and Messrs. H. A. Kidder, G. L. Knight, and W. I. Slichter, were appointed.

Other matters of importance were discussed, reference to which may be found in this and future issues of the Journal.

First Plenary Meeting in United States of the International Electrotechnical Commission April, 13-22, 1926

The first plenary meeting of the International Electrotechnical Commission ever held in the United States opened April 13 and terminated April 22, in the Engineering Societies Building, New York.

More than one hundred delegates, representing most of the European nations and accompanied by about twenty ladies, arrived in New York about noon on April 13, on the Steamship *Andania*, and were met at the pier by a delegation of the official Reception Committee, including Messrs. John W. Lieb, Chairman, Frank W. Smith, C. E. Skinner, P. G. Agnew, F. R. Low, Elihu Thomson, C. O. Mailloux, Clayton H. Sharp, A. E. Kennelly, and C. A. Adams.

The first session, designed for the purpose of extending a welcome to the visitors, was held under the sponsorship of the United States National Committee in the Auditorium of the Engineering Societies Building, on Tuesday evening, April 13. Chairman John W. Lieb, of the Reception Committee, presided, and an address was made by Honorable Herbert Hoover by telephone from Washington, transmitted directly to the audience by amplifiers. Thomas A. Edison, Honorary President of the Reception Committee, sent greetings by telegraph from Florida, and a cablegram was read from the former Premier of Great Britain, Lord Balfour. Dr. Elihu Thomson, Past-President of the I. E. C., welcomed the delegates on behalf of the United States National Committee, and Dr. Howard T. Barnes, President of the Canadian National Committee, extended the greetings of the Dominion. Responses were made for Great Britain by Colonel R. E. Crompton, C. B., Honorary Secretary, I. E. C.; by M. E. Genissieu, of France; A. F. Enstrom, of Sweden; Professor V. List, of Czechoslovakia; Dr. P. Strecker, of Germany. The ceremonies were closed with the address by the President of the I. E. C., Guido Semenza, of Milan, Italy, on "Accomplishments and Aims of the International Electrotechnical Commission."

In a quotation from President Semenza's address, "when we unify nomenclature in electrical science and manufacture, and when we establish unified ratings for machines, then we shall have simplified production," the aims and activities of the I. E. C. are fittingly described. Out of the International Electrical Congress held in St. Louis in 1904 has grown this international standardizing body representing some twenty-four nations and to them has been due much of the international cooperation by which greater uniformity of practise, nomenclature and rating has facilitated international commerce. Through the medium of the U. S. National Committee standards in America have been communicated to the International body and the standardizing bodies here have been made fully acquainted with progress in the international field.

The Reception Committee tendered a luncheon to the visiting delegates at the Hotel Commodore on Wednesday at 12:30. Dr. John W. Lieb presided. Among the speakers were Dr. M. I. Pupin, President A. I. E. E.; Sir Archibald Denny, Dr. Guido Semenza, Dr. Clayton H. Sharp and Dr. C. O. Mailloux.

Numerous inspection trips to points of engineering interest, luncheons, and other events were carried out during the entire stay of the delegates in New York. For the ladies, a special program was arranged by the Entertainment and Hostesses Committees, including motor trips, theatre parties, teas, etc. On Thursday, April 15, a luncheon was tendered, to the chairman and secretaries of the various bodies engaged in standardization in the United States and abroad, by the American Engineering Standards Committee.

On Monday evening, April 19th, a banquet was tendered by the electric light and power companies of New York City to the visiting and American delegates and ladies, about three hundred in number, at the Hotel Astor. Mr. Gano Dunn, Past-President of the American Institute of Electrical Engineers and Chairman of the National Research Council, acted as toastmaster. The speakers were Hon. James J. Walker, Mayor, City of New York, John W. Lieb, Vice President, N. Y. Edison Company, Guido Semenza, President I. E. C., E. Uytborck, Chairman Belgian Delegation, C. Feldmann, President, Dutch Electrotechnical Committee, Domingo Santa Mario, Chili, E. Huber-stockar, Switzerland, and Sir Richard Glazebrook, Great Britain. Professor Lombardi extended an invitation to hold the next meeting in Italy.

On Wednesday evening, the 21st, with the visiting delegates of the I. E. C. as hosts, a banquet was given to the U. S. National Committee, also at Hotel Astor. President Guido Semenza presided. On behalf of the visitors he presented a beautiful statue of Nike, the winged Goddess of Victory. In response, Dr. Clayton H. Sharp, President of the U. S. National Committee thanked the delegates for the emblem of friendship and expressed the hope that this country would again have the privilege of entertaining the commission. Representatives of several of the nations represented expressed their felicitations.

INTERNATIONAL ELECTROCHEMICAL COMMISSION DELEGATES' VISIT TO THE WHITE HOUSE, WASHINGTON, D. C.

A complete list of the delegates from all countries follows:

LIST OF DELEGATES

Signor Guido Semenza, President, I. E. C.
Dr. C. O. Mailloux, E. E., Honorary President, I. E. C.
Col. R. E. Crompton, C. B., R. E., Honorary Secretary, I. E. C.
Mr. C. le Maistre, C. B. E., General Secretary, I. E. C.

Austria:
Herr Bretschneider, Vice-President, Austrian Standards Committee;

Belgium:
E. Uytborck, Secretary, Belgian Electrotechnical Committee;
L. Colson, General Director, Electrical Section, Belgian State Railways;
M. Danly, Société Financière de Transports et d'Entreprises industrielles;
Franz Dupont, Chief Engineer, Ateliers de Construction electrique, Charleroi;
C. Baron Forgeur, Director at Head Office, Ministry of Industry;
M. Victor Lagasse de Locht, Société Générale des Chemins de fer Economiques;

Canada:
James Kynoch, Chief Engineer, Canadian G. E. Co.;
John Murphy, Consulting Engineer, Dominion Government;
H. T. Barnes, President, Canadian National Committee;
I. L. Durley;

Czechoslovakia:
V. List, Chairman, Czechoslovakian Electrotechnical and Standards Committees;
F. Pergler, Czechoslovakian Standards Committee;
B. Rosenbaum, Secretary, Czechoslovakian Standards Committee;

Chili:
Domingo Santa Maria;

France:
G. J. Darrieus, Cie Electromécanique;
J. J. Frick, Société Alsacienne de Constructions Mécaniques;
E. Genissieu, Ing. en chef des Forces Hydraulics et de distribution d'energie au Ministére des Travaux Publics;
P. Girault, Cie. Fr. Thomson-Houston;
E. Roth, Société Alsacienne de Constructions Mécaniques;

Germany:
P. Strecker, President, German Electrotechnical Committee, Professor at Heidelberg;
P. Schirp, Secretary, German Electrotechnical Committee and V.D.E.;
L. Fleischmann, Allgemeine Elektricitas Gesellschaft;
Herr Hochtl, Chief Government Architect;
Dr. M. Kloss, Professor at Charlottenberg;
Oberingenieur A. Maier; German Standards Committee;
Dr. Moldenhauer, Markisches Elektrizitats-Werk;
Dr. Rudenberg, Siemens-Schuckertwerke;
Herr Schlothauer, Counsellor of Commerce;
Herr Schuchardt, Counsellor of Commerce;
Rich. Stern, Rhenania-Ossac Mineraloiwerke;
Herr Stotz, Engineer and Gen. Mgr., Stotz Company;
Director Strehlow;
K. W. Wagner, Office of Engineering Research, Administration of Posts and Telegraphs;
Dr. Kienzle, German Standards Committee;

Great Britain:
Sir Richard Glazebrook, K. C. B., Chairman, British National Committee;
Sir Archibald Denny, Bart., Chairman, British Engineering Standards Association;
L. B. Atkinson, Director, Cable Makers' Association;
C. P. Sparks, C. B. E., Vice-Chairman, British National Committee;
S. C. Bartholomew, General Post Office;
E. G. Batt, General Electric Co.;
W. S. Burge, English Electric Co.;
P. Dunsheath, W. T. Henley's Telegraph Works;
A. R. Everest, British Thomson-Houston Co.;
P. Good, Secretary of the British Delegation;
W. Lee, Silvertown Lubricants, Ltd.;
S. W. Melsom, Callender's Cable & Construction Co.;
A. C. Michie, Consulting Chemist;
R. B. Mitchell, Municipal Electrical Engineer, Glasgow;
A. P. Mossay, Messrs. Mossay & Company;
J. S. Peck, Metropolitan Vickers Electrical Co.;
C. Rodgers, O. B. E., Secretary, British Electrical & Allied Manufacturers' Association;
T. Roles, Municipal Electrical Engineer, Bradford;
P. F. Rowell, Secretary, Institution of Electrical Engineers;
F. Wallis, English Electric Co.;
K. Edgcumbe, Everitt Edgcumbe & Co.;
W. S. Marshall, Shell-Mex., Ltd.;

Holland:
C. Feldmann, President, Dutch Electrotechnical Committee and Professor at the Technical University, Delft;
W. H. Tromp, Secretary, Dutch Electrotechnical Committee;
C. Pot, Director of the Electrotechnical Works, formerly W. Smit & Co., Slikkerveer;
T. Rosskopf, Director of Transformer Works, Nijmegen;
C. Van der Bilt, Professor at the Technical University, Delft;
G. J. Van de Well, Extraordinary member of Patent Service;

Italy:
G. Semenza, President, I. E. C.;
L. Lombardi, President, Italian Electrotechnical Committee and Professor at Technical Engineering College—Rome;
G. Bianchi, Italian State Railways;
Carlo Clerici, Soc. Edison per la Fabbricazione delle lampade Ing. Clerici;
Piero Ferrerio, Società Générales Italiana Edison di Electricci;
Oreste Jacobini, Italian State Railways;
G. Minucciani, Italian State Railways;
E. Morelli, Professor of Electric Machinery Construction at the School of Engineering, Turin;
Ing. Luciano Pello;
Natale Ratti, Riva Company of Milan;
E. Theseider-Dupre, Italian State Railways;
Ingr. R. Vallauri, Professor of Electric Traction at the Milan Technical School;
E. Virgilli, Italian State Railways;

Norway:
E. Heiberg, Director, Norwegian Industrial Standardisation Bureau;

Poland:
C. Daewnowski, Secretary, Polish Electrotechnical Committee;
Mr. Roginski, Secretary, Polish Standards Committee;

Russia:
M. Chatelain, Chairman, Russian Electrotechnical Council, Vice-President, Russian Standards Committee;
Mr. Lapiroff-Scoblo, Russian Standards Committee;
Mr. Papernoff, Secretary, Russian Standards Committee;
Mr. Zischievsky, Russian Standards Committee;

Sweden:
S. Norberg, Vice-President Swedish Electrotechnical Committee and Swedish General Electric Co.;
A. F. Enstrom, President, Swedish Standards Committee;
Mr. Ericson, Secretary, Swedish Electrotechnical Committee;
Amos Kruse, Secretary, Swedish Standards Committee;
Mr. Nordstrom, Swedish Standards Committee;
H. Nystrom, Secretary, Electric Manufacturers Association;
Mr. Osterberg, Asst. Secretary, Swedish Standards Committee;
G. Thielers, Swedish General Electric Co.;

Switzerland:
E. Huber-Stockar, President, Swiss Electrotechnical Committee;
A. Huber-Ruf, Engineer, Brown Boverie Co.;
Charles Burlet, Electrical Engineer, Swiss Federal Railways;
C. Hoenig, Chairman, Swiss Standards Committee;
Hans Max Schindler, Ateliers de Construction, Oerlikon;
Antoine Schrafl, Swiss Federal Railways, (Construction and Working); Paul Thut, Bernese Power Works;

Spain:
Vicente L. Ramirez, Vice Consul in New York;

United States of America:
C. A. Bates, Electrical Engineer, Bryant Electric Company;
W. F. Durand, Professor of Mechanical Engineering, Stanford University;
A. E. Kennelly, Professor of Electrical Engineering, Harvard University;
F. R. Low, Editor, *Power*;
C. O. Mailloux, Consulting Engineer;
J. Franklin Meyer, Physicist, Bureau of Standards;
A. H. Moore, Electrical Engineer, General Electric Company;
R. W. Owens, Design Engineer, Westinghouse Electric & Mfg. Co.;
F. D. Newbury, Manager, Power Engineering Department, Westinghouse Electric & Mfg. Co.;
D. W. Roper, Supt. of Street Department, Commonwealth Edison Company;
C. E. Skinner, Assistant Director of Engineering, Research Department, Westinghouse Electric & Mfg. Co.;
E. A. Snyder, Chemist, General Electric Company;
N. W. Storer, General Engineer, Westinghouse Electric & Mfg. Co.;

Following the adjournment of the plenary session the delegates left on the official tour, to cover a period of twelve days, April 23 to May 5 inclusive. Transportation for the entire trip was furnished to all accredited foreign representatives and many sight-seeing trips, luncheons and dinners were arranged by local committees in the various cities. The cities visited were: Philadelphia, Washington, Pittsburgh, Chicago, Detroit, Niagara Falls, Ottawa, Montreal, Boston, and Schenectady.

Plenary and Technical Meetings

The technical work of the Commission is placed in the hands of advisory committees, of which there are now ten studying the following subjects:

- Nomenclature
- Rating of electrical machinery
- Symbols
- Prime movers, hydraulic and steam
- Resistance of aluminum
- Lamp caps and holders
- Voltages for distribution systems and test voltages for apparatus
- Traction motors
- Insulating oils
- Rules and regulations for transmission lines

Experience has shown the necessity for making it a rule that no decision of an advisory committee shall be submitted to the Plenary Meeting for ratification until the national committees have had an opportunity of instructing their delegates on the subject. Whilst this leads to an apparent delay, it can be asserted that in the long run it is really the quickest way, as it reduces to a minimum changes in the decisions reached.

At the New York meetings, a number of matters were ready for final decision, as the following reports will show:

Nomenclature. This committee is engaged on one of the most difficult, yet perhaps the most valuable of the tasks undertaken by the Commission. The value to the world of a unified technical language is not easily measured, and the production by the I. E. C. of an electrical vocabulary will provide that unity and stability to the language of the engineer, which is so essential to a clear understanding of the written word among all the nations.

The advisory committee consists of representatives from ten countries, but it has found it necessary to delegate the preliminary work to a subcommittee consisting of: Dr. C. O. Mailloux (U. S. A.), Professor Lombardi (Italy), Mr. Van der Well (Holland), Professor Janet (France), Mr. Wharton (England), Dr. Strecker (representing the Teutonic languages), and Professor Chatelain (representing the Slavonic languages). This subcommittee will submit to the different national committees a list of terms and will ask each of the national committees to study the definitions of these terms in the national vocabularies which have already been submitted, and to inform the subcommittee which definition they consider most suitable for adoption. With these replies before them, the subcommittee will submit to the full committee a recommendation in regard to the first list of definitions for adoption by the I. E. C. The British vocabulary has been accepted as the model for the arrangement and classification of the subject matter.

Note: Five countries have already sent in their national vocabularies in either English or French.

Rating of Electrical Machinery. This committee reached definite decisions in regard to the temperature rises of large machines, including steam turbine-driven alternators and alternators not steam turbine driven if of similar high speed construction. The following table shows the decisions:

TEMPERATURE RISES OF LARGE MACHINES
(INCLUDING TURBO-TYPE MACHINES)

TABLE I
LIMITS OF TEMPERATURE RISE OF ROTORS MEASURED BY RESISTANCE METHOD

	Class "A" Insulation	Class "B" Insulation
Rotors of steam driven alternators, and all other alternating current machines of similar high speed construction............	....	90 deg. cent.
Rotors of salient pole machines above 750 kv-a. and of which the stator cores exceed 50 cm. in 1 length axially................	60 deg. cent.	80 deg. cent.

TABLE II
LIMITS OF TEMPERATURE RISE OF STATORS MEASURED BY EMBEDDED TEMPERATURE DETECTOR METHOD

	Two, or more, coils per slot		One coil per slot	
	Class A	Class B	Class A	Class B
Steam driven turbine driven alternators and all other alternating current machines of similar high speed construction having an output of 5000 kv-a. or more.........	60	80	Detector, outside coil insulation 55*	70*
			Detector, inside coil insulation 65	85
All salient pole machines having either an output of 5000 kv-a. or more, or core length of one met. or more........................	60	80	Detector, outside coil insulation 55*	70*
			Detector, inside coil insulation 65	85

*For machine windings up to 7000 volts. For machine windings of more than 7000 volts the limiting temperature rise is reduced below the figures specified in the table one and a half degree centrigrade.

Decisions were reached in regard to the methods to be employed for temperature measurements when made by embedded temperature detectors.

The classification of insulating materials into Classes *O*, *A*, *B* and *C*, was definitely confirmed. The classifications agreed upon are practically identical with those which have prevailed for some time in this country, and therefore are not reproduced here.

It was decided to recommend to the national committees the following high-voltage tests on electrical machines:

HIGH-VOLTAGE TESTS

Rotating machines....	Test voltage (one minute)
10,000 kv-a. and up E up to 2000 volts....	$1000\ v + 2\ E$
E over 2000 volts to 6000 volts..........	$2.5\ E$
E over 6000 volts.....	$3000\ v + 2\ E$

I. E. C. Publication 34, Volume I. This I. E. C. publication contains the rules for machines up to 750 kw. size, and it has been decided to extend the scope of these rules and include the decisions reached in regard to large machines so as to make it applicable to all machines other than those for traction purposes.

Spark Gap Dimensions. The British Committee made a proposal that the I. E. C. should establish an international series of spark gap dimensions, and after some discussion, the American spark gap dimensions, which had come into almost universal use, were recommended for adoption.

Experts' Papers. Following the practise started at the Hague, President Semenza invited papers from different countries on subjects named by him, and the following papers were read:

Subject—In each country, what is the importance of the demand for an overload and what are the main reasons for such a demand?

Mr. F. Dupont, Belgium,
Mr. C. F. Hirshfeld, U. S. A.,
Mr. A. Huber-Ruf and Dr. Behn-Eschenburg, Switzerland,
Mr. C. Rodgers, O. B. E., Great Britain,
Mr. R. Liljeblad, Sweden,
Dr. M. Kloss, Germany.

Subject—The Ambient Temperature as a testing temperature of reference and as a climatic entity.
Mr. Roger T. Smith, Great Britain.

Subject—The true meaning of Ambient Temperature, limits of temperature and temperature rise.
Professor E. Morelli, Italy.

Subject—Is it possible to formulate general laws of equivalence between electrical machines having ratings with different temperature rises?
Mr. A. Huber-Ruf and Dr. Behn-Eschenburg, Switzerland.

Subject—Can the thermal capacity of electric machines be made a simple and practical element of Rating?
Dr. A. E. Kennelly, United States.

A general discussion on these papers took place, and at the conclusion, Professor Feldmann, Chairman of the Rating Committee, in his summary of the discussion made the following observations:

1. That there is no general demand for the inclusion of a sustained overload in the I. E. C. rating.
2. If conditions of service or industry make a second rating desirable, the I. E. C. rating should be stated on the nameplate.

Advisory Committee on Terminal Markings. This committee received a report of the small committee which had met in Paris, and invited the members of this committee, with one or two additions, to continue their study at this meeting. This committee is preparing a statement of the position in regard to terminal markings in the different countries for reference to the national committees.

Marking of Battery Terminals. It was found that with the exception of Czechoslovakia, all countries used red for the positive terminal, and blue for the negative terminal of batteries, and Professor List, representing the Czechoslovakian Committee, stated that he was authorized to say that if a decision was reached to adopt that coloring, his country would alter theirs to conform, although this meant reversing the colors now in use in that country. It was therefore unanimously agreed to recommend the adoption of red for the positive terminal and blue for the negative terminal.

There was some discussion as to whether this decision should not be qualified by recommending that brown be used in cases where red is being used as a danger signal, but it was definitely agreed that no confusion was likely to arise, and this proposal was not accepted.

VOLTAGES AT CONSUMERS' TERMINALS

Direct current	Alternating current	
	Single phase	3-Phase
		Between phase and neutral
1 x 110	1 x 110	110
2 x 110	2 x 110	127
4 x 110	1 x 220	220
1 x 220		
2 x 220		
1 x 440		
1 x 115	1 x 115	115
2 x 115	2 x 115	133
4 x 115	1 x 230	230
1 x 230		
2 x 230		
1 x 460		

One or other of these two series only being used in any country.
Note—In three-phase systems the resulting pressures between the phases corresponding to the standard pressures between phase and neutral given in the above table (column 3) may be considered as standard.

ALTERNATING CURRENT—3-PHASE

Nominal (Mean Value at consumers' terminals)	Maximum Voltages
1,000	1,100
3,000	3,300
6,000	6,600
10,000	11,000
15,000	16,500
20,000	22,000
30,000	33,000
45,000	50,000
60,000	66,000
80,000	88,000
100,000	110,000
150,000	165,000
200,000	220,000
300,000	330,000

Advisory Committee on Symbols. This committee successfully completed the work of preparing a comprehensive list of graphical symbols for heavy current engineering. The importance of the establishment of what is, in effect, a universal language for electrical diagrams hardly needs emphasis. This committee was, in addition, able to submit for definite adoption a list of graphical symbols for electric traction.

Symbol for Ohm. It was definitely decided to adopt Ω as the symbol for ohm.

Advisory Committee on Prime Movers. More sessions of the Advisory Committee on Prime Movers were held at the New York meeting of the International Electrotechnical Commission than at any of the previous meetings. At these sessions the committee discussed the important elements of test codes for water turbines and steam turbines. The five regular sessions were held on April 14, 15, 16, 19 and 20th and between these sessions two large sub-committees developed detailed reports on each of the test codes.

At the first session President Semenza introduced Dr. William F. Durand of Stanford University, California, and Past President of the American Society of Mechanical Engineers, as the Chairman of the Advisory Committee on Prime Movers for the New York meeting. The roll call of official delegates showed that the following countries had sent representatives: Canada, Czechoslovakia, France, Great Britain, Italy, Norway, Sweden, Switzerland, United States of America. Germany is a member of this Advisory Committee but was unable to send a delegate on this subject to the New York meeting. The United States was represented by Dr. Fred R. Low for Steam Turbines and Mr. H. Birchard Taylor for Water Turbines.

At the opening sessions devoted to Water and Steam Turbines, respectively, the Advisory Committee discussed more or less in detail the various proposals of the several national committees which had been presented at the Hague meeting or had been distributed by mail prior to the New York meeting. Topics of the proposals concerning which differences of opinion developed were referred to sub-committees for further study. The two sub-committees submitted full reports at the Tuesday evening meeting, April 20th, and abstracts of these reports were presented to the Plenary Meeting on the following day.

The report on Water Turbines presents thirteen different porposals which cover important decisions in matters of definition, tolerance or margins in guarantees, speed regulation, pressure variations, methods of test and measurement.

The report on the testing of Steam Turbines covers rating, speed regulation, information to be furnished with an enquiry or

order, interval between installation and test, tolerances or margins in guarantees, weighted average steam consumption and methods of making corrections to test data.

Advisory Committee on Lamp Caps and Lamp Holders. Agreement was reached in regard to the dimensions of Bayonet lamp caps and holders. The differences which have hitherto prevailed between the dimensions used in the two or three countries using this type of holder have been successfully eliminated. Agreement has not yet been reached in regard to the screw cap and holder, there being a difference in the depth of the thread between the continental and American standards, and a compromise, which will not put out of action the very large number of lamp holders in use all over the world, is being sought.

Advisory Committee on Voltages. The Plenary Meeting accepted the recommendation of this Advisory Committee that the following voltages should be used for new systems:

Definition of Nominal Pressure. The nominal high voltage shall be the mean voltage at the consumers' terminals and shall be called nominal I. E. C. Voltage of the network of that pressure range.

The maximum voltage at the generators and secondary terminals of transformers shall be considered to be about 10 per cent higher than the mean voltages at the consumers' terminals.

The maximum and minimum values of the voltages according to paragraph 1, and the variations occurring under working conditions will be considered at a later meeting.

Preferred Nominal High Voltages. The high voltages which are underlined in Tables I and II are recommended as the preferred high voltages.

This committee is now endeavoring to set up a series of voltage ranges for insulators for overhead line construction and switch gear.

Advisory Committee on Traction Motors. This committee recommended to the Plenary Meeting the adoption of a specification for traction motors, subject to the French Committee agreeing to one or two of the points which their delegate was unable to accept without reference back.

The following are the principal points:

Scope: The specification relates to all types of Traction Motors.

Classes of Rating: Two classes of rating are recognized:

(a) The I. E. C. continuous rating

(b) The I. E. C. one-hour rating

Overload Test: Sixty seconds with current equal to twice the one-hour rated current at rated voltage without mechanical injury or flashover or damage to commutation.

TEMPERATURE RISES

Continuous rating	Armature & Field Windings	Class A material	Resistance	85
			Thermometer	65
		Class B material	Resistance	105
			Thermometer	75
	Commutator & Collector	Class A and B	Thermometer	85
One hour rating	Armature & Field Windings	Class A material	Resistance	100
			Thermometer	75
		Class B material	Resistance	120
			Thermometer	97
	Commutator & collector	Class A and B	Thermometer	90

Service Conditions: The rating is based on the assumption that the air temperature will not exceed 25 deg. cent.

Advisory Committee on Insulating Oils. This committee in the course of its discussions made considerable progress and has recommended to the national committees the following recommendations:

(a) That the viscosity of transformer oil be expressed as kinematic viscosity using as a unit the kinematic centi-poise.

(b) That during the next year the viscosity of transformer oil shall be determined at 20 deg. cent. and 40 deg. cent. to the end that at a future meeting of the Advisory Committee a decision can be reached to adopt a single temperature.

(c) That in order to arrive at a practical short-time acceptance test, the research test has to be established first. After all practical and recognized forms of research test have been considered, then the question of the acceptance test to be adopted could be decided. At present only the research test is to be studied and the National Committees should retain their present acceptance tests.

(d) That in order to obtain data to furnish the basis of discussion at the next meeting of the Commission, the following four characteristic tests on transformer oil shall be made: Swedish, Swiss, German, U. S. A.

These tests to be carried out at the following two temperatures:

(a) At the standard temperature as prescribed by the National rules.

(b) At a temperature of 110 deg. cent.

Advisory Committee on Rules and Regulations for Overhead Transmission Lines. This committee has reviewed the rules and regulations for overhead transmission lines in the different countries and it has expressed the wish that those responsible for overhead line construction in the various countries should get into touch with the I. E. C. through their national committee, so that in future they can formulate their rules on the model already laid down. It has been decided that an attempt shall be made to keep the comparison of the rules of the different countries, which was prepared by the Belgian Committee, up to date and furnish each national committee with a copy of this every year.

The Belgian Committee has been nominated to act as Secretary for this work.

A. I. E. E. Annual Business Meeting New York, May 21, 1926

The annual business meeting of the A. I. E. E. will be held on Friday, May 21, at 8:15 P. M. (daylight saving time) in the Engineering Societies Building, 33 West 39th Street, New York City. At this meeting the reports of the Committee of Tellers on the annual election of Institute officers will be presented, as well as the report of the Board of Directors for the year ending April 30, 1926.

In connection with this meeting an interesting program will be offered by the New York Section. More complete information on this meeting will be mailed to the Section membership in advance of the meeting.

Carnegie Institute Special Summer Session

As a result of the demand that has been developing during the past few years, it is announced that this year courses in electricity are receiving special attention in the plans for the Summer Session at the Carnegie Institute of Technology in Pittsburgh. According to plans, the College of Industries will give six weeks' courses, from June 28 to August 6, in elementary electric wiring, advanced electric wiring, elementary principles of electricity, advanced electricity, and elementary principles of radio communication. It is reported that the radio course has been an outstanding success in the summer school work during the past three years.

In addition the College of Industries will give a course in Engineering Drawing and other arts.

Future Section Meetings

Baltimore

Inductive Interference, by H. S. Phelps. Engineers' Club. May 21, 8:15 P. M.

Cincinnati

Joint Meeting with Cincinnati Engineers' Club. Talk by Dean Schneider, University of Cincinnati. May 20.

Connecticut

Annual Meeting. New Haven. May 19.

St. Louis

Automatic Telephoning in St. Louis. May 19.
Annual Meeting. June 16.

Detroit-Ann Arbor

Standard Distribution Systems, by B. L. Huff, Commonwealth Power Corporation, and
A-C. Low-Voltage Networks, by H. P. Seelye, The Detroit Edison Co. May 18.

World Power Conference

According to announcement recently made by the State Department, the World Power Conference will be held at Basle, Switzerland, August 31st to September 12th, 1926; Mr. O. C. Merrill, Executive Secretary of the Federal Power Commission and member of the American Institute of Electrical Engineers has been appointed by President Coolidge as the United States delegate to this convention, the nomination having been made in response to an invitation received from the Swiss National Committee of the World Power Conference when the first world Power Commission met in London, 1924. This Commission was organized for the purpose of obtaining information and data concerning industrial and economic sources of power, both national and international. The meeting this year will be held simultaneously with the International Exhibition for Inland Navigation and is a special session called to discuss certain economic and financial features in the production of power.

Increase in Salaries of Federal Judges

The new Graham Bill in support of the increase of salaries for Federal Judges has been approved. It is believed that this will have a strong influence for good in maintaining the caliber of the courts, and their proceedings.

Museum of Peaceful Arts

A commission has been appointed to investigate the technique of museum development abroad in conjunction with the establishing here of a Museum of Peaceful Arts. These delegates will report back on their respective commissions; Mr. John W. Lieb has been appointed to report on light, fuel and power; Doctor Samuel W. Stratton, president of the Massachusetts Institute of Technology, on ship models, navigation and aeroplanes; Doctor H. Foster Bain, formerly Director of the United States Bureau of Mines and now Secretary to the American Institute of Mining Engineers, will attend the International Geological Congress to be held in Madrid in May, Doctor Louis Livingston Seaman will study medicine and hygiene and Doctor Ambrose Swasey, manufacturer and inventor, will report upon optics and physics. Elmer Ambrose Sperry, inventor and electrical engineer, sailed for Europe early in April, to study gyro-compass, aeroplane and ship stabilizers, high-power search lights and other devices in line with his special interests. Mr. Calvin W. Rice, Secretary of the American Society of Mechanical Engineers, and honorary secretary of the Museum, also sailed on April 10th. Other interests will be investigated and developed.

AMERICAN ENGINEERING COUNCIL

REPORTS ON COUNCIL WORK

At the recent meeting of the A. E. C. Administrative Board, Louisville, Ky., April 2nd, important matters upon which the Council has been working were reported as having shown encouraging progress. Progress Reports of the Department of Public Works and from the Committee on Street and Highway Safety were received. Of the seven continuing committees established by the Second National Street and Highway Conference, it was determined by the committee in charge that engineering representation should be had on at least five.

John Fritz Medal Presented to Edward Dean Adams

Edward Dean Adams was presented with the John Fritz Gold Medal on March 30 in the Engineering Societies Building, New York. Mr. Adams was chosen the medalist for the year 1926 for great achievement as an "engineer, financier, scientist, whose vision, courage and industry made possible at Niagara Falls the birth of hydroelectric power." The John Fritz Medal is awarded annually by representatives of the A. I. E. E., the A. S. M. E., the A. I. M. E. and the A. S. C. E. for notable scientific or industrial achievements. It was established in 1902 to perpetuate the memory of the achievements of John Fritz in industrial progress.

Dr. F. B. Jewett, Chairman of the Board of Award presided at the presentation and addresses were made by Hon. J. M. Beck, formerly Solicitor-General of the United States and Dr. A. E. Kennelly of Massachusetts Institute of Technology. Major F. J. Miller Chairman of the Board during 1925 presented the medal and Mr. Adams responded with a speech of acceptance.

Hon. J. M. Beck in commenting on the accomplishments of the medalist said in part:

It is a curious fact that our nation, so wonderfully rich in achievement, has been singularly slow and niggardly in the recognition of worth, outside the narrow sphere of political life, and very limited in that respect. This may arise from two divergent theories that have always marked the life of America: the one, the theory of the pioneers, the ideal of inequality, and the other, the political theory of America, the ideal of equality. The two ideals are not consistent, although each has persisted in the minds of America and each has sensibly influenced the other.

As to the theory of inequality, by which I mean the theory that in the inevitable competion of life, "the race is to the swift and the battle to the strong," and that the true glory of man is in superiority rather than in equality—this theory has been the driving force of the American people.

But over and against this dynamic purpose of the American people—each man to do the best for his own life and to rise above his fellows if he can—is the political philosophy that all men are created equal. Nowhere in the Constitution is any power given to the Federal Government to recognize achievement, with one exception, and that a very restricted one, found in our patent system.

With few exceptions, such as the Congressional Medal of Honor for distinguished service in the Army, our Government has from the beginning steadily discountenanced any official recognition of public service.

Because of this lack of fitting recognition of genius and ability by the State, the Engineering Societies are to be the more congratulated for having thus supplied the deficiency in their own field. I wish that every department of activity had a "John Fritz" medal that would mark great achievement in some line of work. There are certainly great advantages in the fact that a medal like the John Fritz Medal should come from those who are experts in the particular field of human activity in which the achievement has been made. And yet I venture to express the hope that some day our nation will create a great national commission which would once a year award a medal to some citizen who, either in that year or in his lifetime, had rendered some exceptional service to the State.

There is one other thought to which I want to give very inadequate expression, and that is the respect in which the award of this medal to Mr. Adams particularly appeals to me. Mr. Adams is of that class of men—a very rare class—who, by example and precept, go far to solve what is the great enigma of our time, the reconciliation of the ever-increasing growth of dynamic power with the growth of the spiritual power in human life. In other words, if there be one enigma which thoughtful men of all nations

are now considering more deeply than at any previous time in history, it is whether the high potential of dynamic power either raises or lowers the high potential of man's spiritual nature. In other words, whether the excessive mechanization of human life is not leading to certain evils that may well give concern to all who try, timidly at best, to scan the future.

It would be easy to demonstrate the enormous part that mechanical invention had played in the progress of mankind. But on the other hand, there are many wise and thoughtful men who perceive that an excessive mechanization of human society is bound to have baleful and portentous effects upon the human spirit. It is the greatest problem with which, in my judgment, humanity has to deal.

If there be any solution of this question, it lies, it seems to me, in a class of men, true leaders in human life, being developed, who are men of telescopic, rather than of microscopic brain.

With the mechanization of human society, human society becomes complex; and as it becomes complex, there is an unavoidable tendency to specialize; and as men become more specialized, of necessity there is a certain disintegration and a lack of solidarity of the social forces of human life. One remedy for that is to develop a class of leadership in the community of men of telescopic brains, who are not merely the devotees of any one branch of human activity, but whose minds are broad and have a natural taste and interest for everything that pertains to mankind.

That is the characteristic of Edward Dean Adams.

It is not only on the personal side of his character that I would prefer to dwell, but it is in respect to his versatility that I think this John Fritz Medal is so well and wisely bestowed. Indeed, all mankind has been his interest. In any department of activity, be it philanthropy, art, literature, music, engineering, industry or finance, wherever he has seen an opportunity for service, he has undertaken to render that service.

I do not know how I can better end these scattering and inadequate observations, or end my individual tribute to Mr. Adams than by quoting the words of no less a man than George Washington, applied to the first electrician of America and the first inventor of his age—Benjamin Franklin.

And so, interpreting the sentiments of all Mr. Adams' friends I venture to say, in the words of Washington: "If to be venerated for benevolence; if to be admired for talents; if to be esteemed for patriotism; if to be beloved for philanthropy can gratify the human mind, you must have the pleasant consolation to know that you have not lived in vain."

Dr. A. E. Kennelly in paying further tribute to Mr. Adams spoke in part as follows:

Looking back from 1926 to the year 1890, it seems now so easy to imagine how a power-transmission plant might then have been brought into existence, in view of the developments which have occurred since that period; but at that date, it was a matter of extraordinary difficulty. Competent scientists and engineers were at variance in their opinions, as to how power might be developed and transmitted from the Falls.

It is therefore all the more wonderful that, in the history we are considering this evening, the initial steps were taken upon a scale that was then gigantic. The Niagara plant is a monument to our medalist, in that the vast scheme he gradually developed, commencing in 1890, has known no retrogression or change of plan, upon any appreciable scale. The great hydro-electric transmission system, as he first visualized it, has come steadily into existence, step by step. It required great foresight, courage, patience and tenacity of purpose, to take the responsibility that rested on his shoulders, as the leader of a band of financiers, organisers and engineers, to initiate that great undertaking.

It may be claimed that Mr. Adams has transported part of the cataract from Niagara to a myriad homes and factories.

He has carried there the power of those falls and the gleam of their light. There is not a fan motor spinning in any of those homes, but follows imitatively and obediently from afar, the whirl of the great Niagara turbine wheels. There is not a light that shines electrically within those homes, but may be regarded as borrowing its gleam from the laughing waters of the intake canals, as they take their plunge over the wheel pits. Even the laughter-loving children who lay their weary little heads upon their pillows at night, take one more glance at the incandescent lamp, just before some loving hand turns it off, to catch, if possible, one more gleam from the cataract, to carry with them into dreamland.

Not only has the power of this nation and of the whole world been advanced in a material sense by this marvelous deed; not only has American life been made richer, more beautiful, more wonderful by this achievement; but we ourselves have received a certain apotheosis by this conquest of the Falls.

So long as human records persist, and so long as the human race is able to read them, Niagara will retain its place as one of the great glories of the world and inseparably associated with it will be the conquest of the Falls, by the harnessing of their waters. When the bridle was thrown over them, the reins lay in Mr. Adams' hands.

We are privileged to see the culmination of that great work recognized by this ceremony here tonight. All honor to the man and to the deed.

In his response in accepting the medal Mr. Adams told something of the history of the Niagara development. Among other things he said:

A consideration of the nebulous state of the art of hydro-electric development and electrical transmission of power at that time is necessary to a proper understanding and appreciation of the work begun at Niagara Falls in 1890-1891. Contemplation of the original project reveals also the remarkable foresight of the founders and of the International Niagara Commission formed for the purpose of reporting on the project. At that time multi-phase work was virtually unknown in this country and the only alternating current apparatus consisted of small single-phase belted machines never run in parallel and seldom driving motors. The size of the hydraulic and electric units adopted at Niagara Falls was far greater than anything ever attempted. The style was absolutely new.

The history of the enterprise is contemporaneous with that of the electrical industry. The Niagara River Hydraulic Tunnel, Power and Sewer Company was organized in 1886 to promote the development of Niagara River under the plans of Thomas Evershed. Its present name, The Niagara Falls Power Company, was adopted in 1889 at which time contracts were made with The Cataract Construction Company for all work contemplated including hydraulic, mechanical and electrical design as well as the management and operation of the completed project.

Although the financial set-up of the original Niagara Falls Power Company and the personnel of its directorate have been greatly overshadowed by the engineering achievement, this part of the company's activities is none the less historic. It marked the liberation of American industry from European financial dominance. Heretofore all projects of any magnitude in the United States were financed in Europe and the hydro-electric development at Niagara Falls was perhaps the first great enterprise in this country built with American capital.

And yet, while The Niagara Falls Power Company sought no funds in Europe, it did seek there engineering aid and advice, for the reputation of the Swiss, Italians and French in hydraulics was well established, and England excelled in mechanics.

It was evident that the services of only the most experienced should be enlisted for guidance in such an enterprise and that commitment to the project should await consultation with those specializing in the general branches of the science involved.

Investigations in Europe led to the formation of a group of international scientists who undertook the joint consideration of engineering projects under the title of The International Commission, with headquarters in London. The records of that Commission form an important chapter in the history of the several sciences and particularly that of electricity inasmuch as the formation of that commission marked probably the first of the notable international conferences of scientists for industrial purposes. Lord Kelvin, then Sir William Thomson, presided as Chairman.

The decisions to abandon the old method of water-power development by a mill over a wheelpit and to adopt a central station for the development of water power and its distribution by compressed air, electricity or water under pressure were announced December 14, 1891. The official decision to adopt the alternating current was announced May 6, 1893, and the first contract for electrical generators was executed in October, 1893, for three alternators of 5000 horse power each.

The decision to adopt electricity, and particularly alternating current electricity, was not accepted without protest.

The controversy between the proponents of direct current and alternating current raged furiously in the early '90s. Thomas A. Edison, the electrical wizard, was the staunch and uncompromising advocate of direct current in the United States, and in Europe, Sir William Thomson, afterwards Lord Kelvin, the most famous physicist of his day, also espoused the cause of direct current. Westinghouse and Stanley in this country, and Ferranti, Brown, Mascart and Turrettini and others in Europe, championed alternating current.

However, it is obvious that the electric light and power industry would scarcely have made the remarkable advances it has were it not for the adoption of the alternating current in the initiation and propagation of which The Niagara Falls Power Company has borne a prominent and historic part.

Thus the influence of Niagara has spread broadcast over the earth, as though it were foredestined to inaugurate new impulses towards the development of world progress through the peaceful arts. Niagara has stimulated and focussed attention on water-power development, on electric transmission and on the utilization of electricity in the electro-chemical, electro-metallurgical and kindred arts. It is symbolic of engineering courage, daring and achievement, and prophetic of the fact that man is continually adapting and applying the natural resources and his genius toward the advancement and glory of civilization.

Prior to the presentation exercises a dinner was given to Mr. Adams in the Engineers' Club at which short addresses were made by W. H. Onken, Jr., editor of the *Electrical World*; L. B. Stillwell, chairman of the Engineering Foundation, and Prof. C. F. Scott of Yale University.

A large number of messages of congratulation were received from well known scientists, engineers, financiers, public officials and others.

Research Graduate Fellowships at University of Wisconsin

COLLEGE OF MECHANICS AND ENGINEERING

For the purpose of promoting engineering research and the development of qualified research men, the University of Wisconsin has established three research fellowships in the College of Engineering. These fellowships are granted under the following conditions:

Each fellow will be appointed for a period of two years, subject to satisfactory service. The salary will be $900.00 for the first year and $1100.00 for the second year. The fellow will be required to devote not less than half his time to assigned research work in the College of Engineering, but will, in any case, be given opportunity to complete his work for the M. S. degree within the two-year period. Candidates must be graduates of engineering colleges of recognized standing, and preferably should have had one or two years' graduate study or teaching or engineering experience. The period of service required will be the usual academic year, including the short vacations. The College of Engineering possesses well-equipped laboratories in which a considerable amount of research work is always under way. Results are published, from time to time, in bulletins of the Engineering Experiment Station. A total of sixty-three bulletins have been published up to the present time.

Applications for these fellowships for the year 1926-27 are now invited. For further information and application blanks, address F. E. Turneaure, Dean, College of Mechanics and Engineering, Madison, Wisconsin.

First Part of New Electrical Safety Code Now Ready

Rules for the installation and maintenance of electrical equipment in generating stations and substations are given in a new publication of the Bureau of Standards of the Commerce Department. These rules cover the general protective features of the station, as well as specific sections dealing with grounding, rotating equipment, storage batteries, transformers, conductors, fuses, switches, switchboards, and lightning arresters.

The first part of the code is known as Handbook 6 of the Bureau of Standards. Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

Special Exhibit of the American Electric Railway Association

During the period of October 4th to 8th inclusive, the American Electric Railway Association will hold its 45th Annual Convention at Cleveland, Ohio, with a special Manufacturers' Exhibit, to which both floors of the large Cleveland Public Auditorium will be given over. October 6th has been set aside as a day devoted entirely to demonstration of the exhibit and no technical sessions of any kind will divert attention from it on that day,—a day of inspection only.

Muscle Shoals Bids

The Special Joint Congressional Committee appointed to negotiate a lease of the Government Muscle Shoals property has received seven bids for leasing the entire project and two bids for leasing Plant No. 1.

These bids were opened April 10th by Representative James, of Michigan, Acting Chairman of the Committee, and momentary announcement is expected as to recommendations for the acceptable bid.

New York Section Holds Student Convention

On Friday, April 23rd, the New York Section held its first Student Convention. The convention was held in conjunction with a regular monthly Section meeting. All the details of the part taken by the students representing the eight colleges in the New York District were worked entirely by a Student Convention Committee, the New York Section officers and faculty representatives acting merely in an advisory capacity.

The convention proved a great success as instanced by the number and enthusiasm of the students participating and the quality of the student papers and discussion. Friday morning was devoted to inspection trips to the General Electric Lamp Works, the I. R. T. repair shops and the Bell Telephone Laboratories. The afternoon session held in the Engineering Societies Bldg., was opened at 2.30 by Student Chairman, J. C. Arnell, who promptly called upon Past-President Farley Osgood. Mr. Osgood gave an address devoted largely to advice to student prospective engineers, on the type of education likely to produce best results. Mr. Osgood's talk was very enthusiastically received. Eight students then presented papers as follows: "Recent Developments in the Manufacture of Vacuum Tubes," by D. Y. Smith, Cooper Union; "Field Measurements in Radio," by Mr. Remy, Columbia; "Measurements of High-Frequency Oscillations," by Lloyd Goldsmith, Brooklyn Polytechnic; "Engineering Applications of the Gyroscope," by Lincoln Walsh Stevens; "Automatic Telephony," Mr. Schneerveis, City College; "Cooperative Education from the Student's View Point," E. C. Fischer, Newark College of Engineering; "The New Cooperative System at N. Y. U." Theodore Smith, New York University. These papers were actively discussed. A committee appointed by the New York Section then judged the papers and a prize of $25.00 in gold was awarded Mr. Goldsmith, of Brooklyn Polytechnic, for the best presentation.

Following the afternoon session, the students and Section members, about 200 in all, had supper at the Fraternity Club. The New York Section held a regular meeting at 8.15 p.m. in the Auditorium of the Engineering Bldg. Chairman Kidder, presiding, announced the results of the election of Section officers for 1926-27, as follows: Chairman, E. B. Meyer, Public Service Electric Co. of N. J.; Secretary-Treasurer, O. B. Blackwell, A. T & T. Co.; Executive Committee, J. B. Bassett, General Electric Co.; and C. R. Jones, Westinghouse Elec. & Mfg. Co. A paper on "Refrigeration-Theory, History and Recent Developments" was then presented by A. R. Stevenson, Research Engineer, General Electric Co.

Philadelphia's Sesqui-Centennial

Any Institute member who may visit Philadelphia during the Sesqui-Centennial Year, 1926, will be extended the privileges of the Engineers Club of Philadelphia for a period of ten days, provided he brings a letter of introduction from an officer of the Institute.

Another announcement of interest to Institute members in connection with the Sesqui-Centennial is that a number of meetings will be held in Philadelphia during September by the Congress of American Industry.

ENGINEERING FOUNDATION

ARCH DAM INVESTIGATION

The work of the test investigations on the so-called "Stevenson Creek Test Dam," situated on a tributary of the San Joaquin River, 60 miles east of Fresno, Calif., is progressing. Since the December bulletin, the excavation in the granite for the dam foundation has been completed, the remainder of the instruments and accessories for the test obtained, the installation of the

construction plant finished, the test party camp established in camp and methods and programs for the test determined so far as possible in advance of actually putting them into practise. While the concrete is being placed, many instruments will be inbedded and preliminary observations taken. Other tests on concrete materials, concrete instruments and methods have been progressing. As previously stated, the Committee in charge will welcome any information which may be used in the study and preparation of the report, constructive criticism of its program and methods and general discussion of the design of arch or multiple-arch dams. Such correspondence should be addressed to the secretary, F. A. Noetzli, 928 Central Building, Los Angeles, California.

Westinghouse Annual War Memorial Scholarships

The Educational Department of the Westinghouse Electric and Manufacturing Company has just announced the plans for awarding the 1926 War Memorial Scholarships. These awards are made annually, the successful candidate receiving $500 during each year of his collegiate training, or a maximum of $2000.

Applicants eligible to compete for these Scholarships include sons of employees who have been with the Company five years, or more, and employees who have been continuously in the service for at least two years and who shall not, on September 1, have exceeded the age of 23.

Chandler Gold Medal Award

Award of the Chandler Gold Medal was made by Columbia University to Samuel Wilson Parr, professor of applied chemistry, University of Illinois. Professor Parr delivered his lecture at Havemeyer Hall, Columbia University, Friday evening, April 23d. Friends of the late Professor Charles Frederic Chandler, pioneer in the chemistry of this country and founder of the American Chemical Society, presented to the trustees of Columbia in 1910 a sum of money constituting the Charles Frederick Chandler Foundation; it is the income from this fund which is used to provide a lecture by some eminent chemist and the gold medal to be presented to the lecturer in further recognition of his achievements in science.

PERSONAL MENTION

W. J. Swales, after twelve years of service in Latin America and Cuba and of late Superintendent of the Cia Electrica De A. Y. T. de Santiago de Cuba, has resigned his position to return to his home in Canada, where he will enjoy a well earned vacation of three or four months with relatives and friends.

P. M. Rainey, who joined the Western Electric Company immediately after his graduation from college, has been appointed Telephone Sales Manager of the Graybar Electric Company, successor to the Western Electric Supply Department. This new incorporation took place the first of the present year.

Charles Byron Isaacson, formerly of the All Amenia Cables, Inc., is now associated with the Allied Engineering Company, New York City, as director and officer in charge of commercial development.

William A. Moore has accepted a position with the New York Edison Company, as Engineer of Purchases. For the past eight years Mr. Moore was with Hugh L. Thompson, consulting engineer, Waterbury, Conn. He was also chairman of the A. I. E. E. Connecticut section for the year 1924-25.

William B. Herbst, who was for eighteen years affiliated with the Duquesne Light Company, has resigned to become assistant electrical engineer for The Department of City Transit, Philadelphia, Pa.

H. M. Friend has just returned to the Brooklyn Edison Company after a thirteen months' leave of absence spent with Hugh L. Cooper & Company, consulting engineers on the Muscle Shoals Development. Mr. Friend attended to the inspection of all wire, cable and insulators for the Wilson Dam Power House, supervising and testing the installations.

Harrison D. Panton, who, for the past three years has been the principal of Harrison B. Panton & Company, Raleigh, N. C., has joined the organization of Francis R. Weller, consulting engineer, Washington D. C. Mr. Panton's new work will take him to Ocala, Florida, where he will be chief engineer in charge of all Florida-Georgia operations of the Weller organization.

E. O. Shreve, manager of the San Francisco office of the General Electric Company since 1918, has been named manager of the industrial department of the company with headquarters at Schenectady, filling the vacancy caused by the recent death of A. R. Bush.

J. W. Alvord to Receive Washington Award

John Watson Alvord, consulting engineer, has been selected to receive the Washington Award for 1926. The award will be presented at the Annual Meeting of the Western Society of Engineers on June 2.

The award is made annually by a committee of representatives from the Western Society of Engineers and the A. S. C. E., the A. I. M. E., the A. S. M. E. and the A. I. E. E. It was established in 1917 "to be presented annually to an engineer whose work in some special instance or whose services in general have been noteworthy for their merit in promoting the public good."

Obituary

James Winthrop Thomas, Fellow of the Institute and brother of Percy H. Thomas, died at his home, Plandome, L. I., April 13, 1926, in the 52nd year of his age.

Born at Boston, November 13, 1874, Mr. Thomas attended Exeter Academy, from which he entered the Massachusetts Institute of Technology, graduating in 1895 with a Mechanical Engineering degree. After serving a short apprenticeship with the Boston and Maine Railway Company in their shops at Cambridge, he went with the Wyoming Shovel Works, Wyoming, Pa., where he became assistant superintendent; thence he went to the Westinghouse Church Kerr & Company, for whom he was in charge of important installations including Westinghouse Lamp Works at Watsesing, N. Y. and Westinghouse stoker works at Attica, Nassau Hotel, Long Beach, L. I., N. Y. He then became engineer of the New England Engineering Company for a short period, leaving them to join the United Gas and Electric Company of Connecticut, where for many years he handled a great variety of work for their various properties.

Mr. Thomas was a member of The American Society of Mechanical Engineers, Fellow of the Institute of Electrical Engineers since 1920, a member of the Technology Club of New York and of the Phi Beta Epsilon Fraternity.

Herbert Wallace Cheney, who, for the past twenty years has been connected with the electrical engineering department of the Allis-Chalmers Manufacturing Company, died at his home in Milwaukee March 22d, 1926, after an illness of two months.

Mr. Cheney was born at Coldwater Lake, Michigan, February 7, 1872. Here he received his primary education through the small country school later attending the Valpariso University. After graduating from the university, he returned to Coldwater to teach and later entered the University of Michigan for the purpose of completing his engineering studies.

Following his university course, he was, for a short time, with Frank M. Dunlap, Consulting Engineer, Detroit, Michigan, spending also a few months with Charles A. Strelinger Co., Detroit, Michigan, as designer of machine tools. In January

1893 he entered the employ of the Leland & Falconer Manufacturing Company of Detroit who later became the Cadillac Motor Car Company. Six years later, Mr. Cheney went with the Westinghouse Electric & Mfg. Co., In 1904, when the Allis-Chalmers Company took over the Bullock Electric Manufacturing Company, Mr. Cheney joined the engineering department of the Bullock Plant, Cincinnati, as engineer in the design of detail electrical apparatus. In 1908 the engineering work was consolidated at the West Allis Works and Mr. Cheney moved to Milwaukee his work being particularly in connection with detail apparatus, airbrake equipment, small motor-driven air compressors, motor starters, etc.; he was also in executive charge of the experimental department for them. When Allis-Chalmers were making arrangement with A. Reyrolle & Company for the building of armorclad switchgear in this country, Mr. Cheney was sent to England with other engineers, to investigate the design of this new switchgear. To this work he was devoting his attention at the time of his death. Mr. Cheney was a Fellow of the Institute; he also served the Milwaukee Section as its chairman and on its program and membership committees. He was a member of the American Society of Mechanical Engineers, the Milwaukee Engineers' Society with which organization, during the past year, he was chairman of a committee on Education and Graduate Training. He was of a nature which endeared him to a large circle of friends while his earnest interest in all undertakings caused him to be held in high esteem by his associates.

William F. Meschenmoser, Vice-President of the Russell & Stott Company, New York City, died on March 16th, 1926. Mr. Meschenmoser was born in Brooklyn, December 4th, 1876. His fundamental education in mathematics, physics, chemistry, electrical and mechanical engineering was practically self acquired. He studied train control systems for two years, designing and drafting, one year; design and shop, electrical and mechanical for four years; was machine shop superintendent for five years and machinist and apprentice for four years. From 1894 to 1899, he was superintendent of design and building small special machinery for the Excelsior Co. He then identified himself with the F. W. Mills Company as superintendent of automatic electrical and mechanical machinery. From 1903 to 1904 he was working for himself at general electrical and mechanical machine design and construction supervision, but in 1904 joined the Kinsman Company, with whom he was engineer with general supervision of drawing room and field. For a number of years, Mr. Meschenmoser was active on the Committee of Application to Marine Works, beside rendering valuable service to the Institute and the profession in many other ways.

Charles G. M. Thomas, Associate of the Institute and Vice-President of the Consolidated Gas Company of New York died at his home, Flushing, L. I., March 23, 1926. Mr. Thomas was born July 2, 1866, in New York City and was educated in the city schools and the College of the City of New York. In 1888 he joined the Standard Gas Light Company of the City of New York and remained with them until 1901 in varying capacities, Cashier until 1893 and manager until 1901. He was then made vice-president and general manager of the Newtown & Flushing Gas Company, the New York and Queens Gas Company, the Williamsport (Pa.) Gas Company and the Dallas, (Texas) Gas Company, operating from New York City. In this office he remained until 1907, when he concentrated as vice-president and general manager of the New York & Queens Electric Light and Power Company, of which he was also chairman of the Board of Directors at the time of his death. Mr. Thomas' popularity and success in his undertaking may be emphasized, perhaps, by the fact that over 500 people were present at the services held for him at the Dutch Reform Church, Flushing.

Gordon Oke Philp, who, since 1919, has been superintendent of the Hydro-Electric Power Commission of Ontario, died at Niagara Falls, of blood poisoning contracted several months ago. Mr. Philp his associates felt, was destined for a most brilliant future and the Commission acknowledges the loss of a most capable executive. Born at Port Hope, August 17, 1892, he was educated through the public and high schools there. He decided to become an engineer and as soon as possible entered the University of Toronto, graduating from there with his degree of Bachelor of Applied Science in 1914. Vacation periods were spent with the Midland Construction Company in Central Ontario. After graduation he entered the engineering department of the Electric Power Company and when this company was taken over by the Ontario Government in 1916, he joined the operating staff of the Hydro-Electric Power Company. When the Commission acquired control of the Ontario Power Company, Mr. Philp was chosen as the man to assume the position of general superintendent, work required considerable skill and tact. During the last few years, added responsibility has been given him until, at the time of his death, he was satisfactorily holding the position of general superintendent of all operations and maintenance of the Commission's three properties; Queenston Development Company, the Ontario Power Company and the Toronto Power Company. Mr. Gaby, chief engineer of the Hydro-Electric Power Company, pays Mr. Philp the following tribute: "He has achieved success—who looked for the best there was in others and gave the best he had. Whose life was an inspiration and whose memory is a benediction." Mr. Philp joined the Institute in 1919 as an associate but advance to the grade of Member in 1925.

Willard G. Carlton, Superintendent of Power of the New York Central Lines and Fellow of the Institute, died at his home in Yonkers, New York, April 15th, of pneumonia.

Mr. Carlton was born in Warren, Illinois, February 20th, 1869. He was educated in the grammar and high schools of that town prior to his attending Cornell University, from which he graduated in the class of 1892. For one year immediately after his graduation, he was with the General Electric Company at Lynn, Massachusetts, taking their students' course, which he completed in 1893 and joined the Chicago Edison Company, with whom he remained in varying capacities until 1905. He left them to become Superintendent of Power for the Electric Division of the New York Central and Hudson River Railroad, in charge of distribution of power for the operation of electric trains in and near New York City. Mr. Carlton has been described as "an engineer of unusual originality, resourcefulness and force, with a prominent part to play in shaping the development of engineering." As chief operating engineer for the Chicago Edison and Commonwealth Electric Company, he had charge of all underground and overhead distribution systems and substations as well as all direction of extensions of distribution systems for the company. There is little doubt that Mr. Carlton leaves behind him much of future achievement in the profession as well as a host of friends. He served the Institute as a member of the Board of Directors 1908-11 and as Vice-President during the years 1911-13, beside being extremely active in its Committee work. He was a member of the Engineers Club, the New York Engineering Society, The American Society of Mechanical Engineers, the National District Heating Association, the Cornell Club of New York and the New York Railroad Club, all of whom were cognizant of the profitable and pleasant relationship.

Chester W. Lyman, director and vice-president of the International Paper Company until his resignation about a year ago, died at the Massachusetts General Hospital, April 15th. Mr. Lyman was born in New Haven 64 years ago, the son of Chester Smith Lyman, for many years professor in the Sheffield Scientific School, Yale University. Mr. Lyman attended the Hopkins Grammar School of New Haven and recently helped to raise funds for its reorganization and development. He graduated from Yale in 1882, and after a period of service with the United States Coast Survey, in 1885 identified himself with H. Parsons

& Company, starting his career as a paper manufacturer. In 1890, he joined the Herkimer Paper Company, Herkimer, N. Y., becoming its manager and director. Upon the absorption of this company by the International Paper Company, he continued his interest with them as assistant to the president until he was made vice-president in 1916. In 1895 one year after joining the Institute he was awarded the degree of M. A. for special studies in electrical engineering.

Mr. Lyman has contributed many articles to the trade journals and was an active member of the American Paper and Pulp Association. He also belonged to the American Forestry Association Sons of the American Revolution; and the University, Yale, Piping Rock and Midday Clubs.

Louis Anthyme Herdt. Macdonald Professor of Electrical Engineering, McGill University and vice-president of the Montreal Tramways Commission, died suddenly at his office, McGill Engineering Building, April 11, 1926.

Born at Trouville, France, June 14, 1872, Professor Herdt, while still quite young, came to Canada with his family; his early education was in the Montreal High School, he thereafter entering McGill University to graduate with honors from the Mechanical Engineering course in 1892. During his three years' study at McGill, five months out of each year he was working as assistant engineer for the Laurie Engine Company of Montreal. In 1893, he took a course in electrical engineering at the Institut Electrotechnique Montefiori, Liege, Belgium, graduating with a diploma of electrical engineering. From May 1894 to September 1895, Professor Herdt was assistant electrical engineer to the Thomson Houston International Company, Paris, whence he returned to McGill University, as demonstrator of electrical engineering, becoming consecutively lecturer, assistant professor, associate professor, and, ultimately, head of the department. Doctor Herdt was president of the Electrical Service Commission of Montreal, a member of the Engineering Institute of Canada, and Fellow of the American Institute of Electrical Engineers. In 1907 he was appointed delegate to the International Electrotechnical Commission, meeting then in London, England, and it was with deep sympathy and regret that the Commission, meeting in this country for the first time this year, heard of his untimely death. He was appointed Officer d'Academie de France in 1905 and Chevalier de Legion d'Honeur in 1923. Doctor Herdt was the author of several technical papers and contributed materially to the work of profession, both through the technical press and the engineering bodies with which he was identified. Beside his membership in the Engineering Institute of Canada, Doctor Herdt belonged to the Montreal Engineering Club.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (MARCH 1-31, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

DIE ANWENDBARKEIT DER GEOPHYSIKALISCHEN LAGERSTATTENUNTERSUCHUNGSVERFAHREN, INSBESONDERE DER ELEKTRISCHEN UND MAGNETISCHEN METHODEN.

By Rudolf Krahmann. Halle (Saale), Wilhelm Knapp, 1926. 40 pp., 10 x 7 in., paper. 2,50 gm.

With the object of supplying the mining interests with a comprehensive, understandable presentation of the fundamental principles of the practical use of geophysics in the study of ore deposits, the author has prepared this brief survey of the practical geophysical methods for the exploration of ore deposits. The various methods, using the measurement of electromagnetic conductivity, specific potential, magnetic intensity, gravity, elastic waves, earth temperatures and radioactivity are described, and their possibilities pointed out. A bibliography is included.

BEITRAG ZU DEN GRUNDLAGEN DER SCHNELLAUFENDEN HALBDIESELMOTOREN.

By Karl Büchner. Halle (Saale), Wilhelm Knapp, 1926. 48 pp., illus., 11 x 7 in., paper. 3,50 mk.

A lecture upon certain directions in which there is a tendency toward technical advance in the utilization of heavy oil. The author calls attention to the possibilities of solid-injection for high-speed automobile engines as well as for stationary and marine Diesel engines. He next speaks of recent satisfactory adaptations of hot-bulb engines to automobiles, in controversion of the usual idea that this type is an antiquated step in the evolution of the engine. Finally, he suggests the desirability of more thorough investigation of the reactions underlying the formation of mixtures which ignite easily and burn rapidly. He devotes special attention to this third point.

DIE BEWEGLICHKEIT BINDIGER UND NICHT BINDIGER MATERIALIEN.

By V. Pollack. Halle (Saale), Wilhelm Knapp, 1925. 139 pp., 10 x 7 in., paper. 9,80 g. m.

Professor Pollack's monograph which brings together our knowledge of the mobility of cohesive and non-cohesive materials, treats a matter of great importance to geologists and civil engineers. The behavior of loam, clay, colloidal mud, sand, etc., under varying conditions of pressure and moisture is described and information given on their plasticity, cohesion, consistency and similar properties.

DYNAMICAL THEORY OF SOUND.

By Horace Lamb. 2nd edition. Lond., Edward Arnold & Co., 1925. 307 pp., 9 x 6 in., cloth. $6.00. (Gift through Longmans, Green & Co.)

Although a treatise on thi. subject is of necessity to a great extent mathematical, the author has tried to restrict himself to the simplest and most direct methods and processes possible, in view of the questions treated. In this sense the book is elementary and will, the author hopes, serve as a stepping stone to the writings of Helmholtz and Rayleigh.

This edition has been corrected and revised.

ECONOMICS OF THE RADIO INDUSTRY.

By Hiram L. Jome. Chicago, A. W. Shaw Co., 1925. 332 pp., diagrs., tables, 8 x 6 in., fabrikoid. $5.00.

A discussion of the economic and legal problems caused by the development of wireless communication. Taking the point of view that the function of radio is to render a more or less distinctive service of communication, the author analyzes its service problems as they affect society. He first discusses the development and extent of the industry, then most effective ways for making this service available to the people. The problems confronting the organizations rendering the service are then considered, while the final section of the book discusses the future of radio service and its relation to other social agencies and means of communication.

DIE ELEKTRISCHE TELEGRAPHIE MIT DRAHTLEITUNG, vol 1; Die Telegraphie mit Morsezeichen.

By J. Herrmann. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 134 pp., illus., 6 x 4 in., cloth. 1,50 mk.

The first volume of a brief practical textbook on telegraphy. This book is confined to telegraphy with Morse signals, the subject of printing telegraphs being left for a second volume.

The book opens with a brief review of the elements. The various circuits are then discussed, after which the author proceeds to cable telegraphy and high-speed systems. An excellent brief survey of the subject.

ENGINES OF HIGH OUTPUT; Thermodynamic Considerations.

By Harry R. Ricardo. Lond., Macdonald & Evans, 1926. (Reconstructive technical series.) 110 pp., graphs, tables, 9 x 6 in., cloth. 7/6.

Some years ago Mr. Ricardo published a series of articles giving a brief general analysis of the possibilities and limitations of high-speed gasoline engines. The present book is the first volume of a revision and amplification of that analysis. It deals particularly with the thermodynamic aspects of the problem. The author inquires into the factors that determine the efficiency of gasoline engines and discusses their application to practical design.

ENGLISH BRASS AND COPPER INDUSTRIES TO 1800.

By Henry Hamilton. N. Y., Longmans, Green & Co., 1926. 388 pp., illus., 9 x 6 in., cloth. $6.00.

Dr. Hamilton traces the development of these industries from their beginnings in the sixteenth century down to the year 1800, when they were firmly established in Birmingham, the city in which they are concentrated today. He is particularly interested in industrial organization, hence, it is the industrial and commercial organization of these industries which he studies rather than the evolution of manufacturing processes. The result is an interesting work which throws new light on industrial development during its period, of interest to students of economics, as well as students of the particular industries under discussion.

DIE ENTWICKLUNG DER DIESELMASCHINE.

By R. Schöttler. Halle (Saale), Wilhelm Knapp, 1925. 50 pp., illus., 11 x 8 in., paper. 3-mk.

Professor Schöttler's monograph gives a concise account of the evolution of the Diesel engine from its beginnings in 1893 to the present time. The development of modern types and of the various details of present designs is covered thoroughly, although briefly, and there are numerous bibliographic footnotes.

DIE FEILE.

By Otto Dick. Berlin, Julius Springer, 1925. 251 pp., illus., 11 x 8 in., boards. 18.-mk.

A handsomely printed, profusely illustrated history of the file, by the engineer of one of the largest German file factories. The book is divided into three parts. Part one, on the history of the file, traces this tool chronologically from the Stone Age to modern times. The second part describes the development of file and rasp cutting machines from the earliest—invented by Leonardo da Vinci in 1503—to the forms in use today. Part three describes the making of files and shows the evolution of the methods. The work is an unusually well planned and executed history of a tool, a model technical history.

GESCHICHTE DER EISENDRAHTINDUSTRIE.

By O. H. Döhner. Berlin, Julius Springer, 1925. 106 pp., illus., 11 x 8 in., cloth. 12-gm.

The author of this handsomely printed little book is a wire manufacturer in Westphalia, the "cradle," as he says, of the wire industry. He traces the manufacture of wire from the earliest times to the beginning of the present century, describing the successive steps by which the industry has advanced to the present stage. Although brief, the book is a careful, critical history, based on long study. The illustrations are carefully chosen from old sources.

DIE GRUNDLAGEN DER HOCHFREQUENZTECHNIK.

By Franz Ollendorff. Berlin, Julius Springer, 1926. 639 pp., diagrs., 9 x 6 in., cloth. 36-r.m.

This textbook is the result of an investigation carried on by the author for the purpose of improving the course of instruction in high-frequency engineering at the Danzig Technical High School. The aim has been not to provide the student with a collection of rules but to give him a thorough grounding in fundamentals, equip him for the independent solution of problems that arise in practice, and especially to teach him to understand scientific literature. Little attention is therefore given to specific machines and commercial varieties of equipment, but rather to topics which are of fundamental physical importance, as, for example, the theory of electro-magnetic radiation.

HANDBOOK OF SAFETY AND ACCIDENT PREVENTION.

By Fred G. Lange. N. Y., Engineering Magazine Co., 1926. 512 pp., illus., graphs, 9 x 6 in., fabrikoid. $5.00.

This handbook aims to bring together the information essential to a proper understanding of the Safety First movement. It gives a general view of the entire field of safety work, describes definite methods of procedure in installing programs for accident prevention, describes many successful methods and provides references to the literature.

INTRODUCTORY ELECTRODYNAMICS FOR ENGINEERS.

By Edward Bennett and Harold Marion Crothers. N. Y., McGraw-Hill Book Co., 1926. 665 pp., illus., diagrs., tables, 8 x 6 in., cloth. $4.50.

In an article published during 1923 in the JOURNAL of the American Institute of Electrical Engineers, Professor Bennett argued the need for separate instruction for engineering students of superior aptitude and those of moderate aptitude; and the provision of introductory textbooks giving a profoundly technical treatment of their subject for the first group and books giving a moderately technical treatment for the second. This text represents the notion that the authors have of the type of introduction to the electrical theory and the electrical principles that are fundamental to design, development, research and technical supervision in the electrical field which students of superior aptitude should receive.

The text is based on the instruction given for seven years at the University of Wisconsin. It aims to facilitate the acquirement of a profound understanding of the subject and is in the form of a connected development in which the observations, definitions, units and laws are taken up in the sequence in which the units of the electrostatic system are defined, each in terms of those preceding it.

RAILWAY TRACK AND MAINTENANCE . . . 4th edition of "Railway Track and Track Work."

By E. E. Russell Tratman. N. Y., McGraw-Hill Book Co., 1926. 490 pp., illus., tables, 9 x 6 in., cloth. $5.00.

A technical account of track construction and maintenance of way, intended for railroad engineers and officials, and for students. It gives the general principles and purposes that underly the design and maintenance of tracks and the systems applicable anywhere in practice. It also gives many details about the equipment, material, appliances and methods used by individual railroads in different parts of the country, under various conditions of traffic and climate. Bridge, signal, telegraph and emergency work are included. This edition has been entirely rewritten.

RECENT ADVANCES IN PHYSICAL AND INORGANIC CHEMISTRY.

By Alfred W. Stewart. 5th edition. N. Y., Longmans, Green & Co., 1926. 312 pp., illus., diagrs., plates, tables, 9 x 6 in., cloth. $6.50.

Contents: The older and the newer chemistry.—X-Ray spectra and automic numbers.—Elements of the rare earths.—Hafnium.—Phenomena of radioactivity.—Disintegration theory and the radioactive series.—Radon, thoron and actinon.—The isotopes.—The isobares.—Analysis of positive rays.—Results obtained with the mass spectograph.—The segregation of isotopes.—Atomic nucleus and its artificial disruption.—Outer sphere of the atom.—Active hydrogen.—Active nitrogen.—Some new hydrides.—Hydrides and the periodic system.—Some effects of intense drying.—Tesla-luminescence spectra.—Conclusion.—Indexes.

The advance in our knowledge in recent years has compelled Dr. Stewart to recast this book so completely that it is practically a new work. New chapters have been written and old text eliminated until but five chapters of the 1920 edition remain.

The new work gives brief, yet comprehensive accounts of recent additions to our knowledge, with numerous references to their literature.

TRAGBARE AKKUMULATOREN.

By Richard Albrecht. Berlin u. Leipzig, Walter de Gruyter & Co., 1926. 135 pp., illus., diagrs., tables, 6 x 4 in., cloth. 1,50 mk.

This book is devoted to portable forms of storage batteries and is confined to the three types—lead, nickel-iron and nickel-cadmium—which have been used commercially.

The author first describes the construction, mode of action and handling of the lead accumulator. This is followed by descriptions of the alkaline accumulators, especially the Edison battery, and a comparison of the two classes. The principal uses of storage batteries, for radio communication, ignition portable lamps and as substitutes for primary batteries are then treated. The book closes with a chapter on methods of charging.

TRAGEDY OF WASTE.

By Stuart Chase. N. Y., Macmillan Co., 1926. 296 pp., 8 x 5 in., cloth. $2.50.

This book is intended to call attention to the waste in industry occasioned by useless and vicious goods and services, by idleness, by unscientific methods of production and distribution and by the waste of natural resources. The author attempts to set forth with some detail the loss through each of these four channels and to estimate the man-power lost through the first three and the waste through the fourth. No solution is suggested, but the book has interest as a vivid, thought-provoking presentation of industrial abuses.

TURBO BLOWERS AND COMPRESSORS.

By W. J. Kearton. Lond. & N. Y., Isaac Pitman & Sons, 1926. 333 pp., illus., diagrs., tables, 9 x 6 in., cloth. $6.00.

Although the turbo blower and turbo compressor have become important in many industrial processes, there have been few serious publications about them in the English language and until now, no book concerning them. In the present work, offered to meet the want, the author has attempted a general treatment which may be useful to students, designers and operating engineers.

A short introduction deals with the principle of the centrifugal compressor and compares reciprocating and rotary compressors. The theory of air compression and the changes of state peculiar to centrifugal compressors are then treated. A theory of the turbo-compressor is then presented, followed by a discussion of the various losses and their influence. Regulating devices are described. Under design, special attention is given to the strength of impellers and the critical speeds of shafts. Methods of testing and some results of tests are given.

UBERSTROME IN HOCHSPANNUNGSANLAGEN.

By J. Biermanns. Berlin, Julius Springer, 1926. 452 pp., illus., diagrs., 9 x 6 in., cloth. 30.-mk.

A rewritten, enlarged edition of "Magnetische Ausgleichsvorgaenge in elektrischen Maschinen." The author discusses transient phenomena in various alternating current systems. Short-circuit processes and their peculiarities are treated in detail as are protective devices. The author is chief engineer of the A E G transformer and high-tension material works and has kept especially in mind the needs of the practising engineer.

VECTORIAL MECHANICS.

By L. Silberstein. 2nd edition. Lond. & N. Y., Macmillan & Co., 1926. 205 pp., 9 x 6 in., cloth. $4.00.

"The main object of this book is to present the chief principles and theorems of theoretical mechanics in the language of vectors and thereby to contribute to the diffusion of the use of vectors," says the author. The book is so arranged that it gives an almost systematic exposition of the chief principles of mechanics which may be used by those acquainted with little more than Alembert's Principle, while to readers thoroughly informed on the subject in its Cartesian form it presents a translation of their knowledge into the shorter vectorial language.

The new edition differs from the first only by the inclusion of some miscellaneous notes.

VIBRATION IN ENGINEERING.

By Julius Frith and Frederick Buckingham. Lond., Macdonald & Evans, 1924. (Reconstructive technical series). 123 pp., diagrs., 9 x 6 in., cloth. 7/6.

The matter of vibration in machinery is frequently of vital importance to makers and users, yet when information is wanted on the subject, it is found that the literature is scattered and difficult to collect. For that reason this book will be of value.

The authors have endeavored to bring together and coordinate the various problems in sound, the strength of materials, mechanics and harmonic motion which enter into the question, and to present the subject of engineering vibration as a whole. They present the subject first from the physical, then from the mathematical point of view, thus making provision for two types of minds.

Addresses Wanted

A list of names of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Detroit, Mich.
2.—H. R. Bailey, Room 923, Electric Bldg., Portland, Ore.
3.—J. Roy Barclay, 3424 Harrison, Kansas City, Mo.
4.—I. Bergenstrahle, 425 West 114th St., New York, N. Y.
5.—Hubert L. Clary, 782 West 24th St., Milwaukee, Wis.
6.—J. F. Clinton, 3682 Broadway, New York, N. Y.
7.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
8.—Hugh Denehy, c/o The Secretary, The Inst. of Elec. Engrs., Savoy Pl. Victoria Embankment, London, W. C. 2, England.
9.—Ralph Elsman, 120 Broadway, New York, N. Y.
10.—Charles A. Foust, 10505-93rd St., Woodhaven, N. Y.
11.—George Frasher, 1209 So. 4th Ave., Louisville, Ky.
12.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
13.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
14.—William A. Hincy, Colonial Apts., Media, Pa.
15.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
16.—D. Brainerd Jones, 131 25th St., Jackson Heights, N. Y.
17.—John E. Lewis, 376 Meyran Ave., Oakland Sta., Pittsburgh, Pa.
18.—F. A. Lindlof, 610 So. Spring St., Los Angeles, Calif.
19.—Charles Wm. Lucek, 1454 First Ave., New York, N. Y.
20.—Charles W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
21.—Shu-Sing Man, Apt. 53, 541 West 124th St., New York, N. Y.
22.—J. A. McDermott, Y. M. C. A., Lima, Ohio.
23.—Irving Menschik, c/o Dublier Cond. & Radio Corp., 48 W. 4th St., New York, N. Y.
24.—Erwin H. Mitchell, c/o Schmeltz, 481 6th St., Brooklyn, N. Y.
25.—Raymond W. Noddins, 230 East Ohio St., Chicago, Ill.
26.—Frank O. Nottingham, Jr., 417 Rugby Rd., Schenectady, N. Y.
27.—G. C. Poulson, 500 Danforth St., Syracuse, N. Y.
28.—Robert H. Russell, 1128 Warren West, Detroit, Mich.
29.—Lieut. A. G. Scott, 68 West 107th St., New York, N. Y.
30.—Kermit G. Seaman, P. O. Box No. 68, Boulder, Colo.
31.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Natl. Bank, Cincinnati, Ohio.
32.—C. D. Smith, 857 St. Charles St., New Orleans, La.
33.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
34.—L. H. Thullen, 280 Madison Ave., New York, N. Y.
35.—O. G. Utt, 4738 Kansas City, Mo.
36.—Leo A. Van Etsen, 1100 Park Ave., New York, N. Y.
37.—John D. Walker, 2686 Woodstock Ave., Swissvale, Pa.
38.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.
39.—C. A. Winder, Southern Equipment Co., San Antonio, Tex.
40.—M. L. Younger, 1814 Diamond St., Philadelphia, Pa.

Past Section and Branch Meetings

SECTION MEETINGS

Boston

Acoustical Engineering, by J. B. Taylor, General Electric Co. Illustrated. March 16. Attendance 80.

Cleveland

Inspection trip to Nela Park Development Laboratories, during which H. D. Blake gave a talk on "New Developments in Incandescent Lamps." After dinner an address was also made by R. W. Shenton on "The Search for the Obvious." Joint meeting with Akron Section. February 18. Attendance 250.

Connecticut

The New England Power Pool, by Samuel Ferguson, Hartford Electric Light Co. March 9. Attendance 110.

The Addition and Subtraction of Colors in Lighting Applications, by A. C. Dick, Westinghouse Lamp Co. March 19. Attendance 50.

Denver

The High Lights of the Gas Industry, by C. A. Harrison, Public Service Co. of Colorado. Luncheon Meeting. January 26. Attendance 60.

The Application of Electricity and Magnetism in Chemistry and Metallurgy, by Dr. M. F. Coolbaugh, Colorado School of Mines. March 19. Attendance 27.

Structural Thermo Insulation, by W. A. Grossman, Intermountain Insulex Co. Luncheon Meeting. March 30. Attendance 75.

Science and the Industries, by Dr. M. I. Pupin, National President, A. I. E. E. March 30. Attendance 800.

Erie

Industrial Electric Heating, by C. P. Yoder, Erie County Electric Co. Illustrated with slides. February 16. Attendance 75.

Mercury-Arc Rectifiers, by D. C. Prince, General Electric Co. Illustrated with slides. March 16. Attendance 65.

Fort Wayne

The Gyroscope, Gyrocompass and Gyropilot, by O. B. Whitaker, Sperry Gyroscope Co. March 18. Attendance 130.

Indianapolis-Lafayette

The Gyroscope, Gyro-Compass and Gyro-Pilot, by O. B. Whitaker, Sperry Gyroscope Co. March 19. Attendance 52.

Communication by Electrical Undulations, by J. Lloyd Wayne, III, Indiana Bell Telephone Co. April 12. Attendance 18.

Lehigh Valley

Power-Factor Correction, by L. W. W. Morrow, *Electrical World*, and *What Diversity Factor and Load Factor Mean to a Community*, by N. E. Funk, Philadelphia Electric Co. March 12. Attendance 102.

Automatic Control of Centrifugal Pumps, by Otto Haentjens, Barrett-Haentjens Co., and

Wallenpaupack Hydro-Electric Development of the Pennsylvania Power and Light Co., by Wm. E. Lloyd, Jr. A dinner preceded the meeting. March 26. Attendance 202.

Los Angeles

General Transportation Situation in Los Angeles, by D. W. Pontius, Pacific Electric Railway Co.;

Industrial Heating, by Max Lee, Westinghouse Elec. & Mfg. Co., and C. J. Cipperly, General Electric Co.; and

Principles of Domestic Electric Refrigeration, by G. H. Hopkins. April 6. Attendance 96.

Lynn

Signal Control for Steam Railroads, by W. H. Reichard. General Railway Signal Co. March 18. Attendance 65.

Madison

The Self-Starting Synchronous Motor, by S. H. Mortensen, Allis-Chalmers Mfg. Co. Joint meeting with University of Wisconsin Branch. March 23. Attendance 50.

Minnesota

Automatic Starters for Synchronous Motors, by G. J. Shavor, Electric Machinery Mfg. Co., and

Synchronous-Motor Applications, by F. H. Milliken, Electric Machinery Mfg. Co. March 29. Attendance 90.

Niagara Frontier

The Quest of the Unknown, by H. B. Smith, Worcester Polytechnic Institute. A dinner preceded the meeting. March 17. Attendance 48.

Oklahoma

Electrical Engineering and State of Oklahoma, by F. G. Tappan, University of Oklahoma;

Oil-Field Electrification, by D. L. Johnson, Westinghouse Elec. & Mfg. Co.; and

Educational Problems, by J. H. Felgar, University of Oklahoma. March 9. Attendance 28.

Philadelphia

Institute Activities, by F. L. Hutchinson, National Secretary, A. I. E. E., and

College, Then What? by Farley Osgood, Consulting Engineer. March 8. Attendance 180.

Pittsburgh

Surge Investigations with the Klydonograph, by J. H. Cox, Westinghouse Electric & Mfg. Co. March 9. Attendance 157.

Oil-Circuit-Breaker Situation from Operator's Viewpoint, by E. C. Stone, Duquesne Light Co., and

High-Power Laboratory and Plans for Test Demonstration, by W. R. Woodward, Westinghouse Electric & Mfg. Co. Dinner preceded the meeting. April 13. Attendance 435.

Pittsfield

Uses of Vacuum Tubes for Purposes Other than Radio, by W. C. White, General Electric Co. March 9. Attendance 55.

The Automobile of Today and Tomorrow, by Herbert Chase, Erickson Co. March 16. Attendance 200.

Portland

Factors Affecting Radio Reception, by C. H. Watson;

The Barrage System of Reception, by A. G. Simson, and

Radio Interference, by Ellis Van Atta, Pacific Power and Light Co. March 17. Attendance 86.

Rochester

Modern Views of Electricity and Matter, by H. C. Reutchler, Westinghouse Electric & Mfg. Co. February 5. Attendance 125.

Railway Electrification—Domestic and Foreign, by H. K. Smith, Westinghouse Electric & Mfg. Co. March 5. Attendance 60.

In the Land of Buddha, by H. B. Smith, Worcester Polytechnic Institute. March 16. Attendance 120.

San Francisco

The Hydro-Electric Power Development at Hetch Hetchy, by N. P. Eckart and J. P. Ost. A dinner preceded the meeting. February 26. Attendance 160.

The Electron Theory in Modern Physics, by M. I. Pupin, National President, A. I. E. E. A dinner preceded the meeting. March 26. Attendance 450.

Saskatchewan

Rural Telephone Development in Saskatchewan, by W. J. Patterson, Minister of Telephones, and

The History of the Telephone, by J. D. Pearl, Northern Electric Co. A motion picture, entitled "From Mine to Consumer," was also shown. March 25. Attendance 125.

Schenectady

Transmission of Pictures by Wire, by B. K. Rhodes, New York Telephone Co. Illustrated with slides. March 12. Attendance 350.

Refrigerators, by A. R. Stevenson, General Electric Co. March 26. Attendance 350.

Seattle

The Development of Sub-Station Practises, by Joseph Hellenthal, Puget Sound Power and Light Co. Illustrated with slides. March 17. Attendance 43.

Sharon

Behind the Scenes, a demonstration presented by the Bell Telephone Co. March 26. Attendance 500.

Among the Fjords of America, by L. O. Armstrong. Illustrated with slides and moving pictures. April 6. Attendance 503.

Spokane

Results of National Survey of Engineering Education, by H. V. Carpenter, State College of Washington. March 19. Attendance 31.

Springfield

The Manufacture of Incandescent Lamps, by H. W. Crafts, General Electric Co. Illustrated with slides and a film. January 25. Attendance 66.

Methods of Medical Treatment of Interest to Electrical Engineers, by Dr. McIver Woody, Gilbert and Barker Mfg. Co. March 22. Attendance 60.

Toronto

Power Transformers, by C. A. Price, Canadian Westinghouse Co. Illustrated with slides. March 19. Attendance 115.

The Self-Propelled Unit Rail-Car, by R. J. Needham, Canadian National Railways. April 9. Attendance 52.

Urbana

Piezoelectricity: Its Scientific and Engineering Applications, by Prof. J. T. Tykociner, University of Illinois. March 11. Attendance 95.

Utah

The Evolution of the Dynamo, by B. F. Howard, Mountain States Telephone & Telegraph Co. March 24. Attendance 43.

Washington

Electrical Apparatus Applied to Dredging Operations, by H. C. Giroux. Illustrated. April 13. Attendance 41.

Worcester

Analogies in Mechanics and Electricity, by Prof. W. S. Franklin, Massachusetts Institute of Technology. March 31. Attendance 50.

BRANCH MEETINGS

Alabama Polytechnic Institute

Business Meeting. March 3. Attendance 23.

Opportunities of the Engineer outside of the Big Corporations, by Prof. Hill. A motion picture, entitled "Letting Dynamite Do It," was also shown. March 10. Attendance 24.

Railway Electrification, by C. E. Haynie, student, and

Orthophonic Reproduction, by J. A. Douglas. March 17. Attendance 18.

Banking and Banking Business, by Prof. A. L. Thomas. March 24. Attendance 26.

Engineering in the Big Cities, by R. O. Lyle, student, and

Rescue Methods of Submarinist, by S. L. Hancock, student. A motion picture, entitled "Beyond the Microscope," was shown. March 31. Attendance 23.

Early History of the Alabama Polytechnic Institute, by Dean John J. Wilmore. April 7. Attendance 19.

University of Arizona

Temperature Change in Induction Watt-Hour Meters, by B. Cottrell;

Elimination of Echoes in Long-Distance Telephone Sets, by T. E. Davis, and

Patents and Patent Laws, by D. M. Dexter. March 6. Attendance 20.

Temperature Rise in D-C. Machines, by Chas. Dunn, and

The Boston Tech Cooperative Course, by R. Fulton. March 13. Attendance 16.

Recent Telephone Development, by Mr. Guyman. March 20. Attendance 20.

Ethics, by Prof. Paul Cloke. Motion picture, entitled "Short Cuts to Quantity Production," was shown. March 27. Attendance 17.

Armour Institute of Technology

Artificial Resuscitation and First Aid, by Dr. J. T. McNamara. January 22. Attendance 101.

Electric Shovels, by M. T. Goetz, A. R. Waehner and C. W. Burcky, students. Illustrated with slides. A talk on the same subject was also given by A .A. Thompson, General Electric Co. February 18. Attendance 28.

Business Meeting. March 4. Attendance 27.

A motion picture, entitled "The King of the Rails," was shown. March 18. Attendance 54.

Brooklyn Polytechnic Institute

Home Lighting, by J. J. McMullan; *High-Frequency Radio Oscillations*, by Lloyd Goldsmith; *Public vs. Private Ownership of Public Utilities*, by Harry Walker; *Lord Kelvin*, by James Dalton and Dominic Chiarello, and *Regenerative Braking*, by Fred Wahlers. March 26. Attendance 25.

California Institute of Technology

A motion picture, entitled "The Story of Anaconda," was shown. March 9. Attendance 8.

A motion picture, showing the manufacture of high-tension cable by the Okonite process, was shown. March 31. Attendance 16.

Case School of Applied Science

General Motor Applications, by Mr. Rogers, General Electric Co. March 2. Attendance 64.

D-C. Engineering Applications, by Mr. Franklin, General Electric Co. March 9. Attendance 59.

Experiences of Student Engineers, by R. C. Putnam. April 7. Attendance 33.

Clemson Agricultural College

Group Versus Individual Motor Drive, by J. R. Cooper; *Electric Elevator Practise*, by B. D. King; *State-Owned Power Again*, by O. M. Harrelson; *Battling Bandits by Broadcasting*, by J. A. Warren, and *Current Events*, by R. H. Mitchell. March 4. Attendance 18.

University of Colorado

Radio Wave Propagation, by Mr. Cassel. April 7. Attendance 50.

Cooper Union

Motion pictures, entitled "Speeding Up Our Deep-Sea Cables," "Telephone Inventors of Today," and "Putting a Telephone Together with Trick Photography," were shown. March 27. Attendance 46.

University of Denver

Principles of the Watt-Hour Meter and Testing, by R. R. McLaughlin, and

The Auto-Valve Lighting Arrester, by A. R. Bitter. March 26. Attendance 16.

The Evolution of the Dynamo, by H. T. Howard, Bell Telephone Co. Illustrated with slides. April 9. Attendance 30.

University of Florida

High-Frequency Alternators, by J. W. Graff. March 22. Attendance 8.

Georgia School of Technology

Motion pictures, entitled "The Wizardy of Wireless" and "Beyond the Miscroscope," were shown. March 23. Attendance 58.

University of Idaho

Motion picture, entitled "Yoke of the Past," was shown. March 16. Attendance 31.

State University of Iowa

Automatic Control for Power Stations, by E. J. Hoetman;

Electric Signs, by P. W. Hubbard, and

Phototelegraphy, by P. A. Loyet. March 10. Attendance 42.

The Value of Student Branches to Engineering Societies, by Prof. W. H. Kavanaugh, University of Pennsylvania. March 17. Attendance 73.

An illustrated talk was given by Dean W. G. Raymond on a report from The Society for the Promotion of Engineering Education. Joint meeting with A. S. M. E. and A. S. C. E. March 31. Attendance 41.

A motion picture, entitled "The Insulation of Wires and Cables," was shown. April 7. Attendance 42.

Kansas State College

Choosing Your Vocation, by Mr. Reece, Bell Telephone Co. Match 25. Attendance 89.

University of Kansas

Synchronous Machines, by Mr. Henningson, General Electric Co. A motion picture on the Okonite process of insulation was shown. March 4. Attendance 75.

The General Electric Test, by A. Havenhill, General Electric Co. Illustrated. March 18. Attendance 65.

Lafayette College

Inspection trip to the Easton Central Office of the Lehigh Telephone Co. March 24. Attendance 20.

Massachusetts Institute of Technology

Water Power Developments in the United States, by Col. William Kelly, Technical Director, N. E. L. A. April 2. Attendance 20.

Michigan State College

Advantages at the General Electric Company of a Tester, by Professor Cory; *The Educational Advantages of the Westinghouse Company and the New York Edison Co.*, by Prof. Naeter; *The Advantages of the Telephone Business from the Educational Standpoint*, by Mr. Osborn, and *The Engineer in Public Utility Work*, by Prof. Kinney. February 25. Attendance 35.

Milwaukee School of Engineering

A motion picture, entitled "The Life of Thomas A. Edison," was shown. March 23. Attendance 30.

Motion pictures, entitled "The Westinghouse Plant" and "The Story of Dynamite," were shown. April 7. Attendance 31.

Montana State College

Fifty Years of Service, by Thomas Neal, and

Railway Electrification Progress During 1925, by H. K. Miller. March 15. Attendance 149.

Development of Electric Lighting, by J. C. Lorimer, General Electric Co., April 1. Attendance 139.

University of Nebraska

Business Meeting. March 5. Attendance 32.

Motion picture, entitled "Temperature and Motor Endurance," was shown. April 1. Attendance 40.

University of Nevada

Meters and Lightning Arresters, by W. C. Smith, General Electric Co. Motion pictures on the life of Thomas Edison were also shown. March 17. Attendance 44.

College of the City of New York

Business Meeting. March 11. Attendance 15.

New York University

Opportunities with the General Electric Company, by Mr. Rugan. Illustrated with moving pictures. March 25. Attendance 53.

University of North Dakota

Pioneers in the Electrical Industry, by Nels Anderson, student,

Rural Transmission Lines, by O. B. Medalen, student, and

The Brunswick Panatrope, by George Russ, student. March 22. Attendance 20.

Northeastern University

Wire Cable and Insulation, by C. D. Davis, Simplex Wire and Cable Co. March 25. Attendance 25.

Ohio Northern University

Business Meeting. March 24. Attendance 36.

Business Meeting. The following officers were elected: Chairman, M. Heft; Vice-Chairman, A. Mathews; Secretary, L. Wadsworth; Treasurer, K. Heming. March 31. Attendance 36.

Ohio State University

Talk by C. F. Kettering, President, General Motors Research Corp. February 26.

Dinner Meeting, at which C. S. Coler, Westinghouse Elec. & Mfg. Co., spoke. March 10.

Developments in the Telephone World, by C. P. Cooper, Ohio Bell Telephone Co. March 12. Attendance 88.

Ohio University

Power Rates and Methods of Fixation, by F. M. McKay, Southern Ohio Power Co. The following officers were elected: President, N. R. Smith; Vice-President, Frank Morgan; Secretary, J. E. Quick; Treasurer, T. R. Root. March 18. Attendance 17.

Oklahoma Agricultural and Mechanical College

The Field of Engineering, by Prof. Edward Kurtz. The following officers were elected: President, W. J. Beckett; Vice-President, Hal Horton; Secretary, Lee Rogers. February 17. Attendance 25.

Business Meeting. Moving picture of Yellowstone Park was shown. March 10. Attendance 47.

Motion pictures, entitled "The Wizardy of Wireless," "The Audion," "Via Radio," and "The Spirit of Service," were shown. April 7. Attendance 80.

University of Oklahoma

Business Meeting. February 25. Attendance 15.

University of Pittsburgh

Public Utilities as a Field for Engineers, by M. R. Scharf, Duquesne Light Co. February 12. Attendance 35.

Engineering Education, by James G. Pattillo, student, and

The Philadelphia Company, by James H. Hoffman, student. February 19. Attendance 29.

Purdue University

Automatic Elevator Control, by R. C. Parker. A motion picture, entitled "Insulation," was also shown, followed by a talk by Prof. Alfred Still. March 30. Attendance 20.

Rensselaer Polytechnic Institute

Automatic Train Control, by W. H. Reichard, General Railway Signal Co. Illustrated with slides. March 17. Attendance 175.

Rhode Island State College

The Electric Clock to be Made Universal, by Mr. Larson; *Mercury-Steam Turbine Generators*, by Mr. Rolston, and *Marine Electric Installations*, by Mr. Wilbourn. March 1. Attendance 15.

The Narragansett Electric Light Plant, by F. R. Smith. March 15. Attendance 17.

Rutgers University

Imagination in Engineering, by H. C. Powell, and

Manufacture of Electrical Porcelain, by Mr. Henderson. March 8. Attendance 21.

University of Southern California

Recent Developments of the General Electric Co., by Mr. Hill. March 4. Attendance 19.

Syracuse University

High-Frequency Induction Furnaces, by N. C. Reed. March 1. Attendance 19.

Long-Distance Transmission, by W. H. Schmidt. March 8. Attendance 18.

Hydrogen as a Cooling Medium, by R. F. Pearson. March 15. Attendance 19.

Voltage Regulators, by R. H. Watkins. March 29. Attendance 18.

Texas Agricultural and Mechanical College

Safety First, by R. K. Eason, student, and

Problems Confronting the Telephone Companies in Large Cities, by C. A. Richardson. March 19. Attendance 51.

University of Texas

Business Meeting. The following officers were elected: President, A. B. Atkinson; Vice-President, V. J. Graham; Secretary-Treasurer, T. S. Gray, and Corresponding Secretary, J. D. McFarland. March 25. Attendance 10.

Virginia Military Institute

Requirements for Recording and Reproducing Sound, by F. M. Barberie, and

Subterranean Heat as a Source of Energy, by R. W. Bouldin. March 16. Attendance 43.

Interior-Frosted Lamps and Corrugated Bulbs, by H. B. Bringhurst;

Training the Staff for Operating the Modern Power Plant, by J. O. Neville, and

Opportunities for the Technical Man in the Pittsburgh District, by J. S. Jamison. April 7. Attendance 46.

State College of Washington

Transformers, by Professor R. D. Sloan. Illustrated with slides. April 1. Attendance 73.

University of Wisconsin

Self-Starting Synchronous Motors, by S. H. Mortensen, Allis-Chalmers Mfg. Co. The following officers were elected: Chairman, Benjamin Teare; Secretary-Treasurer, Neal B. Thayer. March 23. Attendance 52.

Worcester Polytechnic Institute

The Land of Buddha, by Prof. H. B. Smith. Illustrated with slides. March 29. Attendance 45.

University of Wyoming

Business Meeting. April 7. Attendance 16.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.

63 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to **EMPLOYMENT SERVICE, 33 West 39th Street, New York City,** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL SALES ENGINEER, for company manufacturing carbon brushes and generators, and carbon specialties. Locations, Kansas City, and Birmingham, Alabama. R-9391-C.

EXPERIENCED TRANSFORMER ENGINEER, familiar with design and practice relating to high-tension, transformers and high-tension, small distribution and special purpose transformers. Must be capable of original work, both theory and practise. Position with a new division of an old line manufacturing company not previously engaged in the manufacture of high-tension electrical apparatus. R-9452.

SALES ENGINEER, to take on line of established renewal products. Must have acquaintances among the engineers of power railway and industrial companies. Exclusive territories in Philadelphia, Pittsburgh, Chicago, Pacific Coast, Buffalo, St. Louis, and Atlanta. R-9511-C-S.

SALESMAN, 25-35, electrical engineering education, who has had experience preferably with one of the large electrical manufacturing companies in the design and sale of electric motors and generators and who has had sales experience. The work will be development of the use of roller bearings in electric motors and generators, and sale of bearings in this market. Considerable traveling necessary. Apply by letter. Headquarters, New Jersey. R-8616-C.

ENGINEER, 30-40, who has had experience as production and schedule engineer in industrial or public utility work. Must be able to plan and direct work of schedule division of engineering department, including the progress and schedule of engineering and construction work, time study, budget records, and production control. Apply by letter. Location, Pa. R-9403-C.

ELECTRICAL ENGINEER, experienced on design transformers. Work will be on electrical welding transformers. Salary $200-$250 a month. Apply by letter. Location, Chicago. R-9157-C.

SALES ENGINEER, to handle distribution and power transformers on salary basis. Must be familiar with public utilities and be resident of Pennsylvania. Apply by letter. Headquarters, Pennsylvania. R-9454.

MEN AVAILABLE

GRADUATE OF M. I. T., 1924, in electrical engineering, age 26. Four months Western Electric Company, sixteen months Telephone Company. Desires position electrical engineering work. New England preferred, but will go anywhere. Salary approximately $35 a week. Available immediately. C-1045.

ELECTRICAL ENGINEER, age 29, with thorough technical education, desires position with consulting firm or public utility, preferably in the West. Three years teaching electrical engineering and four years' experience in test, sales and engineering with General Electric Company. Familiar with power transmissions and related fields. Available after June 15th. C-1118.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, desires permanent position engineering work Pacific Coast. Two years drafting, designing with electrical manufacturing company, two years substation design, rate engineering large public utility. Good character, pleasing personality, efficient worker; several languages; European university graduate; 27, married. Minimum salary $175.00 a month. Present employed. Available month's notice. C-1109.

RADIO ENGINEER, thoroughly educated, experienced, wants position technical correspondent or development engineer large radio company. Past four years employed as operating engineer, second in charge, in two of New York's broadcasting stations. Designed, constructed, installed a third large broadcasting station Second Radio District. Two years' magazine, special feature writing experience. Not interested position broadcasting station. Available two weeks' notice. Minimum salary $3000. C-1108.

ELECTRICAL ENGINEER, age 27, single, 1923 graduate. Experience with public utilities on the construction, maintenance and operation of transmission and distribution systems. Also familiar with the routine clerical work of both central and district offices. Desires position as electric supervisor, or position leading to executive responsibility. Available on short notice. Location immaterial. B-9897.

ELECTRICAL ENGINEER, college graduate, B. S. degree in E. E., age 29, single. Two and one-half years' Westinghouse test, one month electrical maintenance work in large factory, seven and one-half years' experience electrical construction and supervising work in power houses, substations and transmission lines. Location anywhere in the United States, preference West. Available on week's notice. B-7637.

ELECTRICAL AND MECHANICAL ENGINEER, graduate with honors. G. E. Test, switchboard and central station engineering department; experienced shops, drafting, design and layouts H. T. transmission and protective gear. Desires operating experience with power company. Available May. Location immaterial. B-7623.

ELECTRICAL ENGINEER, four years' design and development experience with large manufacturing company. Would like similar work with a well established company in the Middlewest. College graduate, 28, married. C-1132.

SALES ENGINEER, age 34, married, well acquainted with New England markets, desires to represent electrical manufacturer in this territory. Experienced in selling to dealers, jobbers and manufacturers. Technical education, ten years' engineering and selling experience. Present connection with internationally known manufacturer. Salary and expenses. Available one month. A-1330.

ELECTRICAL ENGINEER, age 32, married, twelve years' experience power plant, substation, industrial, construction, operation, etc., four years with Westinghouse, power plant, substation, switching, metering, drafting, design, control and servicing engineer, eight years industrial and public utilities. Desires engineering, drafting, or supervision in greater New York. Available immediately. B-3172.

SALES ENGINEER-ASSISTANT ENGINEER, married, technical graduate in electrical engineering. Experienced distribution (AC or DC) high voltage transmission, power station design, power systems, also experienced field work and taking off an inventory, and inspection of electrical goods, cable, wire and materials, experience in radio reception, transmission and de-

sign. Good sales personality, convincing talker, thorough workman. B-6558.

ELECTRICAL ENGINEER AND PHYSICIST, age 34, graduate of several leading universities, on instruction staff of well known institution for five years, also commercial experience. Extensive work in electrical and radio development, also patent experience. Position in electrical development, patent work, or with public utility desired. Location, East. B-165.

ELECTRICAL-MECHANICAL DRAFTSMAN, age 27, married, technical education, field and office experience on machinery and power house construction. Available immediately. Anywhere. B-7666.

ENGINEER, E. E., desires position with consulting engineer in industrial development, or as professor. Fifteen years' responsible university positions, including charge of electrical and physics laboratories, development, project, analysis, commercial tests; editorial experience; specialist in illumination. Wants opportunity with future prospects, utilizing broad education, general experience and mature powers. B-2824.

ELECTRICAL ENGINEER, age 33, married, ten years electrical construction experience, desires position as superintendent, or assistant to general manager of construction. Experienced in construction of transmission lines, both overhead and underground, automatic and manually operated high tension substations. Diversified experience in sugar mill and malleable iron foundry practise. At present employed, best of references. Minimum salary $3000. A-3191.

ELECTRICAL ENGINEERING GRADUATE, age 27, married, two years' commercial and engineering experience with telephone and power companies, one year teaching experience as instructor of electricity and mechanical drawing in vocational department of high school. Desires temporary employment. Available June 20th. B-7028.

EXECUTIVE—A man trained as an engineer, experienced as a factory manager, seeks connection offering opportunity for development. Manufacturing experience covers fifteen years on varied line of electrical products. Possesses vision, initiative, tact and the ability to organize an economical factory administration. Salary and percentage bonus based on results preferred. C-1102.

WANTED position as superintendent of power. Fourteen years' experience in construction, operation and maintenance of power plants and transmission systems. Willing to go anywhere in the United States. Available on one month's notice. C-1152.

RECENT GRADUATE ELECTRICAL ENGINEER, desires part time work, designing, estimating, checking, or calculating. Experience in steam power plant electrical construction, also on transmission line survey. Location, Philadelphia. C-1180.

ELECTRICAL ENGINEERING GRADUATE, age 23, single, with one and one-half years electrical testing, and one and one-half years electrical drafting, desires position as electrical draftsman on power plants, or industrial buildings. Location, East. B-6790.

INDUSTRIAL ELECTRICAL ENGINEER, technical graduate, married, wide experience design, repair, construction of electrical equipment as applied to industrial plants, also power plant construction. Desires position with large industrial plant as industrial electrical engineer. Location, Central States. Available on reasonable notice. C-1194.

ELECTRICAL ENGINEER, graduate 1921, desires position with engineering or industrial concern where rapid promotion depends on ability only. Broad experience, operating and distribution problems, industrial electrification, high tension laboratory. At present foreman for test division with leading public utility. Available on two weeks' notice. Age 32, married. Minimum salary $2700. C-1190.

ELECTRICAL ENGINEER, capable graduate E. E., age 29, single. Has had one year's experience on the General Electric Company test, and five years in distribution engineering and construction work. Has specialized in underground engineering and am thoroughly familiar with A. C. low voltage network systems. Has also had considerable experience with electrolysis mitigation. Location immaterial. Available on short notice. C-1191.

EXECUTIVE-MACHINE TOOL ENGINEER, age 38, with all round designing, manufacturing and selling experience, desires connection with eastern company that can take on the manufacture of a semi-automatic production machine. Salary $5500 plus commission or royalty to be arranged. B-9603.

ELECTRICAL AND MECHANICAL ENGINEER, age 40, married, technical university graduate. Fifteen years of practical experience in design, test and operation of A. C. and D. C. motors, generators and switchboard panels; elevator construction, hoisting equipment and installations. Development and production work. Available on reasonable notice. Location, New York City or vicinity. B-5240.

ASSISTANT PROFESSOR OF ELECTRICAL ENGINEERING, age 39, married, desires promotion to associate or full professorship in Middle Atlantic or Midwestern university. Initiative. An all around good teacher. Prefers the advanced subjects. Mathematician. Reading knowledge of German and French. Bachelor's and Master's degrees. Ten years' teaching, three years' practical experience. Salary $3250 to $4000. B-2663.

PATENT ATTORNEY, age 24, electrical engineer, having three years' experience in the Patent Office handling both electrical and mechanical cases, desires to locate with a patent attorney, or with a large manufacturing company in the vicinity of Chicago. C-610.

MANAGER OR EXECUTIVE, age 43, married, seventeen years' electrical experience successful in managing and operating electrical public utility; especially successful in dealing with the public. Desires position in larger field. Salary $6000. C-1179.

ELECTRICAL ENGINEER, fifteen years' experience, mostly in design of alternating current machines. Post graduate technical education. Has done responsible developmental work on transformers, induction motors, direct current motors and new and unusual apparatus. Considerable executive experience. Capable of handling difficult technical problems. Position as executive or responsible technical engineer desired. C-1181.

RAILWAY TELEGRAPH AND TELEPHONE ENGINEER, 36, British, ten years' experience, (also as superintendent), all modern systems, selector, electric staff, condenser-impulse telegraphy, etc. Specialist difficult country. Available May on completion modernization entire system. Desires charge of similar modernization, two or three years, or would accept shorter contract to inspect and recommend with specifications. Location, outside of United States. Fluent French, Spanish. C-2009.

YOUNG MAN, graduating from B. P. I. in electrical engineering, desires a position with an electrical manufacturer or public utility. Especially interested in the field of illumination. Will consider any place that has a chance for advancement. Location, New Jersey or New York City. C-1173.

ELECTRICAL-MECHANICAL ENGINEER, technical graduate, desires connection with contracting or consulting engineering firm contemplating forming an electrical department. Experienced in power and substation design and industrial engineering. At present rehabilitating public utility in South America. C-1141.

ELECTRICAL ENGINEER, desires position as operating or distribution engineer. Age 27, married, technical education. Two years G. E. test, three years electrical superintendent of large industrial plant, and two years with utility company serving 12,000 customers as distribution engineer. Salary $225. Available two weeks' notice. B-9390.

ASSISTANT TO GENERAL ELECTRICAL SUPERINTENDENT of large public utility, available on reasonable notice. Eight years' experience general utility problems, budgets valuations, statistics, accounting, economical engineering investigations, operating problems, high voltage transmission, communication, safety, personnel matters. Sc. B., E. E. degrees, 30, married. Desires permanent position in satisfactory location offering opportunity for advancement. B-3311.

ELECTRICAL ENGINEER, age 27, single, Marquette University graduate 1925, desires opportunity in hydro-electric work. Expects to combine study with work entered. Location immaterial. C-1162.

GRADUATE ELECTRICAL ENGINEER, age 28, married, varied experience in maintenance, drafting, sales engineering, commercial work and operating public utility system. Desires position as assistant manager or superintendent with public utility, or engineer with manufacturing company. Employed at present. Available in thirty days. Location, East Central Atlantic States. Minimum salary $200 a month. B-7827.

ELECTRICAL CONSTRUCTION SUPERINTENDENT, age 38, wide experience electrical construction, operation; ten years construction, eight years general superintendent railways, power plants, substations, general utility work. Present on contract for electrical construction in foreign service. Prefers connection with railway or electrical concern as representative in Latin countries. Technical training. Speaks Spanish, English. Available on five months' notice. C-886.

SALES ENGINEER, who has large acquaintance in the Southern states. Capable of handling any line of heavy apparatus in this district. C-1211.

ELECTRICAL ENGINEER, 27, energetic, inventive and tactful. Past experience: electrical testing and charge of electrical testing apparatus and research, good references. Desires position developing and research of electrical apparatus or machinery. At present employed, but available on two weeks' notice. Greater New York preferred. B-7270.

SALES MANAGER, for manufacturer desiring business relations with central stations and holding companies. Age 39, clean cut aggressive sales engineer with record of sales achievement in public utility field. Graduate engineer. Available in sixty days. Highest references. B-4221.

PROFESSOR IN ELECTRICAL ENGINEERING desired by Harvard University graduate with thirteen years' university teaching experience, and five years of varied and valuable practise, in addition to numerous summers' work. Specialist in high voltage transmission research, theory, design and practise. Important experience with both Westinghouse and G. E. Companies. 43, married, excellent health. C-577-2-C-15.

RADIO ENGINEER AND PRODUCTION MANAGER is open for a connection. For past three years has been acting in those capacities for a well known manufacturer. College education, proven executive ability, clear grasp of audio and radio fundamentals. Well known among the trade fraternities. Best references given and asked for. C-1020.

ELECTRICAL ENGINEER, 33, married, fourteen years' experience design and manufacture electric heating devices, and small specialties, incandescent lamp manufacture, power plant location and finance. Has direct access to large capital for any good proposition in South America and connections in South. Location, Pacific Coast or South America. C-1177-4-A-3.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED APRIL 9, 1926

*ABBOTT, HENRY HERRICK, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

AMSON, ROBERT IRVING, Engineering Assistant, United Electric Light & Power Co., 56 Cooper Sq., New York, N. Y.

ARCHE, MANUEL PENA, Chief Engineer, Cia Cubana de Electricidad, Inc., Camaguey, Cuba.

AXON, WILLIAM RUSSELL, Correspondent, (Engineering), Westinghouse Elec. & Mfg. Co., 30th & Walnut Sts., Philadelphia, Pa.

*AXTELL, HAROLD BENTON, Long Lines Dept., American Tel. & Tel. Co., 518 N. Beaumont St., St. Louis, Mo.; res., Pasadena, Calif.

*BAKER, ARTHUR WILLIAM, Asst. to Special Engineer, American Electric Railway Association, 292 Madison Ave., New York; res., Brooklyn, N. Y.

BAKER, HALSTED W., Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

BAKER, HORATIO ORVILLE, Engineer, Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.

*BARDEN, WILLIAM S., Research Laboratory, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

BARTON, HERTWELL PAUL SMITH, Jr., Asst. Research Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York; res., Brooklyn, N. Y.

BEACH, WILLIAM CHARLES, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Bloomfield, N. J.

*BECK, ALBERT D., Elec. Engg. Dept., Westinghouse Elec. & Mfg. Co., Cleveland Illuminating Bldg., Cleveland, Ohio.

BELLIS, ALFRED PETER SKILLMAN, Asst. General Manager, Insulated Wire Dept., John A. Roebling's Sons Co., 612 S. Broad St., Trenton, N. J.

BINGEL, GEORGE HENRY, Manager, Engg. Dept., C. H. Stevens Co., 30 Church St., New York; for mail, Brooklyn, N. Y.

BIRD, TRUMAN COLUMBUS, Salesman, Line Material Co., South Milwaukee, Wis.; res., Portland, Ore.

BLACK, HUGH MURRAY, Estimator, Elec. Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

*BLAKEY, LAWRENCE MILLARD, Inspector, Hartford Accident & Indemnity Co., Hartford, Conn.

BLOSER, W. C., Electrical Designer, Thomas E. Murray & Co., 55 E. Duane St., New York, N. Y.; res., Bloomfield, N. J.

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*BOOLOS, STEPHEN G., Laboratory Assistant, Brooklyn Edison Co., Brooklyn; for mail New York, N. Y.

BRAKE, WILLIAM JOHN, Asst. Inspector, Light & Power Dept., City of Regina, Regina, Sask., Can.

BRAUE, CHARLES AUGUST, Inspector, Brooklyn, Edison Co., Cor. Johnson & Pearl Sts., Brooklyn; res., Bronx, New York, N. Y.

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*BROWN, ELBERT CHESTER, Asst. Manager, Connecticut Valley Power Exchange, 266 Pearl St., Hartford, Conn.

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BUTHERUS, FREDERICK ROY, Secretary & Supt., British Sangamo Co., Ltd., Ponders End, Middlesex, Eng.

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DANIEL, THOMAS ARCHIE, Electrical Engineer; Development Branch, Western Electric Co., Hawthorne Sta., Chicago; res., Maywood, Ill.

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DAWSON, LEONARD L., Chief Electrician, Elec. Dept., Erie Railroad, 65 Pavonia Ave., Jersey City, N. J.

de BERNARD, EUGEÑIO, Chief Engineer, Compania Cubana de Electricidad, Inc., Contreras 70, Matanzas, Cuba.

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LEE, D. WEBSTER, Inspector of Electrical Construction, Dept. of City Transit, 12th & Chestnut Sts., Philadelphia, Pa.

LEESON, GEORGE EDWARD, District Inspector, Saskatchewan Government Telephones, Yorkton, Sask., Can.

LEONARD, EMERY MAYROW, Designing Transformer, Pittsburgh Transformer Co., Pittsburgh, Pa.

LEVY, MAURICE LEWIS, Asst. Radio Engineer, Stromberg-Carlson Tel. Co., 1060 University Ave., Rochester, N. Y.

LEWIS, JOHN GEESEY, Asst. Chief Engineer, Potomac Edison Co., Cumberland, Md.

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*LORJE, HERMAN, Budget Engineer, Empire Companies, Bartlesville, Okla.

*LOW, HERBERT MELVIN, Electrician, Andes Copper Mining Co., 25 Broadway, New York, N. Y.

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LYSTER, MERTON SOLOMON, Student Bridge Man, The Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Calif.

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MATHEWS, EARL CYRUS, Electric Inspector, U. S. Shipping Board, 207 S. Broadway, Los Angeles; res., Lynwood, Calif.

*McCANDLESS, CARROLL FRED, Meter Dept., Consumer's Power Co., Western Ave., Muskegon; for mail, Ludington, Mich.

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MILMOE, ROBERT, Engineer, Knoxville Power & Light Co., Knoxville, Tenn.

MODLIN, WALTER GEORGE, Division Substation Engineer, Public Service Electric & Gas Co., 75 River St., Newark, N. J.

MOES, GERLACUS, Experimenter, Electrical Laboratory, Simplex Wire & Cable Co., Sidney St., Cambridge; res., Brookline, Mass.

MOXON, ALFRED WILLIAM, Student, Pratt Institute, Brooklyn, N. Y.

*NAKAMOTO, HAYATO, Testing Laboratory, Public Service Electric & Gas Co., 21st St. & Clinton Ave., Irvington; res., Newark, N. J.

NEANDER, MICHAEL T., Engineer in Charge of Construction, First State Electric Power Station, 76 Obvodny Kanal, Leningrad, Russia.

*NICHOLSON, ROBERT FRANCIS, Instructor, Elec. Engg. Dept., Catholic University of America, Brookland; res., Washington, D. C.

NORWIG, JOHN, Jr., Engineering Assistant, United Electric Light & Power Co., 56 Cooper Sq., New York; res., Brooklyn, N. Y.

O'BRIEN, EDWARD CHARLES, Salesman, J. J. O'Brien & Son, 154 E. 23rd St., New York, N. Y.

ONO, YUTAKA, Designing Engineer, Shibaura Engineering Works, Shibaku, Tokyo, Japan.

*ORCUTT, HOWARD S., Engineering Assistant, United Electric Light & Power Co., 56 Cooper Sq., New York, N. Y.

OSBORN, AMBROSE LESTER, District Traffic Supt., Southern New England Telephone Co., 73 Washington St., New London, Conn.

OSBURN, MERVYN PHILLIP, Student Apprentice, Employees Relations Dept., Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

OUELLETTE, EDWARD F., Operator, Main Power House, Ford Motor Co., 1581 Henry St., Detroit, Mich.

PAGANO, LAWRENCE ANTHONY, Engineering Assistant, Brooklyn Edison Co., Inc., 14 Rockwell Place, Brooklyn, N. Y.

PAINTER, CHARLES LEROY, Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pitcairn, Pa.

*PATRICK, PAUL DAVID, Underground Engr. Dept., Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.

PAUL, HERBERT F., Tester, The Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio.

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PIKE, ARTHUR THORNDIKE, Telephone Engineer, Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.

PIKE, WILLIAM KENNETH, Chief Clerk, Service Dept., Westinghouse Elec. & Mfg. Co., 395 Liberty St., Springfield, Mass.

POLLARD, ARCHIBALD HAYWARD, Electrical Engineer, International General Electric Co., Schenectady, N. Y.

POLLEY, LOUIS PALMER, Distribution Engineer, Puget Sound Power & Light Co., 1306 "A" St., Tacoma, Wash.

POWELL, JOHN HAYES, Field Engineer, R. E. Berry, 165 Manchester St., Christchurch; for mail, Lyttelton, New Zealand.

*PURUCKER, RALPH ERHARDT, Student, University of Wisconsin, Madison; res., Jefferson, Wis.

QUEVEDO, ANTONIO, Sales Engineer, Westinghouse Electric International Co., Havana, Cuba.

RATHGEBER, MORTIMER DEMOREST, Substation Operator, Potomac Electric Power Co., Washington, D. C.

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ROCKEFELLER, HARRY C., Sales Correspondent, Westinghouse Elec. & Mfg. Co., East Springfield, Mass.

ROSS, WILLIAM, Salesman, James Martin, 134 W. 52nd St., New York; res., Bronx, New York, N. Y.

RUBEL, WALTER L., Designing Engineer, Memco Engineering & Manufacturing Co., 381 Hamilton St., Long Island City, N. Y.

SAMPSON, GEORGE HENRY, Electrical Engineer, Nashua Manufacturing Co., Nashua, N. H.

SAUL, HARRY KARL, Economy Glass Co., Morgantown, West Va.

SAURWEIN, VALENTINE EMIL, Schedule Supervisor, Ohio Bell Telephone Co., 6205 Carnegie, Cleveland, Ohio.

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SCHNUG, GEORGE, Draftsman, Pacent Electric Co., Inc., 91, 7th Ave. New York; res., Glendale, N. Y.

SCHROEDER, RUSSELL FRANKLIN, Inspector, Brooklyn Edison Co., Johnson & Pearl Sts., Brooklyn, N. Y.; res., North Bergen, N. J.

SCHULTZ, STANLEY WILLIAM, Commonwealth Edison Co., 28 N. Market St., Chicago, Ill.

SEAWARD, EDGAR SMITH, Storage Battery Engineer, Gould Storage Battery Co., Depew, N. Y.

SEKI, YOSHINAGA, Electrical Engineer, Mitsubishi Electrical Engineering Co., Nagasaki, Japan.

*SHAW, RONALD HAYDEN, Student Engineer, Tampa Electric Co., Tampa, Fla.

SINGER, ROBERT H., Asst. Engineer, The Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.

SKINNER, DEAN C., Electrical Draftsman, Youngstown Sheet & Tube Co., Youngstown, Ohio.

SMITH, ADAM W. SIMPSON, Engineering Apprentice, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

SMITH, EUGENE C., Plant Electrician, Russell Mfg. Co., Middletown, Conn.

SPANN, RANSOM D., Captain, Coast Artillery Corps, U. S. A., 39 Whitehall St., New York, N. Y.
SREENIVASAN, KASI, Post Graduate Research Work, Radio Lab., Dept. of Elec. Technology, Indian Institute of Science, Hebbal P. O., Bangalore, India.
STACK, SYDNEY S., Laboratory Assistant, General Electric Co., Schenectady, N. Y.
STROD, ARVED JOHN, Engineer, Miscellaneous Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.
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STYRMOE, JAMES EDWARD, Welding Specialist, Westinghouse Elec. & Mfg. Co., 2211 W. Pershing Road, Chicago, Ill.
SUPPERS, HOBART GARRET, Engineer of Electrical Tests, John A. Roebling's Sons Co., Trenton, N. J.
SUTTON, CLARK A., Electrical Draftsman, Bethlehem Steel Corp., Bethlehem, Pa.
SWAZEY, HOLLIS A., Tester, New York Edison Co., 92 Vandam St., New York, N. Y.
TAYLOR, S. BLACKWELL, Engineer, Reliance Electric & Engineering Co., 1088 Ivanhoe Road, Cleveland, Ohio.
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*VADEN, THOMAS HUNT, Asst. Supt., Eastern Div., Alabama Power Co., Anniston, Ala.
VON SNEIDERN, ARNE A., Laboratory Assistant, General Electric Co., Schenectady, N. Y.
WADLEK, JOSEPH, Draftsman, Transformer Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
*WALLER, JOHN L., Development & Research Laboratory, Rome Wire Co., Rome, N. Y.
*WECKWERTH, HERBERT F., Electrical Engineer, City of Kaukauna, Kaukauna, Wis.
*WELSH, WILLIAM ELWORTH, Division Supt. of Transmission, Penn. Power & Light Co., Ashley, Pa.
WENDLER, HOWARD J., Electrical Designer, Public Service Production Co., 27 Mechanic St., Newark, N. J.
*WHITE, HARRISON GATES, Sales Engineer, Mancha Storage Battery Locomotive Co., 1909 S. Kingshighway Blvd., St. Louis, Mo.
WILFLEY, VERNON BAILEY, Electrical Engineer, Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
WILKINSON, THOMAS ALEXANDER, General Engineer, Westinghouse Elec. & Mfg. Co., 150 Broadway, New York, N. Y.
*WILLIAMS, F. REID, Engineer, Dixie Power Co., Cedar City; for mail, Veyo, Utah.
*WILLIAMSON, ROBERT BLANCHARD, Field Engg. Work, General Railway Signal Co., Rochester, N. Y.
WITTENBERG, ALBERT J., General Foreman, Brooklyn Edison Co., Inc., 14 Rockwell Place, Brooklyn, N. Y.
*WOLF, ALEXANDER, Investigation & Research Section, Philadelphia Electric Co., Philadelphia, Pa.
*WOODWARD, JOHN EGGLESTON, Student Engineer, Standard Oil Co. of New Jersey, Bayway Refinery, Elizabeth, N. J.
*WURST, LEROY LAWRENCE, Field Engineer, Public Service Co. of Northern Illinois, 198 N. Schuyler Ave., Kankakee, Ill.
WYATT, RALPH M., Methods Engineer, Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.
YOUNG, THOMAS JOSEPH, Member, Technical Staff, Research Dept., Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
ZELLWEGER, F., Asst. to Electrical Engineer, Schweitzer & Conrad, Inc., 4421 Ravenswood Ave., Chicago, Ill.
*ZIMMERMANN, ANDREW GEORGE, Switchboard Engineer, The Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Calif.

Total 205

*Formerly enrolled students

ASSOCIATES REELECTED APRIL 9, 1926

BROWN, EDWARD CLAUDE, Consulting Engineer, Edward C. Brown Co., 200 Devonshire St., Boston, Mass.
HACKBUSCH, RALPH ANTHONY, Service Dept., Canadian Westinghouse Co., Ltd., 366 Adelaide St., W., Toronto, Ont., Can.

MEMBER ELECTED APRIL 9, 1926

ZELENTSOFF, JICHAEL EUGENE, Professor, Electrotechnical Institute, Pessochnaia 7, Leningrad, Russia.

FELLOW ELECTED APRIL 9, 1926

CHERNYSHOFF, ALEXANDER, Professor, Polytechnic Institute, Leningrad, Sosnowka, Russia.

TRANSFERRED TO GRADE OF FELLOW APRIL 9, 1926

FLEAGER, CLARENCE E., Chief Engineer, Pacific Telephone & Telegraph Co., San Francisco, Calif.

TRANSFERRED TO GRADE OF MEMBER APRIL 9, 1926

CLARK, JOHN A., Research Engineer, Weston Electrical Instrument Corp., Newark, N. J.
CUNNINGHAM, R. E., Operating Electrical Engineer, Southern California Edison Co., Los Angeles, Calif.
DAVIES, HAROLD C., Station Section, Elec. Engineering Dept., Hydro Electric Power Commission, Toronto, Ont., Can.
FIELDS, ERNEST S., Asst. Electrical Engineer, Union Gas & Electric Co., Cincinnati, O.
GRAHAM, FRANK H., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.
HALE, WILLIAM K., State Electrical Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.
HARRIS, IRVING C., Consulting Engineer, Cone and Harris, Los Angeles, Calif.
HEALY, EDWIN S., Transmission Engineer, Electric Bond & Share Co., New York, N. Y.
HINSON, N. B., System Planning Engineer, Southern California Edison Co., Los Angeles, Calif.
HORN, A. F. E., Manager, General Electric Co., Washington, D. C.
JOHNSON, JAMES A., Works Manager, Canadian Crocker Wheeler Co., Ltd., St. Catherines, Ont., Can.
JONES, ARTHUR L., District Engineer, General Electric Co., Denver, Colo.
PUBLOW, CEDRIC F., Asst. Station Engineer, Hydro Electric Power Commission, Toronto, Ont., Can.
SIMPSON, WILLIAM L., Division Engineer, Postal Telegraph-Cable Co., Chicago, Ill.
SOULE, WILLIAM H., Electrical Superintendent, Mond Nickel Co., Coniston, Ont.
STARR, JAMES H., District Engineer, Condit Electrical Manufacturing Co., St. Louis, Mo.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held April 5 and 26, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

BEDELL, FREDERICK, Professor of Applied Electricity, Cornell University, Ithaca, N. Y.
BOYAJIAN, ARAM, Electrical Engineer, General Electric Co., Pittsfield, Mass.
DAVIDSON, WARD F., Research Engineer, Brooklyn Edison Co., Brooklyn, N. Y.
MARRIOTT, ROBERT H., Consulting Engineer, New York, N. Y.
McQUARRIE, JAMES L., Chief Engineer, International Standard Electric Corp., London, England.
ORSETTICH, ROBERT, Chief Engineer, Wilton Works of General Electric Co., Birmingham, England.
RICHARDS, WILLIAM E., Supt., Electrical Dept., Toledo Edison Co., Toledo, Ohio.
THOMAS, GEORGE N., Contract Engineer and Supt. of Construction, Canadian General Electric Co. Ltd., Toronto, Ontario.

To Grade of Member

BULLARD, WILLIAM R., Assistant Engineer, Electric Bond & Share Co., New York, N. Y.
CAMPBELL, THADDEUS C., Telephone Engineer, Systems Development Dept., Bell Telephone Laboratories, New York, N. Y.
HENTZ, ROBERT A., Electrical Engineer, Philadelphia Electric Co., Philadelphia, Pa.
HODTUM, JOSEPH B., Sales Engineer, Pittsburgh Transformer Co., Pittsburgh, Pa.
HULL, BLAKE D., Transmission & Protection Engineer, Southwestern Bell Telephone Co., St. Louis, Mo.
KEPHART, CALVIN I., Senior Examiner (Valuation), Interstate Commerce Commission, Washington, D. C.
KNUDSEN, H. A., Electrical & Mechanical Engineer, East Bay Municipal Utility District, Oakland, Calif.
KOCH, M. McK., Supt. Electric Distribution, Public Service Co. of Colorado, Denver, Colo.
LOUIS, H. C., Chief of Research & Test, Consolidated Gas Electric Light & Power Co., Baltimore, Md.
MacNAUGHTON, A. K., Supt. of Distribution, Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
McCLELLAN, LESLIE N., Electrical Engineer, U. S. Bureau of Reclamation, Denver, Colo.
McILVAINE, H. A., Engineer, Cleveland Vacuum Tube Works, Cleveland, O.
McROBBIE, HENRY W., Supt. Substations, West Penn Power Co., Connellsville, Pa.
NELSON, EDWARD L., Engineer, Bell Telephone Laboratories, New York, N. Y.
NORRIS, ERIC D. T., Technical Electrical Engineer, Ferranti Ltd., Hollinwood, Lancashire, England.
SIMONS, DONALD M., Development Engineer, Standard Underground Cable Co., Pittsburgh, Pa.
SIMS, WILLIAM F., Field Engineer, Generating Stations, Commonwealth Edison Co., Chicago, Ill.
STEBBINS, ALDEN H., Electrical Engineer, Edward Ford Plate Glass Co., Rossford, Ohio.
STINER, H. WRAY, Commercial Engineer, General Electric Co., Cleveland, O.
THOMAS, HERBERT P., Chief Engineer, Southland Electric Power Board, Invercargill, N. Z.
VAN BOKKELEN, WILLIAM R., Chief Engineer, Coast Counties Gas & Electric Co., San Francisco, Calif.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1926.

Alexander, R. W., Commonwealth Power Corp., Jackson, Mich.
Allison, R. S., Niagara, Lockport & Ontario Power Co., Avon, N. Y.
Ambrose, L. O., The Austin Co., Cleveland, Ohio

Anderson, H. L., Commonwealth Power Corp., Jackson, Mich.
Andrews, C. L., The Pacific Tel. & Tel. Co., Portland, Ore.
Anson, E. H., Gibbs & Hill, New York, N. Y.
Anthony, R. B., Penna. Power & Light Co., Mt. Carmel, Pa.
Arbuckel, J. S., American Brown Boveri Electric Corp., Camden, N. J.
Atkinson, J. N., Newfoundland Power & Paper Co., Ltd., Deer Lake, Newfoundland
Atwood, D. S., Llewellyn Iron Works, Los Angeles, Calif.
Bass, O. B., Canadian Pacific Steamships, Ltd., Vancouver, B. C., Can.
Baudry, R. A. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Bell, C. R., Cleveland Electrical Illuminating Co., Cleveland, Ohio
Bird, C. A., (Member), The Detroit Edison Co., Detroit, Mich.
Bisazza, R., General Electric Co., Schenectady, N. Y.
Blanch, F. D., General Electric Co., Schenectady, N. Y.
Boura, F. G., West Penn Power Co., Pittsburgh, Pa.
Bowen, W. E., Great Western Power Co., San Francisco, Calif.
Boyer, W. A., General Electric Co., Schenectady, N. Y.
Bragg, A. D., General Electric Co., Schenectady, N. Y.
Branson, A. K., Great Western Power Co. of Calif., Oakland, Calif.
Bryarly, M. M., U. S. Veterans Bureau, Washington, D. C.
Buery, G. E., Peninsula Lumber Co., Portland, Ore.
Burt, A. R., Kansas City Railways Co., Kansas City, Mo.
Butler, M. B., Jr., (Member), American Chain Co., Bridgeport, Conn.
Butterfield, H. S., Atlantic City Electric Co., Atlantic City, N. J.
Campbell, A. E., The Ohio Power Co., Canton, Ohio
Chandler, W. G., Brooklyn Edison Co., Brooklyn, N. Y.
Cheney, W. E., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Clark, Sherman B., Northwestern Electric Co., Portland, Ore.
(Applicant for re-election.)
Cooper, W. J., Electrician, St. Paul's Hospital, Vancouver, B. C.
Costella, A. P., The Camden Storage Battery Co., Camden, N. J.
Cottrell, W. J., Allied Industries, Inc., Portland, Ore.
(Applicant for re-election.)
Crowell, R. M., Utah Power & Light Co., Salt Lake City, Utah
Damon, A. C., Simplex Wire & Cable Co., Cambridge, Mass.
Daugherty, T. C., New England Tel. & Tel. Co., Boston, Mass.
Davis, J. C., Jr., Edison Elec. Illuminating Co., Roxbury, Mass.
Davison, C., Mexican Telegraph Co., Orizaba, Verz Cruz, Mexico
Dean, C. P., Bell Telephone Laboratories, Inc., New York, N. Y.
de Celis, F., Mexican Light & Power Co., Mexico City, Mex.
Dedek, F. G., Burroughs Adding Machine Co., Detroit, Mich.
Dellinger, F. E., Los Angeles Gas & Electric Corp., Los Angeles, Calif.
Dennis, E. M., Bloedel Donovan Lumber Mills, Bellingham, Wash.
Dickerson, F. A., New York Telephone Co., New York, N. Y.
Dodds, V. G., Aluminum Co. of America, Philadelphia, Pa.
Dowdy, J. W., Electrician & Licensed Marine Engineer, San Francisco, Calif.
Dring, L. G., New York Telephone Co., New York, N. Y.
Drummond, A. J. United Gas Improvement Contracting Co., Philadelphia, Pa.
(Applicant for re-election.)
Eberhardt, P. W., Duquesne Light Co., Pittsburgh, Pa.
Edward, J. A., Hydro-Electric Power Station, Snoqualmie, Wash.
Ehrke, E. B., Pacific States Electric Co., Los Angeles, Calif.
Ellis, D. W., Beech Bottom Power Co., Power, W. Va.
Erickson, E. O., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Ewing, C., Louisville Gas & Electric Co., Louisville, Ky.
Fawcett, O. M., West Penn Power Co., Pittsburgh, Pa.
Feindel, A., New York Edison Co., New York, N. Y.
French, M. A., Charles H. Tenney & Co., Boston, Mass.
Gambitta, A. F., Research Work, 6 W. 28th St., New York, N. Y.
Gardner, E. W., The Pacific Tel. & Tel. Co., Portland, Ore.
(Applicant for re-election.)
Garretson, F. M., Jr., Cooper Hewitt Electric Co., Hoboken, N. J.
Garvin, J. S., (Member), Bell Telephone Labs., Inc., New York, N. Y.
Gauchet, C. E., General Electric Co., St. Louis, Mo.
Grant, A. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Gray, J. W., Ohio Northern University, Ada, Ohio
Greene, E. M., Commonwealth Edison Co., Chicago, Ill.
Greene, J. H., Sanderson & Porter, New York, N. Y.
Griffin, G. H., Union Carbide Co., Sault Ste Marie, Mich.
Hadley, G. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Haertlein, A., Duquesne Light Co., Pittsburgh, Pa.
Harnett, D. E., Pacent Electric Co., New York, N. Y.
Hartranft, A. C., Philadelphia Electric Co., Philadelphia, Pa.
Henderson, C. L., West Penn Power Co., Pittsburgh, Pa.
Henderson, E. W., Duquesne Light Co., Cheswick, Pa.
Hiltebeitel, J., with H. N. Crowder, Jr., Co., Allentown, Pa.
Hoefflin, A. S., Louisville Gas & Electric Co., Louisville, Ky.
Holtman, J. E., (Member), Westinghouse Elec. & Mfg. Co., Denver, Colo.
Houle, A. V., The New York Edison Co., New York, N. Y.
Hubbard, H. H., Brooklyn Edison Co., Brooklyn, N. Y.
Jarvis, M. M., Burroughs Adding Machine, Detroit, Mich.
Johnson, W. M., Portland Electric Power Co., Portland, Ore.
Judy, E. W., Duquesne Light Co., Pittsburgh, Pa.
Humphreys, D., Newfoundland Power & Paper Co., Ltd., Deer Lake, Newfoundland
Kane, M. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kelly, O. D., West Penn Power Co., Pittsburgh, Pa.
King, J. J., The Pacific Tel. & Tel. Co., Portland, Ore.
Kirchhof, W. H., Philadelphia Rapid Transit Co., Philadelphia, Pa.
Knowles, H. S., Popular Radio Inc., New York, N. Y.
Kucher, A. A., (Member), Westinghouse Elec. & Mfg. Co., Chester, Pa.
Kuriyan, J., Jr., General Electric Co., Schenectady, N. Y.
Lavigne, F. A., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.
Mabee, G. C., Murrie & Co., New York, N. Y.
MacKay, A. T., Western Electric Co., Boston, Mass.
Mathews, P. W., Duquesne Light Co., Pittsburgh, Pa.
Mathewson, D. E., Lockwood Greene & Co., Inc., New York, N. Y.
Matthews, R. F., 214 N. McDowell St., Raleigh, N. C.
McArn, D. G., (Member), Pittsburgh Transformer Co., Pittsburgh, Pa.
McCauley, W. M., Railway & Industrial Engineering Co., Pittsburgh, Pa.
McCreight, R., Jr., Leeds & Northrup Co., Philadelphia, Pa.
McGuire, P. T., Duquesne Light Co., Pittsburgh, Pa.
McIntosh, R. S., Cleveland Railway Co., Cleveland, Ohio
McKinley, J. G., Jr., West Penn Power Co., Connellsville, Pa.
McNairy, J. W., General Electric Co., Schenectady, N. Y.
Meister, M. H., Western Union Telegraph Co., St. Louis, Mo.
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Molter, D. W. C., West Penn Power Co., Pittsburgh, Pa.
Monroe, R. W., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Morphey, L. A., Northwestern Electric Co., Portland, Ore.
Moyers, C. G., West Penn Power Co., Pittsburgh, Pa.
Moyle, E., General Electric Co., Schenectady, N. Y.
Munton, J. D., Atlantic Refining Co., Philadelphia, Pa.
Murdock, H. W., General Electric Co., Inc., Schenectady, N. Y.
Muzsnay, V. G., Sanderson & Porter, Springdale, Pa.
Nelthorpe, F. A., Jr., Puget Sound Pr. & Lt. Co., Seattle, Wash.
Newcombe, J., with John Wanamaker, New York, N. Y.
Newton, LeR. F., Fairbanks-Morse Co., Portland, Ore.
Opsahl, A. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Orgell, C. G., United Gas Improvement Contracting Co., Philadelphia, Pa.
Paton, J., Jr., American Electrical Works, Phillipsdale, R. I.
Paulus, C. F., Cleveland Electric Illuminating Co., Cleveland, Ohio
Pearson, H. E., Pratt Institute, Brooklyn, N. Y.
Pedley, H. L., Commonwealth Edison Co., Chicago, Ill.
Phillips, E. L., (Member), E. L. Phillips & Co., New York, N. Y.
Pla, R. A., General Railway Signal Co., Rochester, N. Y.
Podgainy, C., Freed-Eisemann Radio Corp., Brooklyn, N. Y.
Powell, H. T., Louisville Gas & Electric Co., Louisville, Ky.
Pugh, G. C., West Penn Power Co., Pittsburgh, Pa.
Quinn, J. T., Jr., New England Tel. & Tel. Co., Cambridge, Mass.
Rankin, G. D., The Hartford Faience Co., Hartford, Conn.
Rasmussen, W., Tabulating Machine Co., San Francisco, Calif.
Rice, H. E., New England Tel. & Tel. Co., Boston, Mass.
Rorke, C. B., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Rosado, A., Havana Electric Railway, Light & Power Co., Havana, Cuba
Rosewater, E., A. H. Grebe & Co., Inc., Richmond, Hill, N. Y.

Ross, D. G., General Electric Co., Schenectady, N. Y.
Rudd, T. O., Kerite Insulated Wire & Cable Co., New York, N. Y.
Rupert, C. L., Duquesne Light Co., Pittsburgh, Pa.
Russell, F. W., Louisville Gas & Electric Co., Louisville, Ky.
Samson, D. R., (Member), Dodge Brothers, Inc., Detroit, Mich.
Sanchez, U. C., Compania de Electricidad de Merida, S. A., Merida, Yucatan, Mex.
Sasaki, T., Mass. Institute of Technology, Cambridge, Mass.
Schultz, C. F., Cleveland Railway Co., Cleveland, Ohio
Sillers, T. G. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Sinderson, L. O., General Electric Co., Schenectady, N. Y.
Slater, W. F., with Osburn Monnett, Evanston, Ill.
Smith, J. R., Louisville Gas & Electric Co., Louisville, Ky.
Snow, E. C., Louisville Gas & Electric Co., Louisville, Ky.
Snyder, C., General Electric Co., Schenectady, N. Y.
Snyder, R. J., Brooklyn Edison Co., Brooklyn, N. Y.
Sorke, W. S., Bliss Electrical School, Washington, D. C.
Sprague, C. S., Purdue University, Lafayette, Ind.
Sproule, H. C., Philadelphia Electric Co., Philadelphia, Pa.
Szontagh, John R., General Electric Co., Philadelphia, Pa.
Tavenner, W. B., Graybar Electric Co., Los Angeles, Calif.
Thayer, H. C., Jr., General Electric Co., Schenectady, N. Y.
Thayer, R. C., Great Northern Railway Co., St. Paul, Minn.
Thompson, A. W., Philadelphia Electric Co., Pittsburgh, Pa.
Thomson, J. F. F., General Electric Co., Schenectady, N. Y.
Tienken, W. J., Jr., Pratt Institute, Brooklyn, N. Y.
Troxel, F. D., Sargent & Lundy, Inc., Chicago, Ill.
Walton, I. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Warner, C. W., General Electric Co., Schenectady, N. Y.
Watanabe, J. S., Mass. Institute of Technology, Cambridge, Mass.
Watson, S. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Weigand, W. F., Jr., Philadelphia Rapid Transit Co., Philadelphia, Pa.
Wellman, B., General Electric Co., Schenectady, N. Y.
West, J. I., The Litchfield Light & Power Co., Litchfield, Conn.
White, E., New England Tel. & Tel. Co., Boston, Mass.
Wickersham, W. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Wiltshire, A. J., Marvel Equipment Co., Cleveland, Ohio
Total 173

Foreign

Aiyangar, R. R., Sri Brahmavidyambal Elec. Supply Corp. Ltd., Ramachandrapuram, Trichinopoly Dist., S. India
Bagchi, S. K., Tata Iron & Steel Co., Jamshedpur, India
Belianinov, N., Electrotechnical Institute, Leningrad, Russia
Bentzon, C. E., Mascaron 530, Lima, Peru, S. A.
Bryant, E., Te Awamutu Electric Power Board, Te Awamutu, Auckland, N. Z.
Doberck, W. A., Andersen Meyer & Co., Ltd., Shanghai, China
Entee, F. D., Century Mills, Bombay, India
Geary, S. J., Municipal Electricity Dept., Christchurch, N. Z.
Hooker, J. F., Municipal Electricity Dept., Christchurch, N. Z.
Irwin, J. E., Chile Exploration Co., Chuquicamata, Chile, S. A.
Knight, H. W., Brimsdown Power Station, Brimsdown, Eng.
Kooken, J. R., Chile Exploration Co., Chuquicamata, Chile, S. A.
Lopez, C. E., Cia. Huanchaca de Bolivia, Pulacayo, Bolivia, So. America
Mehta, J. J., The Municipality of Bombay, Bombay, India
Paddock, W. G., Lucknow Municipal Water Works, Aish Bagh, Lucknow, India
Polivanoff, M. C., (Fellow), Technical High School, Moscow, Russia
Rayment, E. G., Bethlehem Steel Co., Dock Central, La Plata, Arg. Rep., S. Amer.
Taylor, F. W., Ferranti, Ltd., Hollinwood, Lancashire, Eng.
Varley, H., The Electric Motor & Stove Hiring Co., Ltd., Leeds, Yorkshire, Eng.
Total 19

STUDENTS ENROLLED

Adkins, Elmer, University of Florida
Bartels, William H., Michigan State College
Baum, Marc, Cornell University
Christoph, Karl J., Columbia University
Clark, John L., Northeastern Univ.
DesBrisay, Aretas W. Y., McGill University
Dresser, Willis R., Mass. Tech.
Eaton, Thomas J., Mass. Tech.
Fannon, Joseph L., Mass. Tech.
Feige, Norman G., Johns Hopkins Univ.
Fekas, Harry J., Mass. Inst. of Tech.
Foss, Kenneth L., Univ. of New Hampshire
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Hancock, Samuel L., Alabama Poly. Inst.
Henderson, Francis C., Tufts College
Hoglund, Ejnar C., Worcester Poly. Inst.
Holton, James L., Rensselaer Poly. Inst.
Hussey, Frank W., Univ. of New Hampshire
Knudson, Jack W., Jr., Univ. of Texas
Laning, Willard A., Jr., Bucknell Univ.
Lee, Yuk-Wing, Mass. Tech.
Maynard, Leo H., Univ. of New Hampshire
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Menger, Francis, Univ. of Texas
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Peterson, Enar F. E., Northeastern Univ.
Rogers, Lee, Oklahoma A. & M. College
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Shaheen, Shahady, Mass. Inst. of Technology
Sickel, Horatio G., Columbia Univ.
Stevenson, Archibald E., Cornell Univ.
St. James, Louis N., Cornell University
Stonefield, John W., Northeastern Univ.
Van Liddle, Newlee, Washington State College
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Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
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Seattle	E. A. Loew	C. E. Mong, 505 Telephone Building, Seattle, Wash.
Sharon	W. M. Dann	L. H. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
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Urbana	**C. A. Keener**	**J. T. Tykociner, 300 Electrical Laboratory, University of Illinois, Urbana, Ill.**
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Arkansas, University of, Fayetteville, Ark	R. McFarland	J. Demarke	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	H. J. Prebensen	W. A. Dean	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	J. C. Arnell	J. H. Diercks	Robin Beach
Bucknell University, Lewisburg, Pa	T. J. Miers	C. A. Rosencrans	W. K. Rhodes
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Colorado, University of, Boulder, Colo	O. V. Miller	L. E. Swedlund	W. C. DuVall
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Rensselaer Polytechnic Institute, Troy, N. Y	F. M. Sebast	K. C. Wilsey	F. M. Sebast
Rhode Island State College, Kingston, R. I	D. B. Brown	S. J. Bragg	Wm. Anderson
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Rutgers University, New Brunswick, N. J	Stanley Hunt	S. B. Aylsworth	F. F. Thompson
South Dakota State School of Mines, Rapid City, S. D	J. V. Walrod	C. Allen	J. O. Kammerman
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Stanford University, Stanford University, Calif	F. E. Crever	C. R. Walling	H. H. Henline
Stevens Institute of Technology, Hoboken, N. J	L. G. Walsh	H. K. Siemers	
Swarthmore College, Swarthmore, Pa	J. S. Donal, Jr.	R. W. Lafore	Lewis Fussell
Syracuse University, Syracuse, N. Y	K. N. Cook	R. H. Watkins	C. W. Henderson
Tennessee, University of, Knoxville, Tenn	D. H. Sneed	H. B. Shultz	Charles A. Perkins
Texas A. & M. College, College Station, Texas	L. H. Cardwell	C. A. Altenbern	F. C. Bolton
Texas, University of, Austin, Tex	A. B. Atkinson	T. S. Gray	J. A. Correll
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WASHINGTON AWARD, COMMISSION OF

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Circuit Breakers.—Bulletin 1643A, 32 pp. Describes the general application of oil circuit breakers. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Capacitors.—Bulletin GEA-352, 12 pp. Describes capacitors for power factor correction and illustrates concrete savings effected in specific installations. General Electric Company, Schenectady, N. Y.

Transformers.—Bulletins 2052 and 2053, 4 pp. Describe Pittsburgh distribution transformers, single phase and polyphase. Pittsburgh Transformer Company, Columbus & Preble Aves., Pittsburgh, Pa.

Disconnecting Switches.—Leaflets L-25404-8. Describing types RH and RV air-break disconnecting switches. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Testing Lead Covered Cable.—Bulletin 101, 16 pp. Describes the facilities for testing, inspection and research work on impregnated paper insulated lead covered cable, of the Electrical Testing Laboratories, 80th Street & East End Avenue, New York.

Cable Joints.—Booklet, 16 pp. Describes patented "Metrolatum filled" high tension cable joints, for cable splices from 11,000 to 66,000 volts. The complete material for each joint is supplied in cartons. Metropolitan Device Corporation, 1250 Atlantic Avenue, Brooklyn, N. Y.

Disconnecting Switches.—Bulletin 501. Describes "Fuswitches" and disconnecting switches. Safety factor, rupturing capacity, flashover, construction and other important features are described in detail. W. N. Matthews Corporation, 3706 Forest Park Boulevard, St. Louis, Mo.

Control Apparatus.—A series of two- and four-page bulletins describing d-c. and a-c. manual and automatic starters, rheostats, crane controls, battery charging and testing equipment. Allen-Bradley Company, 286 Greenfield Ave., Milwaukee, Wis.

Safety Switch.—Bulletins 102, 103 and 104 describe the new "Bull Dog SaftoFuse" switch, being built in capacities of 30 and 60 amperes, 250 volts. The product is briefly described as a fuse carrier with switch contacts which may be withdrawn from the receptacle base. When the carrier is in the "on" position the fuse acts to fill the gap between the blade contacts. This moulded composition unit must be fully withdrawn before the fuses are accessible. Mutual Electric & Machine Company, 7612 Jos. Campau Ave., Detroit, Mich.

NOTES OF THE INDUSTRY

The Cutter Electrical & Manufacturing Company, Philadelphia, manufacturers of I-T-E circuit breakers, has removed its New York office from 1170 Broadway to 12 East 41st Street. The New York representatives of the company are W. C. Jessup, M. B. Cutting and R. C. Heyl.

Lapp Insulator Company, Inc., LeRoy, N. Y., announces the appointment of Harris & Butler, Real Estate Trust Bldg., Philadelphia, as district managers for sale of Lapp products. They will serve eastern Pennsylvania, southern New Jersey, Delaware, Virginia and District of Columbia.

The Robert June Engg. Management Company, Detroit, has moved to larger quarters at 2208 W. Grand Boulevard, Detroit, where it now occupies the entire building. This is the organization's fourth move in four years to larger quarters.

Increase in General Electric Orders.—Orders received by the General Electric Company for the first three months of the present year totalled $86,433,658, Gerard Swope, president, has announced. This compares with $83,846,236 for the first three months of 1925, or an increase of three per cent.

New Diesel Engine.—The Foos Gas Engine Company, Springfield, O., has developed a new Diesel engine with a speed range approximately double that of other designs. The engine weight has been reduced to about 50 pounds as against 100 to 300 pounds per horse power in other Diesel engines. It is also novel in being completely enclosed, and the same is true of its lubrication which is completely automatic.

Static Condensers.—The Westinghouse Electric & Mfg. Company has recently developed a new line of static condensers for individual motor application on motor circuits of 220, 440 and 550 volts for two- and three-phase circuits. The new condenser consists of insulation enclosed in a sheet-metal container and a porcelain terminal housing arranged for conduit connections. The condensers will be displayed at the coming N. E. L. A. Convention at Atlantic City.

Largest Steam Turbine for Commonwealth Edison Company.—A cross-compound turbine, to be rated at 90,000 kw. is being built for installation at the Crawford Avenue Station of the Commonwealth Edison Company of Chicago by the General Electric Company. The turbine will consist of two sections, a high pressure element of 35,000 kw. capacity running at 1800 r. p. m., and a low pressure element of 55,000 kw. at 1200 r. p. m. The addition of the new machine will bring the installed capacity of this station up to 327,000 kw. It is expected that the ultimate capacity of the station will reach 750,000 or even 1,000,000 kw.

The National Carbon Company, Inc., New York, has taken over the plant, inventory and good will of the Corliss Carbon Company, Bradford, Pa., and has also purchased the battery business of the Manhattan Electrical Supply Co., New York, N. Y. The latter purchase includes the battery plants at Jersey City, N. J., and at Ravenna, O., trademarks, patents, etc. The trademark "Red Seal" under which the Manhattan batteries have been advertised will be continued. J. F. Kerlin, president of the Corliss Carbon Company, and formerly assistant general sales manager of the National Carbon Company, Inc., will assume the position of vice-president of the latter company and have complete charge of the sale of all carbon products.

The Wm. Cramp & Sons Ship & Engine Building Company, Philadelphia, has recently secured hydraulic machinery contracts for seventeen units totalling nearly one-half million horse power. The turbines, water wheels and other hydroelectric devices comprising these orders will be installed in Brazil, Japan, Canada and the United States. One contract calls for a 56,000 h. p. impulse wheel, the highest powered of its kind intheworld.

Two 5000 h. p. Moody propeller turbines are intended for the Maribondo Development in Brazil, and two 29,000 h. p. turbines for the Nippon Electric Company, Japan. Two 31,000 h. p. and one 25,000 h. p. units are to be installed in the Norwood Development of the Carolina Power & Light Company. The 56,000 h. p. impulse wheel is being built for the Southern California Edison Company in the San Francisco plant of the Pelton Water Wheel Company, which is owned by the Cramp Company. Two 30,000 h. p. impulse wheels have been ordered by the Feather River Power Company.

The Dominion Engineering Works, Ltd., Montreal, Canadian licensee of the Cramp Company, has secured contracts for three 30,000 h. p. units and three 21,000 h. p. units for the Canadian International Company, and one 28,000 h. p. Moody propeller unit for the Manitoba Power Company.

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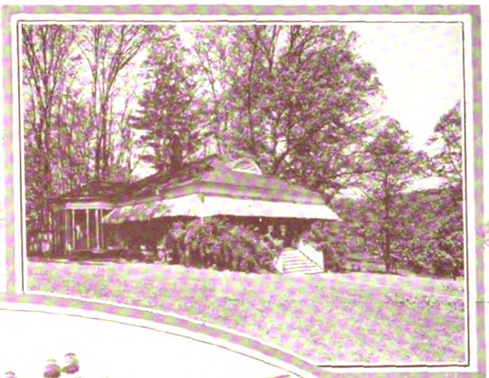
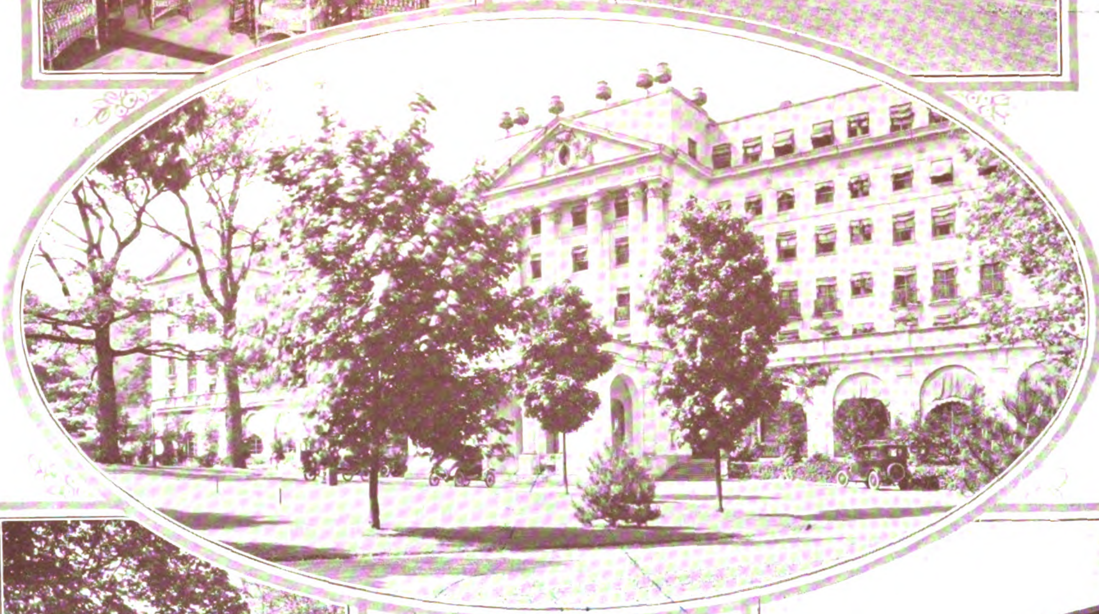
White Sulphur Springs, W. Va., June, 21-25





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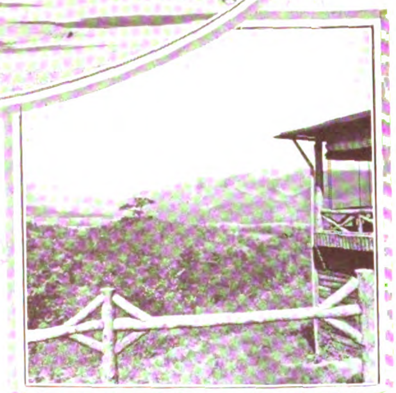

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American Institute of Electrical Engineers

COMING MEETINGS

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV JUNE, 1926 Number 6

Requirements for Admission and Transfer

The rapid growth of the Institute during the last few years has necessarily more directly affected the work of the Board of Examiners than that of any other group engaged in A. I. E. E. activities. Forty-two hundred applications were considered during the year ending April 30, 1926, of which one hundred and forty-four were direct admissions and two hundred and fifty-six were transfers to the grade of Member or Fellow. Each of these latter four-hundred cases were reviewed through the careful examination of the complete professional records as submitted by the applicants and the weighing of the statements of the references. Many cases are of course easily disposed of because of the unquestionable eligibility of the applicants to the grades for which the applications are made. The Examiners have found, however, that there is a considerable group, composed of doubtful cases, and it is this group that requires a large part of the Board's time. Many of these cases are doubtful apparently through the failure of the applicants to devote sufficient time and effort to the submission of their records and references.

The electrical field today is of such vast proportions that no group of men, no matter how carefully selected, is competent to judge the importance of an applicant's work where the outline of that work is confined to a simple statement of dates and positions held. Again, two or more positions with exactly the same titles but in different companies, may involve widely different responsibilities. Considering this simple illustration alone, of hundreds that continually arise, the Board of Examiners urges all applicants to furnish records in sufficient detail to give the Board a definite idea of the engineering nature of their work and the degree of responsibility imposed upon them in the execution of that work. References should be selected particularly to cover the period of work on which the application is based. This usually means the last five or ten years, depending upon the grade desired.

If those instrumental in recommending new members will impress these facts on the applicants, and those applying for transfer will keep them in mind, much unnecessary correspondence will be eliminated and action on all applications will be greatly expedited.

The Board of Examiners feel, and every member of the Institute, as well as everyone outside its membership who comes in contact with it, should feel, that admission or transfer in the A. I. E. E. is not a matter to be regarded lightly but one well worthy of every effort that can be put behind it.

Some Leaders of the A. I. E. E.

John J. Carty, pioneer in the development of the telephone art since 1879, was the twenty-eighth president of the American Institute of Electrical Engineers, through the term 1915-1916.

Mr. Carty was born in Cambridge, Mass., April 14, 1861. Starting at Boston, he has been in the Bell System continuously since he left the Cambridge Latin School in 1879. In 1887 he came to New York, and spent two years with the Western Electric Company in cable and switchboard development. In 1889, he went to the New York Telephone Company, of which he became Chief Engineer.

In 1907 he was appointed by Theodore N. Vail to the office of Chief Engineer of the American Telephone and Telegraph Company, and built up the staff through which he directed the engineering and research work of the Bell System. In 1919 he was elected vice president of the company, which position he still holds.

While at Boston, he designed and constructed the first metallic circuit multiple telephone switchboard. During 1889-1891 he published his original researches in inductive interference and upon his experiments is based the theory of transposed metallic circuits. Mr. Carty has numerous telephone inventions to his credit, including the method of the common battery now in general use, and the bridging bell which forms the basis of all farmers' party-line telephones.

Among the engineering advances made under his administration was the completion, on January 25, 1915, of the transcontinental telephone line, making possible, for the first time, the transmission of speech from coast to coast. In the same year, there was accomplished by the staff under his charge the first transmission of speech by radio across the Atlantic Ocean, across the continent to San Francisco and to the Hawaiian Islands.

From the Institute headquarters in New York, he presided over its National Meeting, held May 16, 1916 in six cities; Boston, San Francisco, Atlanta, Chicago, Philadelphia, and New York. By means of the long distance telephone, the members in these remote cities took part in the discussions and in the parliamentary proceedings of a joint meeting—the first of its kind

ever held. In a message of congratulation, President Wilson said: "To conduct such a meeting by telephone and make it possible for men scattered all over the country to listen to the proceedings and participate in them, is certainly a most interesting evidence of the inventive genius and engineering ability represented by the Institute."

In the Officers' Reserve Corps Mr. Carty was a Major and upon the declaration of war, was ordered into active service. Under the direction of the War Department, and with the cooperation of the telephone companies, he organized in the Bell System, twelve battalions of Signal Corps troops. He was promoted to Colonel in the Signal Corps, U. S. A., and served in France on the staff of the Chief Signal Officer of the A. E. F. In cooperation with that officer, he designed the telephone and telegraph system for the American Army in France, and was Signal Officer in charge of communications, American Commission to Negotiate Peace. He received the Distinguished Service Medal from General Pershing in France, the thanks of the French Army and the Cross of the Legion of Honor.

For many years, Mr. Carty has been active in the movement to encourage scientific research in universities and among the industries. He is now Vice Chairman of the Trustees for the National Research Endowment Fund for the support of pure science research, of which Hon. Herbert Hoover is Chairman. He is also a trustee of the Carnegie Institution and of the Carnegie Corporation; a member of the Council of New York University, a member of the National Academy of Sciences and the National Research Council, Honorary Member of the Franklin Institute, from which in 1903 he received the Edward Longstreth Medal for his "bridging bell system;" and the Franklin Medal in 1916, for signal eminent service in science. In 1916 the Edison Medal was bestowed upon him for "work in the science and art of telephone engineering."

The Japanese have decorated him with the Order of the Rising Sun and the Order of the Sacred Treasure, and twice their government extended to him its official thanks for services in connection with the establishment and development of the telephone system there.

He is a Brigadier General in the Reserve Corps of the United States Army, a member of the War Department Business Council, an Honorary Advisor to the Army Industrial College, and national President of the American Signal Corps Association.

Stevens Institute of Technology, and New York University have conferred upon him the honorary degree of Doctor of Engineering; Yale, Princeton, the University of Chicago, Bowdoin and Tufts the degree of Doctor of Science and from McGill University, and the University of Pennsylvania he has received the degree of Doctor of Laws.

Electrification and Farm Prosperity

The unfortunate condition of agriculture in comparison with the exceptional prosperity of other industries in this country in recent years, has called forth many suggested remedies, among which are various bills now before Congress. Prosperity, however, cannot be obtained by legistation except as it may remove obstacles, and the seasonal character of agriculture and the fact that the farmer buys his supplies at prevailing high prices and sells his product in a competitive low market are facts that cannot be legislated away.

A more promising solution of the farmer's difficulties is suggested in an address by General Guy E. Tripp, at the recent N. E. L. A. Convention. A similar solution was also given in an address by President Glenn Frank at the recent Madison Regional meeting of the A. I. E. E. The remedy is the decentralization of industry.

Electric superpower systems are vital to industrial decentralization. Without these systems, industries will not spread out into the country, regardless of advantages to be secured by doing so, but will remain in congested centers. But wherever superpower systems are well developed, power can be secured almost anywhere. Hence, as superpower systems grow, small factories will multiply in the rural districts.

Now, the chief obstacle to the electrification of our farms is the high cost of bringing electric service to them. It usually does not pay to tap a high-tension line and build a low-tension line to take care of the relatively small demand of a few scattered farms, but it frequently does pay to do these things to serve an industry; and when once a service connection is made and a line is built, neighboring farms can then be supplied with electric power at a reasonable cost. Hence, as small factories multiply in the rural districts, more and more farms will be electrified.

No one questions the great value of electric power to the farmer. Give the farmer electric power at a reasonable cost, and he can immediately relieve himself and his family of a large portion of their burden of labor, reduce his costs, make his profits more certain, and, what is of equal importance, raise his standard of living to a level corresponding to that of the city dweller, which will improve the morale of his family, help to keep his children at home and make it more easy for him to secure efficient labor when he needs it.

To sum up, the decentralization of industry will enable the farmer to broaden the earning capacity of his family, increase the business value of his farm and make his home more attractive. It appears, indeed, to be the most promising, if not the only practical influence that will bring agriculture back into step with other American industries and restore prosperity to it. If this can be done, it will mean the elimination of discontent and radicalism from a large and influential proportion of our population.

Abridgment of

The Quality Rating of High-Tension Cable With Impregnated Paper Insulation

BY D. W. ROPER[1] and HERMAN HALPERIN[1]

Fellow, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*During the past five or six years, practically all of the American cable manufacturers have made some changes in their impregnating compound to produce cable having a low dielectric loss. In a number of cases, these compounds were not well chosen. During the same period, some of the operating companies have reduced the thickness of their insulation, resulting in increased dielectric stresses.*

In a number of cases the compounds, and perhaps also the paper that was used, developed faults that were more serious than high dielectric loss. Some cables have been very deficient in dielectric strength and others have developed a new type of trouble which has been termed "ionization;" after a comparatively short time, the operating voltage of such cable had to be materially reduced or the cable replaced, in order to keep the lines in service.

The cable manufactured during this period has generally passed, with a wide margin, the high-voltage tests required by the specifications. Occasionally a lot of cable which passes these tests by a narrow margin will be shipped by a manufacturer and, in such cases, the service record of the cable is unsatisfactory.

The investigations which form the basis of this paper consist of, (a) laboratory tests to determine what high-voltage tests cable, known to be of good quality, will withstand; as well as similar tests on other grades of cable. (b) A careful examination and dissection of samples of the cable as received from the factory and samples removed from lines which have failed in service or which have been in service for a number of years without failure. (c) A comparison of the operating records of the cable with the results of the dissection and examination of the samples and with the factory inspection and tests made on the cable before shipment. (d) Accelerated life tests on long samples of cable having a wide range in quality.

The results of these investigations have been correlated in a manner which permits of the determination of the relative quality of several lots of cable purchased, as well as changes in the specifications which must be made in order to secure satisfactory high tension cable with impregnated paper insulation.

* * * * * * *

INTRODUCTION

AFTER the first few years of experience with impregnated paper-insulated, lead-covered cables, it was thought that a solution of resin in resin-oil would be most suitable for the impregnating compound, and for a number of years this type of compound was used by practically all the American manufacturers, excepting one or two who instead, used a solution of resin in mineral oil. Cables operating above 7500 volts had a large dielectric loss and this caused many failures due to cumulative heating, and made it necessary to operate them at materially smaller currents than permissible on low-tension cables with no dielectric loss. Upon this point being brought to the attention of the manufacturers about 1917, changes were made in the impregnating compound, so that by 1923 the dielectric loss had been reduced to such an extent that its effect in reducing the carrying capacity became almost negligible.

The test results in recent years indicated that the thicknesses of insulation were more than necessary, and accordingly some of the large operating companies purchasing large amounts of cable made reductions in the thicknesses or increased the voltage rating for a given thickness, for the purpose of reducing cost and increasing line capacities, and *thus* increased the dielectric stresses.

The changes in the impregnating compounds and increase in the dielectric stresses developed a large amount of operating troubles on the newer cables, which made it necessary to replace them in some cases, and reduce the voltage in others.

Up to the time that troubles of this kind developed, it had been customary in this country for the cable manufacturers to supply cable to the larger operating companies under a five-year guarantee; and the manufacturers' expense, due to this guarantee, was very slight as most of the claims were due to defective workmanship in the factory or mechanical damage during shipment. The claims for dielectric loss failures were practically eliminated by the A. I. E. E. rule for maximum operating temperature of 85 deg. cent. minus E, with E as rated voltage in kv. About two years ago, the American manufacturers reduced their five-year guarantee to a maximum of two years.

The principal safeguard of the purchasers had rested in the five-year guarantee, as, for cables above 7.5 kv., normal operating voltage, the factory tests were quite perfunctory. The tests served merely to eliminate sections with very defective workmanship, but gave no clue to the quality of the insulation unless it was very bad indeed.

The situation to-day is not greatly different. High-voltage cable which will meet the requirements of all specifications which it has been possible to obtain and which are published in any country, may prove an utter failure within less than one year of operation at its rated voltage. Troubles of this character have

1. Both of the Street Dept., Commonwealth Edison Co., Chicago, Illinois.

Presented at the Regional Meeting of the A. I. E. E., Madison, Wis., May 6-7, 1926. Complete copies available upon request.

not been confined to any one country, manufacturer, or operating company; several cases of such trouble have occurred within the year immediately preceding the presentation of this paper. High-voltage cables that have proved successful in service will pass all requirements of the most recent specifications by margins of the order of 30 to 100 per cent.

As some of the troubles take two or more years in developing, it is entirely possible for the guarantee period to expire before the trouble has become apparent, and then the operating companies are confronted with the proposition of replacing the cable at their own expense or operating it at a greatly reduced voltage. Therefore, the reduction in the guarantee period threw upon the operating companies, with the aid of the manufacturers, the responsibility of devising tests to be made upon the cable at the factory before shipment, to permit of a determination as to whether or not the cable will operate satisfactorily.

Some manufacturers stated that the troubles were due to imperfect impregnation and suggested an ionization test for the purpose of determining which cables were satisfactory. Such a test has been used in recent specifications. Further improvements were made by making moderate increases in the test voltages, but in spite of these slight changes the troubles continue.

This paper describes the methods which have been used in correlating operating experience on about 4,000,000 ft. of high-voltage, three-conductor cable

TABLE I

QUALITY RATING OF 500,000-CIR. MIL, THREE-CONDUCTOR, 13,000-VOLT CABLE

Item No.		Base Weight	Limits between which values were proportioned		Values for Various Manufacturers				
			Zero Weight	Full Weight					
	Manufacturer Year Made				*A* 1925	*B* 1925	*C* 1925	*B*[1] 1922	*D* 1925-6
	A—Results of dissections and visual examinations								
1.	Workmanship on copper	4	Serious imperfections	No imperfections	2.0	3.0	2.5	3.0	4.0
2.	Workmanship on lead	2	Serious imperfections	No imperfections	2.0	2.0	2.0	2.0	2.0
3.	Workmanship on insulation and fillers	8	Serious imperfections	No imperfections	7.5	6.5	6.0	6.0	5.0
4.	Thoroughness of imprgenation	8	Poor throughout	Perfect throughout	7.0	7.0	4.0	1.0	7.0
5.	Tearing in bending tests	4	2 adjacent tapes at one point; 3 torn tapes per foot of cable	No tears	3.6	3.9	4.0	2.0	1.0
	B—Results of factory and laboratory tests on insulation								
6.	Ratio of max. to min. insulation resistance—for lots —for sections	6	3.0 1.5	1.3 1.075	4.6	4.3	− 1.0	− 8.4	4.4
7.	Dielectric loss at 80 deg. cent, watts per foot	4	0.75*	0.075*	3.6	2.4	3.2	2.2	1.3
8.	Increase in power factor at room temperature from 20 to 100 volts per mil of insulation	8	0.02	0.00	3.2	0.6	0.2	0.0	2.2
9.	Puncture voltage on straight samples, kv	17	74.5	119.0	8.2	9.0	4.0	− 1.7	15.9
10.	Puncture voltage on cold bent samples, kv	18	65.0	104.0	21.2	22.6	8.3	− 8.8	26.3
11.	Ratio of item 10 to item 9	8	0.75	1.0	8.0	8.0	7.4	− 2.9	8.0
	C—General								
12.	Uniformity of insulation	13	Serious variations in quality of insulation	Reasonably uniform quality	11.0	11.0	6.0	7.0	11.0
	Total, Examination	26			22.1	22.4	18.5	14.0	19.0
	Total, Tests	61			48.8	46.9	22.1	−19.6	58.1
	Total, General	13			11.0	11.0	6.0	7.0	11.0
	Grand Total	100			81.9	80.3	46.6	1.4	88.1

*Corresponding power factors of dielectric are 10 per cent and 1 per cent at 60 cycles.

EXPLANATION

Items 1, 2, 3, 4 and 12, in the absence of definite limitations in the specifications, are based on arbitrary standards established for the guidance of the inspectors. The standards for zero weights would generally have caused the rejection of the cable had they been noted at the factory.

The figures for zero weight for Items 5, 6, 8, 9, and 10 are the requirements of the latest specifications under which the cable was purchased. Full weight is given for Items 6, 8, 9 and 10 for values which would give a large factor of assurance for these qualities. All of these values appear possible of attainment in the present state of the art.

Zero weight and full weight for Items 7 and 11 are about the extreme limits of current American practise. The reasons for Item 11 are given at some length in the paper.

In Item 6 the variation in insulation resistance is based on the largest ratios found for the insulation resistances in the lots of cable as submitted for inspection and tests by the manufacturer and also on the largest ratio of the insulation resistances of the several conductors of any given section in each lot. The weight for this item is divided equally between the values for the lots of cable and for the individual sections. The latter part would disappear for single-conductor cable.

The values for Items 1, 2, 3 and 4 were determined by the inspection at the factory plus information obtained during and after installation. The values for Items 6 to 10, inclusive, were based on the averages of the poorest 20 per cent of the test results. In Items 1, 2, 3, 4, 5, 8 and 12 the values given to each manufacturer were proportioned between zero and base weight and no negative values or bonuses were given on these items. In Items 6, 9 and 10 the values were proportioned arithmetically between zero and full weight and negative values were given if the results were poorer than the values for zero weight, and extra weight was given when the results were better than required for full weight. In Items 7 and 11, negative values were given if the results were poorer than required for zero weight, and no extra value was given if the test results were better than required for full weight.

All values are based on tests and inspection of cable received and accepted by the purchaser.

Note: At least 9 mi. of cable are represented in each of the above ratings.

TABLE II

QUALITY RATING OF 350,000-CIR. MIL. THREE-CONDUCTOR, 35,000-VOLT CABLES

Item No.		Base Weight	Limits between which values were proportioned: Zero Weight	Full Weight	Values for Various Manufacturers					
	Manufacturer				*M*	*N*	*O*	*P*	*Q*	M^1
	Year made				1925	1924	1924	1924	1924	1923
	A—Results of dissections and visual examinations									
1.	Workmanship on copper............	3	Serious imperfections	No imperfections	2.7	3.0	2.3	2.6	2.5	2.0
2.	Workmanship on lead............	2	Serious imperfections	No imperfections	2.0	2.0	2.0	2.0	2.0	2.0
3.	Workmanship on insulation and fillers	8	Serious imperfections	No imperfections	7.0	7.5	3.5	3.0	5.0	1.5
4.	Thoroughness of impregnation.......	8	Poor throughout	Perfect throughout	7.0	7.0	7.0	5.0	5.0	3.0
5.	Tearing in bending tests............	3	2 adjacent tapes at one point; 3 torn tapes per foot of cable...........	No tears	2.9	0.5	0.5	2.0	3.0	2.5
	B—Results of factory and laboratory tests on insulation									
6.	Ratio of max. to min. insulation resistance—for lots...............	6	3.0	1.30	6.0	4.8	5.9	5.3	0.3	−4.8
	—for sections............		1.5	1.075						
7.	Dielectric loss at 80 deg. cent.-watts per foot..........................	7	2.1*	0.35*	3.7	2.0	0.0	6.0	6.2	0.1
8.	Increase in power factor at room temperature from voltages of 20 to 100 volts per mil of insulation.......	8	0.02	0.00	3.3	0.4	0.0	0.4	0.0	0.0
9.	Puncture voltage on straight samples, kv..............................	17	160	256	17.7	16.3	7.1	2.3	−1.8	−1.8
10.	Puncture voltage on cold bent samples, kv.........................	17	140	224	20.2	12.1	12.1	10.1	−2.0	−3.4
11.	Ratio of item 10 to item 9...........	8	0.75	1.0	5.6	1.4	8.0	8.0	3.8	2.2
	C—General									
12.	Uniformity of insulation............	13	Serious variations in quality of insulation	Reasonably uniform quality	11.0	12.0	12.0	6.0	10.0	5.0
	Total, Examination...............	24			21.6	20.0	15.3	14.6	17.5	11.0
	Total, Tests.....................	63			56.5	37.0	33.1	32.1	6.5	−7.7
	Total, General...................	13			11.0	12.0	12.0	6.0	10.0	5.0
	Grand Total......................	100			89.1	69.0	60.4	52.7	34.0	8.3

*Corresponding power factors of dielectric are 6 and 1 per cent at 60 cycles.
The same letters are used in Table II and Fig. 12.
The data were obtained from orders of several thousand feet of cable for columns *M* and *Q*; all other ratings represent several miles of cables.
The explanation under Table I also applies to Table II.

purchased in the past six years from ten manufacturers, with the specification requirements and test results so as to determine what changes and additions should be made in the present requirements.

The object of the investigation upon which this paper is based was to determine just what properties of the insulation were responsible for the failures of the cable in service and to indicate the changes that should be made in the cable specifications in order to materially reduce the number of service failures.

OUTLINE OF METHODS

With such a complex material as impregnated paper insulation having a number of widely different and independent qualities or characteristics, it is practically impossible to compare the products of different manufacturers or different lots from the same manufacturer by any single measurement. The most feasible method of making a reasonably accurate comparison is to adopt the scheme which has been used by engineers with other types of material, that is, to assign weights to the various qualities in the light of past experience, and determine from test or inspection data the percentage of the maximum weight for each item which should be allotted to each manufacturer or lot of material.

Rating tables were first used by the authors to compare the quality of cable indicated by proposals from manufacturers, and later to compare cable actually shipped. At first the ratings were purely relative and did not permit a determination of the amount of improvement which the manufacturers made from year to year. To obtain this amount, the basis was later modified so as to make all of the comparisons on a fixed basis, which meant the adoption of a standard for each of the items considered. Tables I and II give such quality ratings for 13- and 35- kv. cables, respectively. Sixty-cycle current was used for all alternating-current tests.

During this period, it was the practise to make a careful examination of the cable immediately adjacent to each fault and also at the manhole ends of the same section of cable. A detailed study of the results of these examinations as the data accumulated and a careful comparison with the test and inspection data permitted the primary cause of the troubles to be determined. A reference to the corresponding test and inspection data then furnished a basis for determining the base weights for each item, a part of the limits between which the values were proportioned, and the values assigned to the several manufacturers for the various items in the tables.

A perfect method of rating the quality of cables would accurately predict their operating performance

over a wide range of quality of insulation and be equally applicable to the widely varying types of insulation now on the market. In the past few years there has been received cable ranging in quality from poor to excellent. The system of the Commonwealth Edison Company includes over 1300 mi. of 9- to 35-kv., three-conductor cable. For all of this cable the service records test and inspection data on the 800 mi. purchased during the past six years from 10 manufacturers were at hand. In making attempts to devise a quality rating method, each new constructive suggestion was tested by calculating a new rating table with the same original data in the endeavor to secure results which would at least rate the cables in their proper order of merit.

By carefully going over the operating records and comparing them with the test and inspection data and the results of examination of the cable near failures, the rating tables were altered and adjusted so as to bring the final results in accord with the operating experience.

While these studies were in progress, a series of tests had been undertaken to determine what high-voltage tests successful cable should withstand. After some data had been obtained, it appeared perfectly feasible to devise an accelerated life test so that the approximate life of the cable would be indicated by the time that the cable withstood the test. This resulted in another method of rating the quality of cables entirely independent of the first.

High-Voltage Tests

For many years it had been noted that the high-voltage tests which the cables actually withstood when tested at the factory were very much higher than the specification requirements. It had also been noted in a few lots of cable which had proved to be of inferior quality that the high-voltage test results were only slightly higher than the specification requirements. A series of high-voltage tests were, therefore, undertaken to determine what changes should be made in the specification requirements in order to eliminate such inferior lots of cable and, at the same time, allow the manufacturer a reasonable margin.

In the initial tests, the sections of cable were from 100 to 200 ft. long. Previous to applying the voltage, several thermometers were fastened to the lead sheath. With voltage on the cable, the sheath, which was grounded, was examined by the test operators about every 10 minutes, in order to detect points where the sheath temperature was higher than the remaining portions. At these points, which were called "hot spots," an additional thermometer was fastened to the sheath.

After failure occurred, portions of the cable including the fault and perhaps "hot spot" sections would be removed, dissected, and examined. The remaining portion of the length was again tested and this procedure was continued until the cable became too short for further tests. Usually three to seven tests were obtained on each original section of cable.

Several test voltage procedures were tried but most of the tests were made with an initial voltage of 3.6 times normal voltage. As this voltage made the tests unduly long for high grade 13-kv. cable, it was decided to increase the voltage 20 per cent after eight hours, and further increase the voltage 20 per cent after a second eight-hour period. Later, in order to obtain voltage-time curves, tests were made on samples from given sections of cable at a number of voltages maintained constant until failure occurred.

About 8000 feet of cable have been used in making some 250 such tests. The cable was about equally divided between new and second-hand cable. In selecting the sections of cable for these tests, samples were obtained from the cable that had been shipped by the several manufacturers. The sections of second-hand cable were selected so as to obtain similar data for cables of a wide range of quality whose service records were definitely known. The sections of cable used for this purpose were removed on account of failure, external damage, or changes in the transmission system.

Discussion of Quality Ratings

A. Workmanship

The first five items in Tables I and II can be considered under the general heading of workmanship. The information for calculating the values for these items was secured from the factory inspection reports and by examination of samples of cable taken from the ends of sections as received or from the middle of the sections whenever possible. Further information was obtained from time to time by the examination of samples of cable taken from sections removed on account of failures in service or other causes.

A large variety of defects in the conductors, lead, and insulation has been noted in these examinations, and values were assigned to the first four items in the rating tables on the basis of the influence of similar defects found at or near the points of failure which have occurred on test or in service.

Impregnation. The impregnation of paper-insulated cable is satisfactory when:

1. The compound is suitable for the purpose.
2. The impregnating process is performed to completely remove the air and moisture and thoroughly impregnate the insulation, filling all voids in the conductor and in the insulation.

Several tests have been evolved to determine whether the compound will be stable, but such a test was not included in the specifications for the cable covered by this paper. Therefore, Item 4 of Tables I and II refers to the completeness of the impregnation only.

The cable manufacturers contributed considerable discussion on the item of impregnation in commenting on the earlier rating tables, and apparently this dis-

cussion was warranted by the importance of the subject. No satisfactory explanation has been obtained for the marked differences found in the impregnation on the three conductors at one place in the cable nor for the large differences in impregnation throughout the length of one section.

When the insulation is examined near a point where failure, due to ionization has occurred, a pronounced difference in the impregnation is frequently found as, for example, the insulation of one conductor filled with the evidences of ionization while the insulation of the other two conductors will be entirely free from such evidence. In other cases, many evidences of ionization will be found in the insulation of all three conductors near the point of failure, but will be entirely lacking in the manhole ends of the same section of cable.

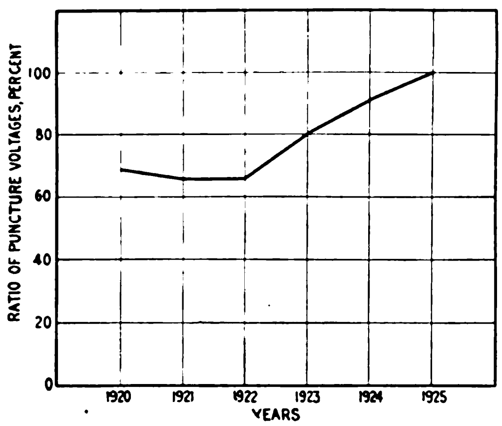

FIG. 1—CHANGE WITH TIME OF RATIO

Puncture voltage on cold bent sample
Puncture voltage on straight sample

Tearing of Paper Tapes in Bending Tests. The routine tests on the cable at the factory include a bending test on an occasional short sample that has been cooled to the minimum operating temperature which, for Chicago, is about minus 10 deg. cent. This is followed by a puncture voltage test and, later by an examination of the paper tapes in a three-foot section of the cable, cut from the middle of the bent portion. The number of tears of the paper tapes are noted and recorded.

During the past few years, the leading American manufacturers have made some marked improvements in the workmanship of the insulation as shown by the paper tapes being applied more smoothly and evenly, the number of torn tapes in the bending test considerably reduced, and the impregnation improved. The extent to which these improvements in workmanship have improved the quality of the insulation is indicated by the reduction in the effect of the bending test on the dielectric strength of the insulation.

The extent of this improvement is shown in Fig. 1 which gives the ratio of the puncture voltage, obtained on the samples that have been subjected to the cold bending test, to the puncture voltage obtained on the straight samples. During the past few years this ratio has risen from about 65 per cent to 100 per cent. It appears therefore that this ratio can be used as an excellent test for workmanship.

B. TESTS ON INSULATION

Insulation Resistance. The insulation resistance test is measured for each of the conductors of each section of the cable, and the greatest present use for the results is as an indication of the uniformity of the manufacturing processes. In Fig. 2 is shown the variation in insulation resistance of 125 consecutive reels as submitted by two manufacturers.

Figs. 3 and 4 show the variation of the power factor of the dielectric with the insulation resistance as obtained from 30 consecutive reels submitted by two manufacturers.

Fig. 5 shows similar data from two different lots of cable submitted several months apart by another manufacturer, and from such data and from other tests showing that no change in the paper was made during the same period, it is evident that the cable manufacturer changed the impregnating compound, a conclusion which has been verified by the manufacturer.

Dielectric Loss at 80 Deg. Cent. For uniformity, the dielectric loss at 80 deg. cent is used for comparison, although for 35-kv. cable it is realized that this is

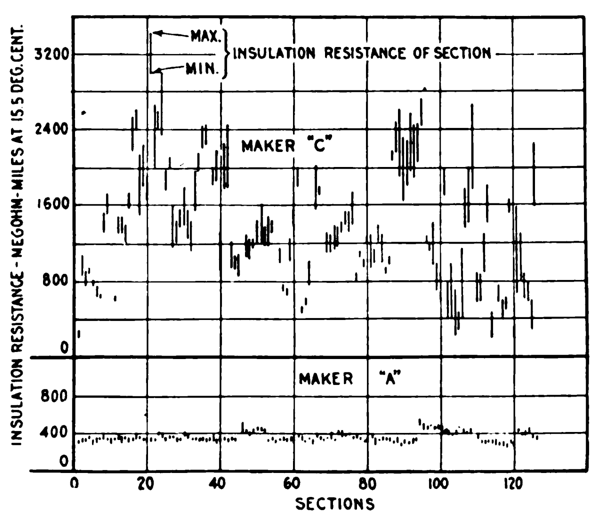

FIG. 2—INSULATION RESISTANCE VS. ORDER OF PRESENTATION OF SECTIONS

500,000-cir. mil, three-conductor, 13-kv. cable made in 1925
Note: The letters used designate the same manufacturer throughout the paper except for Table II and Fig. 12

above the standard maximum operating temperature. However, operating conditions occasionally arise which render it expedient to carry an abnormal load on a cable for a short time rather than open the line and cause interruption of service. The dielectric loss tests at 80 deg. cent. permit the heating of the cable under such abnormal conditions to be predetermined.

The manufacturers are now furnishing cable for voltages up to about 20-kv. with insulation of such

low dielectric loss that this loss does not reduce the carrying capacity of the cable more than one or two per cent. For practical purposes this may be considered negligible. The effect of the power factor of the dielectric on the permissible current loading of cables is indicated by the fact that if the power factor is five per cent then the dielectric losses of three-conductor 13-kv., three-conductor 35-kv., and single-conductor 132-kv., cables of the Commonwealth Edison Company are, about 0.37, 1.75, and 8.0 watts respectively per foot of cable. Since the maximum allowable copper temperature determines the total heat loss in the cable it follows directly that for commercial consideration, as the operating voltage increases, the maximum allowable power factor must decrease. Experience has shown that a dielectric loss of 1.75 watts per foot of the 35-kv. cable does not result in service failures due to cumulative heating. The recent product of some of the leading manufacturers has shown losses materially below this figure.

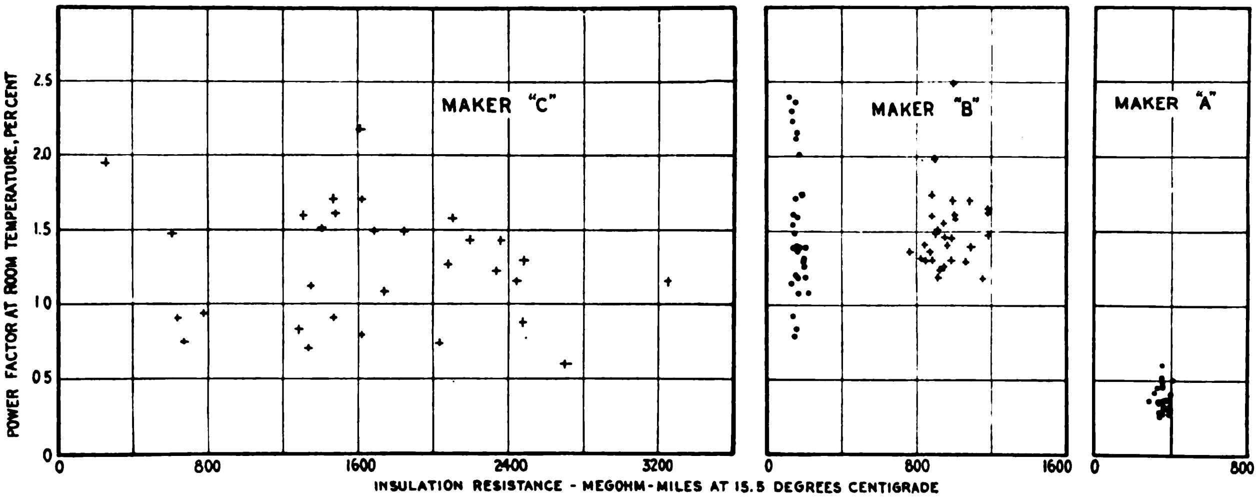

FIG. 3 FIG. 5 FIG. 4

FIGS. 3-4-5—POWER FACTOR VS. INSULATION RESISTANCE

For 500,000-cir. mil, three-conductor, 13-kv. cable, made in 1925 by three manufacturers.

Cables have 18/64 in. insulation between conductors and 14/64 in. insulation between each conductor and sheath

Power factor of dielectric is value obtained at room temperature on each section of cable at 100 volts per mil of insulation thickness. Insulation resistance is average for value for three-conductors obtained by the standard method with direct current

Data are shown for 30 consecutive sections of cable from makers *C* and *A* and for two lots of 30 consecutive sections, each presented several months apart, by maker B.

"IONIZATION" TEST

A test made by measuring the increase in power factor over a certain specified range in voltage, say, from 20 to 100 volts per mil of insulation thickness, is called an ionization test. Several recent specifications require such a test on each section of cable.

Several European manufacturers contend that there should be no increase in power factor for about this change in voltage, while another manufacturer states that increases of one and two per cent for, respectively, single-conductor and three-conductor cables indicates satisfactory impregnation. Probably each statement is correct as applied to the particular combination of paper and impregnating compound in the cable from which the experience was obtained. Fig. 6 shows a number of curves taken from actual tests on samples of commercial cables made by manufacturers that are considered among the leading manufacturers in the world. Some of these cables having the greatest increase in power factor over the specified range in voltage have given the best service, while other cables having a very small increase in power factor have been found

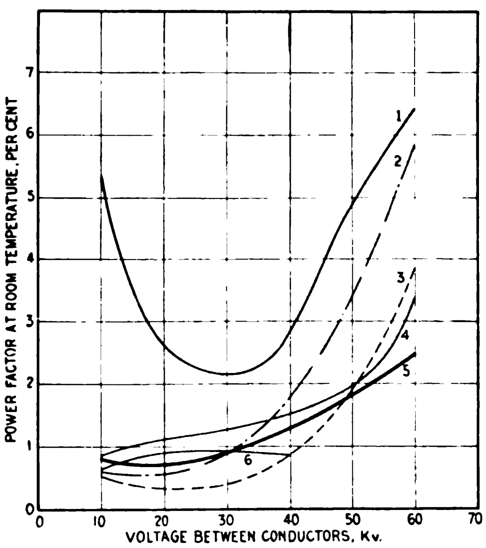

FIG. 6—POWER FACTOR VS. VOLTAGE

For 350,000-cir. mil, three-conductor, 35-kv. cables from various manufacturers

unsatisfactory for service at their rated voltage. In several cases, subsequent tests have developed proof that the impregnating compound was unstable, and this means that a test on the impregnating compound

itself is also necessary in order to insure satisfactory cable.

All these facts indicate the necessity of considerably more information before the proper limits for the increase in power factor can be fixed for the various types of insulation, so that all types will be equally satisfactory.

The visible evidence of high-voltage discharges or of ionization which are found upon dissecting the affected insulation, in the order in which they usually appear to develop in service, are:

a. Waxy flakes and black spots in the compound

b. Black and brown spots in the paper

c. Fern leaf or tree designs in the paper, and pin holes through the paper.

Figs. 7, 8 and 9 show evidences of these defects.

The evidences of ionization are generally found in the largest quantity where the stresses are the greatest, but their distribution throughout the insulation varies widely and appears to be affected by local variations in the impregnation. In the high-voltage tests on samples of cable, the waxy flakes develop only when the tests continue for a long time, of the order of 50 hours or longer; but the other evidences are developed by higher voltages in a much shorter time.

FIG. 7

Waxy flakes and black spots on center filler of three-conductor, 35-kv. cable, impregnated with a heavy grease. Cable was removed after being in service.

FIG. 8—MAGNIFICATION (7) DIAMETERS OF WAXY FLAKE

Removed from space between adjacent turns of tapes of conductor insulation of same cable as in Fig. 7

FIG. 9—PHOTOMICROGRAPHIC CUT OF (7) DIAMETER MAGNIFICATION SHOWING STRIP OF WAX

Along edge of a tape of the conductor insulation of cable impregnated with a heavy oil

DIELECTRIC-STRENGTH TESTS

High-voltage tests on each section of cable were never intended or considered as a test of the quality of the insulation, but were made for the purpose of eliminating sections having serious defects in workmanship. The first test required by American specifications to insure insulation of the proper quality was the requirement of dielectric-strength test on a short sample about seven years ago.

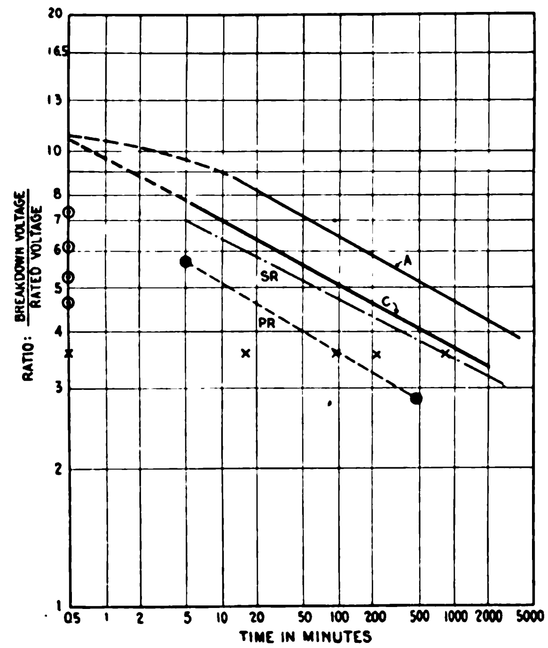

FIG. 10—VOLTAGE-TIME CURVES FOR 500,000-CIR. MIL, THREE-CONDUCTOR 13-KV. CABLES

Curves A and C represent results from tests on 20-ft. samples. Cable A appears quite satisfactory; cable C, inferior and non-uniform, as shown by wide variation in test results.

S R—Suggested test requirements

P R—Present test requirements. •Present specified tests

Typical test results on samples of cables that have proved unsatisfactory in service:

⊙Dielectric-strength tests at factory

×High-voltage tests in Chicago

It has been found that 13-kv., three-conductor cables which met all the requirements of the specifications but which failed on the dielectric-strength test made in accordance with A. I. E. E. standards at a voltage below seven times normal, have been in general quite unsatisfactory. In order to obtain definite information on the proper dielectric strength requirements, a series of high-voltage tests were made on the recent products of two manufacturers, and the voltage-time characteristics thus obtained are shown by lines A and C in Fig. 10. There is also shown typical

results of dielectric-strength tests at the factory and accelerated life tests in Chicago obtained on cable that has proved unsatisfactory in service. Tests on the products of two additional manufacturers give results above line *A*. From these data and the data obtained in factory tests and tests previously described under the subject of High-Voltage Tests, it appears quite certain that if cable will pass the voltage tests corresponding to two or three well separated points on line *S R* in Fig. 10, it will have sufficient dielectric strength to give satisfactory service. However, the cable may be deficient in other respects; for example, in ionization. At the present time it is possible to secure cable from several manufacturers which will average at least 30 per cent higher than the tests so specified and at the same time leave the manufacturer a reasonable margin.

As will be noted from Fig. 10, the test results for the dielectric-strength test for 30 seconds were about the same for cables *A* and *C*, but at lower voltages cable *A* withstood a given test voltage about five times as long as cable C. These data show that the results obtained from a short-time dielectric-strength test are misleading as an indication of the quality of the insulation. In the past, considerable reliance has been placed upon such misleading information regarding the quality of the insulation.

The dielectric-strength tests at the factory and the tests previously described under the heading High-Voltage Tests, when correlated with operating experience indicate that

1. The short-time, dielectric-strengtht est should be made at seven times normal voltage for five minutes; or, if this test introduces pothead or terminal troubles, it will be equally satisfactory to make the test at six times normal voltage for 16 minutes.
2. Satisfactory results can be secured on the short-time test with a sample about 15 ft. long under the lead.
3. A long-time test should be made on samples of the cable, and the requirements for this test should be four times normal voltage for six hours.
4. In order to secure reasonably accurate results on the long-time tests in which the failure may be caused by irregularities that require time to develop, the sample should be about 75 ft. long.

All of the points above mentioned are on line *S R* Fig. 10, and if, for practical reasons, a slight modification is desired in some of these tests, they should be made in accordance with the line.

During the last few months, long-time tests at the factory have been made so as to secure additional information. The test requirements provide that the cable shall withstand 3.2 times normal voltage for eight hours, and the procedure has been that following this test, the voltage has been raised to 5.7 times normal voltage and continued until the cable failed. The samples tested to date have withstood the higher test voltage from about 2 to 12 hours. These data indicate that satisfactory cables which are now being made for 13-kv. service will readily withstand the proposed tests of four times normal for six hours, as well as the test of six times normal for 16 minutes.

The data for lines *A* and *C* were obtained from tests on cables in which the insulation was impregnated with a grease or a heavy oil and their use should be limited to such insulation. The lines indicate that the voltage varies inversely as the seventh root of the time and this law has been found to hold in tests made by F. M. Farmer. It is entirely possible that a different line would be obtained for cable in which the insulation was impregnated with a materially different compound.

Cold Bending Test

Bending-test clauses have been made a part of standard specifications to insure that the cable will not be damaged by the bending incident to its installation in the conduit and training in the manhole. In Chicago, the conditions require that cable installation shall proceed throughout the entire year, except during the very cold days of winter months; and so the specifications for this cable have called for bending tests at temperatures of about minus 10 deg. cent. The need for such a test is indicated by investigations made several years ago which have shown that in 3 per cent of the cable which is in the manholes there are about 20 per cent of the total failures.

Ratio of Puncture Voltage Tests

It has been mentioned under the heading *Workmanship*, that the ratio between the puncture voltage obtained on the sample subjected to the cold-bending test and the puncture voltage obtained on the straight sample, appeared to be an excellent test of workmanship. There is quite a variation in the results of the tests on individual samples; *e. g.*, the puncture voltage on the cold-bent sample is sometimes 10 or 15 per cent higher than that on the straight sample. A study of recent test data shows that if the ratio were required to exceed 75 per cent, it would necessitate good workmanship and still allow an ample margin for the variation between samples.

C. Uniformity of Insulation

This item is a recent addition to the rating tables. In the product of all manufacturers, deficiencies and irregularities are occasionally noted, and some of them can be eliminated only by conscientious workmen and efficient inspectors at the factory.

Non-uniform impregnation is the most common irregularity. Many failures have occurred at points in the cable where there was a marked deficiency in the impregnation. It would be of great assistance in eliminating sections of cable having such deficiencies and in reducing the number of failures which result, if some test which would be a measure of the minimum

quality of the insulation in any section tested could be devised and applied to each section of cable at the factory.

During the high-voltage tests made on three-conductor cable, it was noted that if the voltage was of the order of five or six times normal, a buzzing or crackling noise from the electrical discharges within the insulation could be distinctly heard. At some voltage, not well defined, the internal noise becomes inaudible and, at a voltage somewhat lower, the life of the cable becomes indefinitely long. The indications are that the failures of the insulation which occurred on high voltage tests were brought about by the effect of these internal discharges upon the insulation and that eventual failure of the insulation is inevitable, if the voltage is sufficiently high to cause these internal discharges. If, then, a test could be devised which would indicate the voltage at which the internal discharges begin, this would be an indication of the limiting voltage at the weakest point in the insulation throughout the section of cable tested. Such a test applied to each section of cable would be an invaluable addition to the tests now available, as it would give a direct indication of the minimum quality of any section of cable, whereas, the best that can be accomplished with the present ionization test is to determine the average quality.

The variation in impregnation, plus local defects in workmanship and the resulting variation in the quality of the insulation in a section of cable have been the cause of many failures in service during the last few years in cable that had passed, with a wide margin, all of the requirements of the specifications. Similar variations have been frequently indicated by the results of accelerated life tests on sections of cable; and these tests have shown that if a portion of cable, a few feet long, was removed from a long section of cable, then the voltage rating of the remainder, with the same factor of safety, could be increased by amounts ranging from 15 to over 100 per cent.

Hot Spots

Further evidence of the non-uniformity of the insulation is contained in the record of the hot spots on the lead sheath in the high voltage tests. These hot spots were distributed with great irregularity along most of the sections of cable tested. The temperature of the lead sheath at these hot spots ranged from two or three deg. cent. up to 74 deg. cent. above adjacent portions of the sheath.

In tests on one section of the cable, sudden temperature rises of about eight deg. cent. developed in less than 10 minutes in two hot spots, accompanied by loud crackling and buzzing noises, followed by a disappearance of the noises, and a decrease of about eight deg. cent. in the temperatures. Then the temperatures increased five deg. cent. slowly to the end of the test, when failure occurred elsewhere. A broken filler was found at one of these hot spots.

As the location of the hot spots was recorded by reference to marks made on the original section of cable, it was possible to determine whether the hot spots would reappear at the same locations after an interruption of the test. Sixty per cent of the hot spots which developed in the first tests on 13-kv., three-conductor cable reappeared on subsequent tests. For the 33-kv., three-conductor cable, the corresponding figure was 84 per cent. In those tests where failure was in the cable and the time of the test was sufficient to result in hot spots of two deg. cent. or more above the minimum sheath temperature, 74 and 53 per cent of the failures occurred in hot spots for, respectively, the 35- and 13-kv. cables; 41 and 27 per cent, respectively, of the failures were at the maximum hot spots.

The study of all records shows that, in general, the cable manufacturers that have the best control of their materials and manufacturing processes, as evidenced by the uniformity of test results and inspection data, make the best cable.

Stability of Impregnating Compound

Recently it has been discovered that certain previously used impregnating compounds are entirely unsuitable for use in high voltage cables, that is, cables with average stresses exceeding about 40 volts per mil, and that when such compounds are used, the most perfect process of drying, vacuum treatment and impregnation will not prevent rapid deterioration of the insulation. F. M. Farmer[2] has devised a test which will indicate the relative stability of compounds. From his data it appears feasible to devise a clause for specifications which will eliminate unstable compounds. A large number of failures of the 35-kv., three-conductor cable can be directly traced to this cause aswell as a smaller number of failures occurring on 22-kv. and 13-kv., three-conductor cables.

Comparison of Quality Ratings with Accelerated Life Test Results

The relation between the quality ratings given in Table I and the results of the accelerated life tests made upon sections of the same cable is shown in Fig. 11. The variations of the individual points from the curve as drawn are no greater than might be expected from the variations in the quality of the insulation. As the accelerated life test for those cables having a life of only a few years has been found to be a fairly accurate indication of the service record of those cables, it appears that the curve in Fig. 12 verifies the results of the quality rating table, as a prediction of the service records of the cables of widely varying quality.

As the zero base weights in Table I practically correspond with specification requirements, Fig. 11 indicates that if the cable passes the specifications with a narrow margin, it will be unsatisfactory in

2. "Tests on High-Tension Cable," by F. M. Farmer, presented at Regional Meeting of A. I. E. E. at Madison, Wisconsin, on May 6-7, 1926.

service, and this indication is confirmed by experience. In the tests at the factory for cable B', the dielectric-strength tests were passed by a narrow margin, and there was a high percentage of failures in the voltage test on each section; there were several failures, both in the test after installation and in the first few months

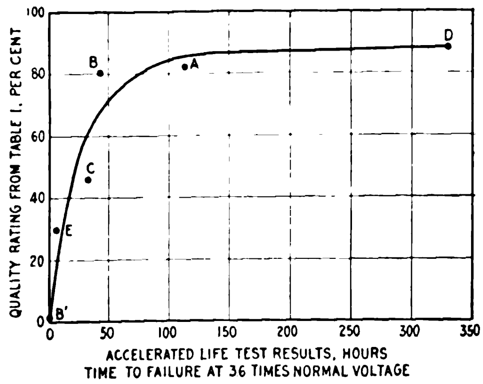

Fig. 11—Relation of Quality Ratings with Accelerated Life Test Results, for 500,000-Cir. Mil, Three-Conductor, 13-Kv. Cables

Tests which were at 46 kv. and higher were evaluated for 46 kv., which results in a maximum dielectric stress of about 72 kv. per cm.

of service. A very similar experience was had with another manufacturer. A study of the rating table clearly indicates the changes in the specifications that must be made in order to eliminate such cable by means of the factory tests.

Cable E was of slightly higher quality and gave somewhat better results in the factory tests and in

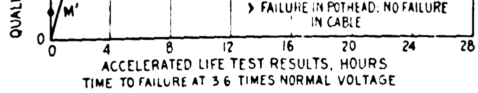

Fig. 12—Relation of Quality Ratings with Accelerated Life Test Results, for 500,000-Cir. Mil, Three-Conductor, 35-Kv. Cables

Tests were at 127 kv., which results in a maximum dielectric stress of approximately 125 kv. per cm.

service. Cable C was of still better quality, but the quality as indicated by inspection and all of the tests was very irregular. About 10 miles of this cable was installed and placed in service last fall, and one service failure, which was due to no apparent cause, occurred within two months.

Cables shown by A and B and installed last fall have had no failures in service. The quality of these cables appeared so high that lengths of about 300 ft. each were installed on 25-cycle, 20-kv. lines last fall in order to verify the quality rating as determined from the table. No failures on these test lengths have occurred to date.

Table II is a rating similar to Table I for typical examples of several different grades of 35-kv. cable which have been received to date. Fig. 12 shows the relation between these quality ratings and the accelerated life test results. Several of the cables represented have proven unsatisfactory for operation at 35-kv.; they developed the signs of ionization previously described and tests on their impregnating compounds show that they would have been rejected by Mr. Farmer's test for stability. The curve in Fig. 12 cannot be drawn with as much accuracy as the curve in Fig. 11, but Table II and Fig. 12 appear to indicate necessary changes in the specifications to insure satisfactory 35-kv., three-conductor cable.

As supplementary to the quality rating tables, the accelerated life tests appear to be a great aid, since they have revealed that even the best cables in Tables I and II still have irregularities; for instance, protruding strands of the conductor, and misplaced and broken fillers. If the tests are made on 13-kv. cable at about four times normal voltage, the results show:

1. Cable of very poor quality will usually fail within a few minutes without any visible signs of deterioration upon examination.

2. Cable of somewhat higher quality which lasts about one-half hour will develop hot spots showing irregularities in the cable, and may also develop slight tree designs and black spots.

3. Cable which will withstand this test for several hours will develop tree designs and black spots accompanied occasionally by punctures through one or more of the layers, perhaps some distance from the test failure; and the temperature of the sheath will rise about 10 to 90 deg. cent. above ambient temperature.

4. In cable of such a quality that it will withstand the test for about 50 to 100 hours, tree designs will usually be more advanced, and if the compound is unstable waxy flakes will probably be formed.

It is recognized that Table I and II are not perfect. They can never be made more accurate than the data from which they are developed, and these data will always vary in accordance with the non-uniformity of the insulation. Changes in the rating tables will be required as additional information is secured and especially to permit the tables to be properly applied to some of the new types of insulation which are now being developed. However, there appears to be no reasonable doubt as to the feasibility of using the quality rating methods outlined in this paper as a basis for modifying the specifications in order to secure cable of the desired quality.

Conclusions

1. All high-voltage tests on samples should be continued until failure occurs.
2. Long-time tests at several times normal voltage should be made on samples of the cable at the factory.
3. A test requirement should be inserted in high voltage cable specifications to prevent the use of unstable impregnating compounds.
4. The ratio of the puncture voltage obtained on the cold bent sample to the puncture voltage obtained on the straight sample appears to be an excellent test of workmanship.
5. A test is needed to indicate the minimum impregnation in a section of cable.
6. The best cable is, in general, made by the manufacturers that have the best control of their processes, as indicated by the uniformity of test results and inspection data.
7. If tests on three-conductor, high-voltage cables are of sufficient duration to develop hot spots, it has been found that (a) a majority of the cable failures will occur in hot spots and about one-third of these failures will be in the maximum hot spots; (b) a majority of the hot spots will reappear in subsequent tests on a given section of cable.
8. Higher quality of the insulation is necessary as the operating voltage increases.
9. If the compound is stable, and test and inspection data are properly correlated with operating experience, then quality rating tables can be used to predetermine with reasonable accuracy;
   a. The relative merits of several different types of insulation or lots of cable.
   b. The service record of any particular lot of cable.
10. Accelerated life tests made at suitable voltages followed by careful dissection and examinations of the insulation give consistent results which confirm the quality rating tables.

The authors gratefully acknowledge the efficient assistance they have received from C. E. Betzer, K. W. Miller, Karl Horine and L. B. Schofield in securing and correlating the information on which this paper is based.

Abridgment of

Dielectric Absorption and Theories of Dielectric Behavior

BY J. B. WHITEHEAD[1]

Fellow, A. I. E. E.

I. Introduction

Of the various component parts entering into electrical systems of all characters, the insulation is the least susceptible to exact computation and design. In few, if any cases of even simple and pure materials are the dielectric properties, resistivity, dielectric strength, specific inductive capacity, either constant or uniform; and in the cases of composite and fabricated insulations of manufacture the variations are extremely wide. As results, in all cases liberal factors of safety to cover the worst probable conditions must be allowed, resulting further in increased size and cost, and in undesirable magnitudes of other properties, such as dielectric loss and phase difference, volume and surface conductivity, circuit capacity and conductance, etc. Little if any attempt has been made to control the inherent characteristics of simple dielectrics, or to study their influence in combinations. Physicists appear to have all but forgotten the unsolved problems of dielectric behavior, or perhaps to have given them up. The control of manufactured insulation appears to be limited to heat treatment, principally for the purpose of elimination of moisture—a sufficiently important object—and to the obtaining of pure raw materials. Studies of the properties of these materials in their bearing on those of the composite final form of the insulation have not appeared in any quantity.

The Committee on Electrical Insulation of the Division of Engineering and Industrial Research of the National Research Council was formed for the purpose of pointing out the directions in which research in this field would be most profitable, and if possible to propose a plan for concerted experimental attack.

The literature describing work already done on dielectrics, from the points of view of both theory and practise, is enormous in volume. Many important data are hidden in this mass, as well as much careful and competent theoretical analysis. In order, therefore, to have as clearly as possible before it the results of all this work, the Committee has deemed it its first important duty to review the entire literature of dielectrics and insulation and to attempt to gather together the important results of the work of others into a series of reviews; and further, to draw from these

1. Professor of Electrical Engineering, Johns Hopkins University, Baltimore, Md.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Copies of complete paper, including bibliography, available upon request.

reviews conclusions as to the most promising directions for future work.

II. Historical Outline

Dielectric theory may be said to have had its origin in the work of Cavendish[2] (1773). Although looking for different values of induced charges amongst various substances, and not apparently noting the distinction between conductors and dielectrics, he nevertheless showed clearly the influence of the specific inductive capacity of the latter, and his measurements give a scale of relative values.

Faraday's elaborate studies on the exact equality between inducing and induced charges on concentric conductors, with and without dielectrics and conductors between them, led to his famous conception of a point to point transference through the medium of the influence of an electric charge, at a point, or on a conductor, at a distance. Following immediately therefrom are his well-known ideas of lines of force, tubes of induction, and dielectric polarization. Maxwell's matchless genius appreciated the importance of Faraday's work and theory, and saw the applicability of the theory of potential, as already developed by Poisson for the magnetic field. Maxwell introduced the conceptions of volume distribution of charge—the polarized molecule—as the active part of the medium demanded by Faraday, electric displacement and its magnetic effect, and built up the theory of dielectric behavior which has ever since constituted without rival, the foundation of all subsequent physical research, and of all electrical engineering applications.

The outstanding features of the theory thus briefly outlined, are the idea of dielectric polarization as developed by Faraday, and Maxwell's generalized analysis of the dielectric field. The treatment built up assumes constant values for dielectric susceptibility and specific inductive capacity, and it is interesting to note that these assumptions are common today in elementary text books, and even in more advanced treatises, in spite of our long knowledge of the limitations pertaining to such a view. The explanation is apparently found in the facts that a few substances show little or no dielectric absorption, and so constant values of susceptibility, and that with care in preparation, the error arising from dielectric absorption may be reduced for many substances to small value. In other words, it seems to be generally assumed that the phenomenon of dielectric absorption, which is not accounted for by fundamental theory, is an anomalous property of certain dielectrics, which would probably disappear if sufficient care were taken in the elimination of impurities. As a matter of fact, however, there are few substances which show no absorption, and many show it in conspicuous degree. Absorption, therefore, should rather be considered a normal property of all dielectrics, although not yet rigidly susceptible to expression in terms of fixed constants or definite functions.

Dielectric absorption made its appearance in the very earliest days of electrostatic experiment in the residual charge of the Leyden jar (1746). It is described at some length in the experiments of Benjamin Franklin (1748). It was thus well recognized by Faraday and Maxwell. In fact, as well known, Maxwell gives us the first attempt at a theoretical explanation, in terms of the normal constants of specific resistance and specific inductive capacity, as described in further detail below.

III. Dielectric Absorption and Related Phenomena

We may conveniently describe the phenomenon of dielectric absorption, and other allied properties of dielectrics in terms of the behavior of a simple parallel plate condenser.

Since it is probable that no dielectric or insulator exists which is entirely free from conductivity, it has been customary since Maxwell's classical analysis, to consider that in all dielectrics the polarization and conduction currents are superposed on each other. We may, therefore, extend our definition of a "normal" dielectric to include also the property of conductivity. Therefore, in the above case we must also recognize the presence of a conduction current, i_o, added to the charging current $i_1(t)$.

Dielectric Absorption as Observed in Experiment. Referring to our elementary condenser, the application of continuous voltage is followed by the instantaneous charging of the geometric capacity, current $i_1(t)$, a conduction current, i_o, which may or may not obey Ohm's law, and a slowly decaying "anomalous," or "absorption," or "residual" current, $i_1{}^1(t)$. If this current, $i_1{}^1(t)$, is all of "reversible" type as is usually the case in solid dielectrics, it builds up the stored or residual charge, $Q_1 = \int_0^t i_1{}^1(t) \,.\, dt$, which after the initial discharge of the geometric capacity, appears as the building up of a difference of potential between the plates if the condenser stands open, or as a slowly decaying discharge current giving a charge, $Q_2 = \int_0^t i_2(t)\, dt$, if the condenser is short-circuited. In such cases (*i. e.*, if $Q_2 = Q_1$), $i_1{}^1(t)$ will be called the "reversible absorption current." In liquid dielectrics there is also a steadily decreasing residual current $i_1{}^1(t)$, but this does not in general obey the same laws as in the case of solids, and in nearly all cases there is no corresponding discharge current $i_2{}^1(t)$. In such cases $i_1{}^1(t)$, will be called the "irreversible" absorption current.

The Reversible Absorption Current. This is the

2. A bibliography of all work referred to, and classified by subject will be found at the end of the complete paper.

absorption current commonly observed in good solid insulators, free from moisture, and there is good experimental evidence that the charge and discharge currents have the same form *i. e.*, in equation (**2**) $i_1^1(t) = i_2^1(t)$. Systematic and reliable studies of the mode of the variation of the absorption currents of charge and discharge, may be said to have begun with Kohlrausch (1854). They received a great stimulus in the experiments of Sir John Hopkinson who made extensive studies in the period 1876 to 1897, and in which he appears to have had the benefits of Maxwell's advice (Paper No. 19). Maxwell was deeply interested in the phenomena in dielectrics and treats them at great length.

Kohlrausch, Hopkinson, Giese, J. Curie, Schweidler, Shuddemagen, Jordan, Tank and others have found that the time variation of the reversible absorption current may be expressed with close accuracy by the empirical formula:

$$i_1^1(t) = a\,t^{-m} \qquad (3)$$

Others have found that the following formulas express their observations more closely:

By J. Curie, Malcles, Wagner, Steinmetz:

$$i_1^1(t) = a\,e^{-bt^n} \qquad (4)$$

By J. Curie, von Schweidler, H. A. Wilson:

$$i_1^1(t) = \frac{a}{1 + b\,t} \qquad (5)$$

By Trouton and Russ:

$$i_1^1(t) = \frac{a}{b + t} + c \qquad (6)$$

By Fleming and Dyke, Thornton:

$$i_1^1(t) = a\,e^{-bt} + c \qquad (7)$$

General Formula. With change in the value of the applied voltage, or of the thickness of the dielectric, the time rate of variation of the current is unchanged, but the values are increased in proportion to the voltage gradient (Curie, Wilson). The stationary final value of the charging current also obeys Ohm's law in most cases, and so may be considered as a normal conduction current. In a few cases, this conduction current is either absent or negligibly small, although the absorption may be quite large; *e. g.*, ebonite (Gaugain, Malclés). Generally, therefore, we may write:

$$i_1^1(t) = B\,.\,C\,E_0 = \varphi(t) \qquad (8)$$

in which B is a constant and $\varphi(t)$ a definite function for the material of the dielectric, and C the geometric capacity proportional to the area and inversely as the thickness.

Temperature has a marked influence on the absorption current. There is universal agreement, that temperature increases both the currents $i_1^1(t)$ and $i_2^1(t)$, as well as the final conduction current.

The Principle of Superposition. One of the earliest features noticed in the phenomenon of residual charge was the occasional reversal of its sign as related to the foregoing charge. Hopkinson (Papers No. 18 and 19) studied this property in glass at great length.

The following more exact statement of the principle of superposition is due to von Schweidler: After any change, ΔE, in the voltage, the actual observed current takes on an additional term, and is made up of a term representing the undisturbed variation of the original current, and a superposed current which so varies as though a voltage of the absolute value of the change in voltage, ΔE, had been applied to the uncharged condenser. If, therefore, at time $t = 0$, the voltage E_0 is applied, and then at times t_1, t_2, t_3, etc., any positive or negative changes of voltages $\Delta_1 E$, $\Delta_2 E$, $\Delta_3 E$ are applied then we have as the value of i_1^1 at any instant t.

$$i_1^1(t) = B\,C\,[\,E_0\,\varphi(t) + \Delta_1 E\,.\,\varphi(t - t_1) + \Delta_2 E\,.\,\varphi(t - t_2) + \,.\,.\,] \qquad (9)$$

Obviously the conduction current is not included in the above expression. Thus, if the final conduction current is subtracted from the charging current, it is seen that the equality of the reversible charge and discharge currents ($i_1^1 = -\,i_2^1$) is merely a special case of the principle of superposition.

Still more generally it follows, if the principle of superposition be true, that for any continuous variation of the voltage as expressed by the function $E(t)$, the reversible absorption current is given by:

$$i_1^1(t) = B\,C\,.\int_0^t \frac{d}{d\,u}\,(E(u))\,.\,\varphi(t - u)\,d\,u \qquad (10)$$

in which t is the instant at which $i_1^1(t)$ is measured and u is the elapsed time controlling the variation of E. We shall see that formula (**10**) is of great importance as a means for computing the value of dielectric loss due to alternating electric stress.

IV. Theories of Dielectric Phenomena

Theories of Dielectric Absorption. Ever since the phenomenon of residual charge was recognized there have appeared suggestions and hypotheses as to the general nature of the underlying processes. Beginning with mere suggestions in the early days, as for example, the slow penetration or "soaking in" of the charge, (readily shown to be untenable) they have increased in elaboration and complexity as further knowledge of the phenomenon has been gained. In reviewing these theories today we are presented with such pictures as a viscous yielding of the dielectric, frictional motion of molecules and electrons, infinitesimal conducting particles embedded in insulating sheaths, the free motion of electrolytic ions, dielectric hysteresis, the capillary motion of water, etc. It is impossible within a limited space to give a complete view of all these theories. It appears best, therefore, to attempt their classification into a few groups and to give one or two conspicuous examples in each group, with some attempt to outline the reasoning and evidence in support.

Most physicists offering explanations of absorption have apparently considered that the observed phenomena in anomalous dielectrics are not consistent with the fundamental equations of the electromagnetic field, and have built other equations based on new special properties of the dielectric, not embraced in the older theory. There is, however, one conspicuous instance, that of Maxwell, in which the fundamental equations are taken as a basis. We may, therefore, select two of our groups in accordance with these two views, and add a third to include those looking to present theories of the internal structure of the atom as bases for the explanation of dielectric behavior. There is also a possible fourth group as proposed by von Schweidler, in which anomalies of conductivity are invoked, but the evidence in support is not so strong as in the other groups.

Our classification of theories of dielectric absorption is then as follows:

1. Those in which the fundamental magnetic equations are retained, and the anomalies of dielectric behavior are attributed to anomalies of the structure of the dielectric medium.

2. Those in which the departures from the fundamental laws are attributed to anomalies of dielectric displacement without reference to underlying mechanism. Dielectric displacement is not proportional to field strength, but dependent on the preceding state of the dielectric.

3. Explanation of displacement and its anomalies is traced to the motion of electrons within the atom.

4. Explanations based on anomalies of conductivity, such as the free motion of ions, electrolytic dissociation, water in bulk or in capillary filaments.

Group I

Maxwell. All students of dielectric theory are familiar with Maxwell's treatment of absorption. He starts with the assumption that all dielectrics have both specific inductive capacity and conductivity as we know them in normal dielectrics, and that under electric force they function simultaneously and independently of each other. The assumption is justified by the experimental facts that conductivity may be observed in even the best insulators, and that poor insulators with very high conductivity also manifests specific inductive capacity. No further assumptions, as for example as to the origin of these properties, are necessary in Maxwell's development.

For simplicity he then assumes a dielectric as built up of a number of plain strata of different materials of thickness a_1, a_2, etc., stating that a medium formed of a conglomeration of small pieces of different materials would behave in the same way, although the case is not susceptible of exact analysis. The obvious assumption then is that every dielectric which shows absorption consists of a mixture of two or more different materials, even though under our closest examination it may appear to be homogeneous. Considering unit cross section, let X_1, X_2, etc., be the electric intensities in the several strata, f_1, f_2, etc., the displacements, k_1, k_2, etc., the reciprocals of the specific inductive capacities, r_1, r_2, etc., the specific resistances, p_1, p_2, etc., the conduction currents, and we have at any instant:

$$p_1 = \frac{X_1}{r_1} \tag{11}$$

$$f_1 = \frac{X_1}{r \pi k_1} \tag{12}$$

and

$$u = \frac{X_1}{r_1} + \frac{1}{4 \pi k_1} \frac{d X_1}{d t} \tag{13}$$

in which u is the current in the outer circuit and so in each layer. Similar equations hold for the other layers. The total e. m. f. on the condenser is the sum of X_1, X_2, X_3, etc. From equations (**13**) the X's may be evaluated as similar functions of u, in terms of the different values of r and k, and so an expression may be had for u in terms of E, *i. e.*, the charging current of the condenser as function of E, the constants of the material and the time t. Maxwell does not derive this expression, but states that if there are n layers of material having *different values of the ratio* $r : k$, the combined general equations (**13**) will form a linear differential equation of the nth order with respect to E, and the $(n - 1)$th order with respect to u, t being the independent variable. He also shows that if the ratio $r : k$ is constant for all layers the case reduces to that of a homogeneous dielectric.

Experimental evidence in favor of Maxwell's theory is very meager, and chiefly limited to indirect and broadly qualitative confirmatory observations. Cohn and Arons tested the assumption that polarization and conductivity occur independently by means of parallel condensers of different dielectrics and found good agreement. Mixtures of xylol and anilin showed a 10,000 fold variation of resistance with only a ⅓ variation of dielectric constant. Rowland and Nichols showed that in perfect samples of calcite and possibly quartz, probably the most nearly homogeneous substances available, there is no absorption. Hertz showed that benzine, a homogeneous fluid, when impure shows absorption, which disappears on purification. Arons claimed that carefully purified paraffin shows no absorption; this is disputed however by Dessau and others. Wagner finds extremely low values of power factor at 5000 cycles for ceresin and paraffin, but that for a 50 per cent-50 per cent mixture the power factor was increased several times. Muraoka by careful purification found no absorption in parraffin oil, petroleum, resin oil, turpentine and xylol. For layers of air and paraffin absorption appears. Many observers have found that the observed curves of charge and discharge currents, while not obeying the exponen-

tial law with a single term, can nevertheless be represented readily by several such terms, as called for in Maxwell's most general case. The principle of superposition as observed by Hopkinson and Curie has been shown by von Schweidler to be a necessary consequence of Maxwell's theory. However, its firmest basis is found in the fact that it introduces no new phenomena nor assumptions, but relies only on properties of matter already well known, and on fundamental electrodynamic equations. This, more than any experimental confirmation, accounts for the firm hold that this theory has on the mind of the physicist of today.

The chief disadvantage that the theory suffers is that it not only has had no quantitative nor exact experimental confirmation, but many experiments appear to offer actual contradiction. Many observers have found other expressions than the exponential for the absorption current, of whom particular mention may be made of Curie, Fleming and Dyke, and Trouton and Russ.

Wagner. Maxwell's development assumes successive layers of different dielectrics, each having different values of r and K. Many layers must be assumed to account for the results of experiment, and this leads to mathematical difficulties. The charging curve for two substances obeys the negative exponential relation to the time as already noted. Using this relation K. W. Wagner examines the curves taken on various substances, and states that only a very few exponential terms are necessary in any case to account for the curves of experiment, and moreover that the time constants of these terms group themselves more or less closely about a principle value T_0.

Group 2. Theories Based on Anomalous Displacement

As the phenomena of anomalous charge and discharge were known long before the discovery of the electron and ionic conductivity, it is natural that early theories as to their causes should have taken the form of analogies with other elastic and viscous phenomena. Thus, one of the earliest, that of Hopkinson, adopted the relations found in the elastic residual properties of ordinary materials under mechanical distortion. Electric displacement is assumed analogous to mechanical displacement. But electric displacement in the fundamental theory is proportional to the electric intensity, and not so in anomalous dielectrics, and so practically all the theories in this class assume a more or less complicated relation between the field E and the displacement D, and of such a kind that D is determined not alone by the instantaneous value of E, but also by the foregoing condition of the dielectric. Such relations exist between deformation and force in elastic media, and between induction and field strength in magnetic media.

Pellat considers the displacement as divided into two parts. The first is that of the fundamental theory:

$$D^1(t) = \frac{K}{4\pi} E(t) \tag{19}$$

the second part $D''(t)$ is assumed to obey the equation

$$\frac{d\,D''(t)}{d\,t} = \alpha\,[\,D''(\infty) - D''(t)\,]$$

$$= \alpha\left[\eta \frac{K}{4\pi} E(t) - D''(t)\right] \tag{20}$$

that is that D'' tends to a final value $D(\infty)$, proportional to E, and the rate of change of D'' is always proportional to its difference from the final value. Pellat calls D^1 the "fictitious" and D'' the "true" polarization; Schweidler, who has developed this theory further prefers the terms "normal" and "viscous" displacement.

Thus for constant E_0 and $t > 0$ we have:

$$D''(t) = \eta \frac{\overline{K}\,E_0}{4\pi}(1 - e^{-\alpha t}) \tag{21}$$

$$i_1{}^1(t) = \frac{d\,D''(t)}{d\,t} = \alpha\,\eta \frac{K}{4\pi} E_0\, e^{-\alpha t} \tag{22}$$

and the function showing the time variation of the reversible anomalous current takes the simple negative exponential form.

By integration of the above equation, we have for any type of variation of the electric force $E(t)$, remembering the principle of superposition

$$D''(t) = e^{-\alpha t} \int_0^\infty \alpha\,\eta \frac{K}{4\pi} E(u)\, e^{-\alpha u}\,.\,d\,u \tag{23}$$

$$= \alpha\,\eta \frac{K}{4\pi} \int_0^\infty E(t - \omega)\, e^{-\alpha\omega}\,.\,d\,\omega$$

and so:

$$D(t) = \frac{K}{4\pi} E(t) + \alpha\,\eta \frac{K}{4\pi} \int_\infty^t E(t - \omega)\, e^{-\alpha\omega}.\,d\,\omega \tag{24}$$

Thus, the variation of the displacement satisfies the principle of superposition, and the theory of Pellat is seen to be a special case of that of Hopkinson, in which $\varphi(\omega)$ is proportional to $e^{-\alpha\omega}$.

The simplicity of Pellat's assumption as to the variation of the displacement, and the close approximation to observations which results in the form of the anomalous charging current, make a strong appeal, in spite of the absence of all suggestion of underlying explanation. In order to supply this deficiency, von Schweidler has extended Pellat's proposal in considerable elaboration, with the aim first to bring it more nearly into accord with observation, and second to present a picture of underlying mechanism.

As regards experimental confirmation Grover, with a-c. studies of paper condensers, concluded that of several theories examined, the Pellat theory as modified by von Schweidler was the only one that could be made to give quantitative results in agreement with the obser-

vations. The quantities studied were changes in capacity and phase difference, with frequency and temperature. It is to be noted, however, that Grover did not examine Maxwell's theory as extended by Wagner, which appeared later, and which involves the same type of variation of the anomalous charging current, and an entirely analogous method of assuming a number of terms and of studying their grouping. It appears certain that an equally good agreement would have been obtained from Wagner's equations. In fact, it is safe to say the same of any theory providing for the medium a sufficient number of terms, all obeying a continually decreasing function $\varphi(t)$ of relatively simple form, but with different values of the constant terms. It appears not improbable that Wagner, not caring for von Schweidler's idea of slow period molecular oscillations, set out to picture a structure of an anomalous dielectric which would involve only the fundamental properties of specific inductive capacity and conductivity, thus adhering to Maxwell's ideas.

Group 3. Theories Based on the Structure of the Atom

Decombe in seeking an explanation of the heating of condensers, notes the remarkable and very general fact, that most thermodynamic modifications are inseparable from noticeable electric phenomena. Thus, mechanical deformations are always accompanied by both heat and electrification, (tribo-, and piezo-electric effects); capillary deformations, shock, cleavage, etc., all result in both heat and electric manifestations. Similar effects are noticeable in chemical relations, as in the thermal variations of crystals, the thermo-electric cell, the Thomson and Peltier effects, etc. He, thus, concludes that dielectric absorption and losses are also to be explained in terms of motions or deformations of electrons within the atom, and he bases an interesting and extended development of this theory on the general electron theory of Lorenz:

Separating the displacement of the ether from that of the material, as in Maxwell's theory:

$$Q = \frac{E}{4\pi} + P \qquad (25)$$

Q being the total charge, and P the "polarization." P, he assumes to be due to electron displacement and it therefore obeys Lorenz's equation:

$$E = a\frac{d^2 P}{d t^2} + b P + c \frac{d P}{d t} \qquad (26)$$

E being the electric intensity and a, b, and c constants of the reactionary forces of acceleration, elasticity, and friction respectively. He assumes further that for frequencies less than those of light the first term on the right is negligible, and so

$$E = b P + c \frac{d P}{d t} \qquad (27)$$

He shows that (27) obeys the principle of superposition, and also that it is satisfied by a value of alternating polarization computed from oscillograms taken by Hochstadter on high-tension cables. He shows further that Maxwell's equations as extended by Hess, when applied to the alternating case reduce to the same form as his own, and so by inverse reasoning, account is made for residual charge. Moreover, he shows that Pellat's arbitrary expression for the variation of the displacement follows immediately from his own equations. He shows also that under alternating e. m. f. the equations lead to a loss proportional to the square of the polarization current $\left(\frac{d P}{d t}\right)$, and a loss per period independent of the frequency, as shown experimentally by Steinmetz, Hochstadter and others. The general conclusion is that all residual effects are due to the term $c\frac{d P}{d t}$, representing a frictional force (electric) within the atom, *i. e.*, to a viscous property of the atom.

The theory is very striking in its agreements with the results of observation and in its simplicity.

Group 4. Theories Based on Anomalous Conductivity

It has often been suggested that dielectric absorption is in fact due to a varying conductivity giving rise to the motion of movable charges of "ions" within the dielectric. Experimental investigations of this idea as applied to solids are very difficult, but the irreversible anomalous current of a poorly conducting liquid offers very much wider opportunity.

Efforts have been made also to extend the same explanation (*i. e.*, ionic conduction) to the anomalous charge and discharge currents of solids, but with little success. von Schweidler has maintained that in an ionized medium the reversible anomalous current can not arise. Also that the principle of superposition cannot be explained in this way, and offers as proof the absence of residual charge in liquid dielectrics. On the other hand, Anderson and Keane have shown that the drifting of free electrons to the positive electrode will result in a space variation of charge sufficient to account for residual charge in accordance with Maxwell's theory, and have checked their conclusions with observations on sulphur. The behavior of glass is especially significant in this connection. The final conductivity of glass has undoubtedly an electrolytic character. Sodium is deposited out of glass on the electrodes, with resulting decrease of conductivity, and the latter may be maintained by providing an anode of sodium amalgam. Lithium may also be used, but apparently no other metals of the chemical group. Moreover the electrolytic action is in accordance with Faraday's laws. It must be remembered, however, that glass is not a homogenous substance and in fact

is generally considered to be a solid solution, and so of highly special character. On the other hand similar behavior has been observed in quartz, certainly not a solution, but in which small quantities of sodium and lithium are usually present. Mercury, quartz, and sodium form an electrolytic cell giving about .5 volts. H. H. Poole has shown the relation $x = e^{a+b+X}$ for the conductivity of glass, a being the thickness and X the field intensity; *i. e.*, the conductivity increases with the field strength. Gunther-Schulze sees in this an evidence of ionic conductivity and ionization by collision as in gases. Thus, while we may not be sure that glass presents a behavior typical of all anomalous dielectrics, it unquestionably is significant as showing the possibility of ionic conductivity in solids.

The Influence of Moisture. Cable paper absorbs up to 10 per cent, or even 20 per cent, by weight of moisture, rapidly at first and then more slowly. Under continuous voltage when comparatively dry (2 per cent to 3 per cent moisture) it shows a typical absorption curve in accordance with formula (3) $i_1{}^1\,(t) = a\,t^{-m}$. With increasing moisture the ordinates increase, and the curve flattens out, becoming horizontal (except for a short initial descending portion) at about 7 per cent moisture. Above this the curve of charging current with time rises gradually (Lübben). These increases are all of the nature of conduction current, for the discharge current does not take on corresponding increases, and follows equation (3) in all cases. Thus, the difference between charge and discharge currents, which usually measures the insulation resistance, increases continually with time after the application of voltage (Wagner). This indicates that the continued application of voltage causes a decrease in resistance. Moreover, the final steady value of resistance is found to depend on the voltage. So that we have the following approximate relations for the resistance r, the conductance g, and the conduction current i, in a fibrous dielectric containing moisture:

$$r = \frac{A}{\sqrt{E}};\; g = g_0\,E^m;\; i = i_0\,t^p \qquad (28)$$

E, being the voltage and A, g_0, m, i_0, p constants.

An ingenious explanation of many of the above relations has been offered by Evershed who supposes that the water is in part contained in the capillary tubes of the fibers of the material. The water is separated by air bubbles, but the walls of the tube surrounding the bubbles are wet with a thin film of water. These films constitute the principle resistance of the complete water path. Under the electric field, water is forced from the drops in the films making their walls thicker and so increasing their conductivity. In the thin state of the films they are very sensitive to slight water addition, but less so as the walls get thicker, corresponding to the observations of experiment. Evershed constructed a model containing a large number of glass capillary tubes, and studied its behavior under the microscope. He found that it gave the typical resistance, voltage, time relations found for fibrous insulation, and that the water films behaved as already stated.

D. DuBois has suggested a somewhat different mechanism for the behavior of water in dielectrics.

J. Curie showed the important part water may play in materials containing no fibers but which are porous. By maintaining porcelain at different degrees of moisture he reproduced different types of charging current curve, among them typical absorption curves as observed for dry substances. Moreover, this moist porcelain polarized up to several hundred volts, gave typical discharge curves and in fact obeyed the principle of superposition. Curie suggests in explanation the linking up of a number of internal individual electrolytic cells due to water and local conducting impurities.

V. Dielectric Behavior under Alternating Electric Force

The alternating losses in condensers were first noted by Siemens (1864), and since then they have been studied by many observers.

For a long time and even up to the present, many have assumed that the cause of these losses is to be found in some special and unknown property of dielectrics, usually called dielectric hysteresis and supposedly arising in some undiscovered molecular phenomenon, similar to that in magnetic materials. It is remarkable that this illusion should have maintained so persistent a hold, for it is easy to see that the phenomenon of absorption causes a lag of charge behind e. m. f. and so is sufficient to account for the energy component of current.

Theories Based on Absorption. *Beaulard* in 1894 and *Hess*, in 1895, gave convincing arguments against the idea of hysteresis, and *Hopkinson*, in 1897, made alternating measurements, attempting to link up absorption with the values of capacity and loss currents.

Rowland extended Maxwell's theory of absorption to the case of a sinusoidal e. m. f. and derived expressions, showing variations with the frequency, of both the capacity and the phase difference. He developed a sensitive electrodynamometer, many special types of bridge connection, and with his coworkers made numerous studies of dielectric loss, failing, however, to find close agreement with the Maxwell theory. The measurements of Curtis, in 1910, also failed to agree with this theory.

von Schweidler. Grover, in 1911, made a similar effort not only with the Maxwell-Rowland expressions, but also by extending the theories of Houllevigue, Pellat, von Schweidler, and Hopkinson, to the alternating case, and checking them with measurements on a number of condensers for frequencies up to 1000 cycles, and temperatures between 10 deg. and 35 deg. He found that von Schweidler's extension of Pellat's theory was the only one which could be made to give

quantitative results in agreement with the observations.

Wagner. Wagner has also extended his picture of the Maxwell dielectric to the alternating case in a series of papers dating from 1913. He assumes the simplest possible case of a two-layer Maxwell dielectric, and further that the conduction and displacement currents flow simultaneously, that the total currents are equal in each dielectric, and that the alternating electromotive force on the condenser is the vector sum of the e. m. f's. on the two layers. This leads at once to a complex expression for the impedance of the condenser, from which the following values of the variable dielectric constant (and so the capacity) and the variable angle of phase difference at once appear:

$$K\,\omega = K\left[1 + \frac{k}{1 + \omega^2 T^2}\right] \tag{30}$$

$$\tan\delta = k\,\frac{\omega\,T}{1 + K + \omega^2 T^2} \tag{31}$$

in which K is the specific inductive capacity corresponding to the geometric capacity, T the time constant in the exponential expression of the anomalous charging current, k a simple function of the electric constants of the two materials, and $\omega = 2\,\pi\,f$.

These two equations are in some degree in qualitative accord with the results of experiment. The former (**30**) indicates a capacity starting at a finite value and decreasing with the frequency to the geometric value at infinite frequency. This behavior is universally found in experiment. The latter equation (**31**) indicates a phase difference starting at zero, at 0 frequency, and with increasing frequency passing through a maximum and then steadily decreasing toward zero at infinite frequency. This general behavior has also been frequently observed. At times the maximum value of $\tan\delta$ may not appear, the frequency at which it occurs being determined by the constant k, and often lying outside the available range. On the other hand many other observations do not follow the comparatively simple relations indicated by (**30**) and (**31**).

Decombe has extended his electron theory of the anomalous behavior of dielectrics, already described in connection with absorption, to the explanation of alternating losses.

F. Tank has studied the Pellat-Schweidler theory for the alternating case, computing the loss as due to absorption, measuring the latter and also measuring the loss, and comparing with the computed value. The method used for computation is typical in the main of the methods used by several others (Wagner, Lahousse) and is briefly as follows: The alternating current due to an e. m. f. $E = E_0 \sin\omega\,t$, flowing in a condenser circuit may be expressed

$$i = (t) = a \sin\omega\,t + b\cos\omega\,t; \tag{33}$$

further by the principle of superposition, see formula (**10**), the anomalous charging current is:

$$i\,(t) = \beta\,C \int_{-\infty}^{t} \left(\frac{d\,E\,(u)}{d\,u}\right) \varphi\,(t - u)\,d\,u \tag{34}$$

t being the instant at which the current is considered, and u the elapsed time since the application of E. Equating the two values of $i\,(t)$, the coefficients a and b may be obtained thus showing the influence of absorption on both the capacity and the apparent conductance of the condenser.

Tank found a remarkable agreement between the measured and computed losses and currents, the per cent differences for the former in the six cases being 3.8, 4.1, − 0.4, 1.6, 13.8 and 23 per cent. He concludes from his work that the alternating losses in solid dielectrics are almost entirely accounted for by absorption, resistance loss being less than 1 per cent of the total, and no evidence of other losses.

Lahousse adopts a slightly different method of approach for computing the loss from the absorption. If E is the electric intensity, I the polarization, and k the dielectric susceptibility ($K = 1 + 4\,\pi\,k$),

$$I = k\,E\,(t) + \int_{-\infty}^{t} k\left(\frac{d}{d\,u}\,E\,(u)\right)\varphi\,(t - u)\,d\,u \tag{35}$$

For a closed cycle, the loss per cycle, w, is:

$$= \int E\,d\,I = -\int I\,d\,E \tag{36}$$

Substituting $E = E_0 \sin\omega\,t$, and introducing two new constants a and β whose values are determined by the integral in (**35**);

$$I = K\,E_0\,[\sin\omega\,t + a\sin(\omega\,t - \beta)] \tag{37}$$

This is the equation of an ellipse between I and E_0, a result independent of the form of $\varphi\,(t)$. Such ellipses have been shown experimentally by Granier. (See below).

Further, from (**36**) and (**37**)

$$w = \pi\,k\,a\,E_0^2 \sin\beta \tag{38}$$

or the loss is proportional to the square of the applied e. m. f. as often observed. Both the foregoing relations are independent of the form of $\varphi\,(t)$, which is contained in β. If $\varphi\,(t) = m\,e^{-nt}$ (Maxwell, Curie, et al), and if n is small as usually observed, the loss per cycle becomes

$$W = \frac{2\,k\,\omega\,m\,E_0^2}{\omega^2 + n^2} = \frac{2\,k\,m\,E_0^2}{\omega} \tag{39}$$

and the total loss

$$W = \frac{k\,m\,E_0^2}{\pi} \tag{40}$$

that is the loss per cycle is inversely proportional to the frequency, and the total loss independent of the frequency. As indicated below, these relations have some apparent support, but the weight of the evidence of experiment shows a loss increasing with the frequency.

J. Granier has investigated in very elegant manner the losses due to absorption alone for alternating frequencies between 0.3 and 150 cycles. He interrupts

the steady alternating excitation at different points on the cycle, and by a careful zero method obtains the total residual charge. This permits the plotting of the absorption-voltage relation for a complete cycle at each frequency. Plotted in rectangular coordinates the curves are found to be almost perfect ellipses, as called for by theoretical analysis (c. f. Lahousse above). The areas of the ellipses, representing the loss per cycle, continually decrease with increasing frequency, also in general accord with theory. The ellipses become quite flat within the range mentioned, and the study of the influence of frequency is continued up to 1500 cycles, using bridge methods. Within the entire range the total loss increases, but less than in proportion to the frequency.

VI. Comparison of Alternating Theory and Experiment

Loss-Voltage. There is almost universal theoretical agreement that the rate of loss varies as the square of the electric intensity. Many observers have studied this relation (see bibliography), and the extreme range of the exponent of the electric force appears to be from 1.3 to 2.7. However, the great mass of the evidence centers about the value 2. It is difficult to account for the values lying below 2, but those lying above permit of quite probable explanation.

Loss-Frequency. In the matter of frequency the several theoretical developments are not in entire accord. Wagner shows the loss proportional to both frequency and phase difference and as the latter first increases and then decreases with the frequency, a uniform variation in the loss is not always to be expected. Lahousse deduces a loss per cycle inversely proportional to the frequency and thus a loss per second independent of the frequency, for all but very low values. The experiments of Granier show a loss per cycle decreasing with the frequency up to 150 cycles, and a loss per second increasing only as the 0.5th and 0.6th power of the frequency, thus seeming to lend some force to Lahousse's conclusion. M. A. Frigon reports the losses in impregnated paper increasing nearly in proportion to the frequency between 20 and 60 cycles. H. J. MacLeod working on such good insulators as glass, pyrex, paraffin, cresin, mica, and with unusually careful conditions finds the losses varying as the 0.85th to 0.9th power of the frequency. Many other observers have reported losses increasing with the frequency but usually in less than direct proportion.

On the other hand, Wagner has examined the variation of the power factor with frequency over a wide range, and finds that the maximum value of the phase difference may occur for different substances in the range of 4 to 1000 cycles per second, and higher. This means that within the commercial range and far beyond, the phase difference may either increase or decrease with the frequency. This is probably the chief cause of the general confusion to be found in attempting to coordinate the results of different observers, and the reason why no simple empirical law has appeared expressing the influence of frequency on dielectric loss.

Loss-Temperature. The influence of temperature on dielectric loss is very great, the loss rapidly increasing with the temperature. But here too, it does not appear possible to expect a definite law owing to the indirect influence of temperature on other properties.

The only considerable attempt to account for the influence of temperature from a theoretical standpoint is that of Wagner. He carries it back to its effect on the time constant of the material, *i. e.*, the factor multiplying t, the time, in the exponential variation of the anomalous charging current. This enables him to bring it through into the alternating case, in its effect on phase difference, and so on the loss. He reports some remarkable general agreements with the results of observation, and his work stands out as a striking support, in the matter of temperature, of Maxwell's theory.

VII. Summary and Conclusions

1. Dielectric absorption is a conspicuous but obscure and little understood phenomenon. Its general character is well known as shown by the decay, with time, of the charging current, residual charge, etc. However, exact and definite forms of even the empirical laws are still lacking.

2. Only solids show the complete absorption phenomena of charge and discharge. Liquids often show an apparent absorption in charging but no residual phenomena. Nearly all solid dielectrics show some absorption. In some substances in a very pure state, *e. g.*, sulphur, quartz, paraffin, it is very small, if not negligible, in amount.

3. Large changes in the absorption in solids may be caused by extremely small changes in composition. Impurities and moisture in very small amounts may cause large changes in absorption.

4. The charging absorption current merges into a final steady conduction current. Both are strongly increased by increase in temperature, the absorption finally disappearing or changing into conduction.

5. The alternating losses in solid dielectrics are due almost entirely to absorption. This is shown by theoretical analysis, and confirmed by experiment. The losses due to conductivity are usually very small compared with those due to absorption, and there is no evidence of losses of other types. There is nothing to indicate a hysteresis loss of the character pertaining to magnetic materials.

6. Theories of the ultimate nature of the phenomenon of absorption are: (*a*) That it arises in the mixture of two or more dielectrics, and depends only on the known quantities, conductivity and specific inductive capacity. This is the theory of Maxwell. (*b*) That it is due to anomalous relation between electric dis-

placement and electric force, the seat of which is within the molecule or atom. Pellat, (*c*) That it may be explained by Lorenz's theory of electron motion within the structure of the atom. Décombe. (*d*) That it is due to water in capillaries or interstices in the body of the dielectric.

7. The most satisfactory theory is that of Maxwell though it is far from firmly established. The evidence is mostly indirect and it still needs quantitative proof. Probably its firmest support is found in the extension to the alternating case in which it explains a number of experimental observations. However, the theories of class (*b*) are susceptible to much the same extension.

8. From the standpoints of both theory and practise there is great need and fine opportunity for further study of the phenomenon of absorption. Thoroughgoing and careful efforts to test Maxwell's theory have been remarkably few in number. It should not be difficult to plan a comprehensive series of experiments for that purpose. Much the same may be said as to the question of the presence of electrolytic conduction in dielectrics, and its importance as a factor in explaining absorption. Moisture is difficult to eliminate completely from many dielectrics. It influences profoundly the permanent conductivity, and probably the absorption. Whether or not it is a definite factor in all absorption is a question needing, and apparently susceptible of experimental solution.

The complete paper includes an extensive bibliography on the subject of Dielectric Absorption.

Compensation for Errors of the Quadrant Electrometer in the Measurement of Power Factor

BY D. M. SIMONS[1] and WM. S. BROWN[1]
Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis;—*In a previous paper, the writers developed the equations for the main errors in the quadrant electrometer for the measurement of power factor, and checked their equations experimentally, the main sources of error being the unavoidable shunting capacity to ground of the test specimens and the charging current from the electrometer needle to the quadrants. In the present paper methods of experimental compensations and elimination of these sources of error are described. Methods of compensation for capacity to ground have been presented before, and in this paper merely some additional refinements are given. The method of compensation for errors due to the charging current in the needle circuit is believed to be new; the method is described herein, the equation is derived in full, and an experimental check is given of the accuracy of the equation.*

* * * * *

I. Introduction

In a previous paper[2], the general equations of the electrometer have been given, both for the ordinary deflection method and for a new null method where the deflection is brought back to zero by inserting resistance in series with the electrometer needle. In order to save space, the previous work will not be described here, but the compensation for errors will be covered, practically as a continuation of the previous article. The following symbols will be used.

E = Voltage on the load taken as numerically equal to the transformer voltage
I = Load current or charging current of the specimen
I_h = Charging current flowing from the needle to the high quadrant
I_l = Charging current flowing from the needle to the low quadrant
r_1 = Resistance across the electrometer quadrants
r_2 = Resistance inserted in the needle circuit in the zero method, *i. e.*, the potential resistance
C_1 = Total capacity to ground of the high quadrant and all connected parts
C_2 = Capacity in the needle circuit
$\cos\phi$ = Power factor of the load
$\cos\psi$ = Power factor of the circuit in which I_h flows
n = Ratio of the transformer voltage to the needle voltage
f = Frequency
ω = $2\pi f$

In the former paper it was shown that the main source of error was due to the capacity to ground of the "high quadrant" and all connected parts, including the capacity to ground of the high quadrant itself, all connected leads, the distributed capacity of the quadrant resistance, and the capacity to ground of the low-voltage electrode of the test specimen, the last usually being a large percentage of the total. Stated differently, a large part of the reading, either by the deflection or null method, is due to the capacity to ground. It was further shown that errors would be introduced by the charging current from the needle to the high quadrant, if the load current is so small that the needle current is no longer comparatively negligible.

In the previous paper, equations were given to include

1. Both of the Standard Underground Cable Co., Pittsburgh, Pa.

2. *The Quadrant Electrometer for the Measurement of Dielectric Loss*, D. M. Simons and W. S. Brown, Trans. A. I. E. E., 1924, p. 311.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

the effect of these two sources of error as well as others. In the present paper it is proposed to give methods of experimentally compensating for these two errors, so that these terms will disappear from the general equation, and so that the final reading may be taken as if these errors did not exist. This also means a great increase in accuracy, since in general the power factor of the unknown will constitute a large part of the reading, if compensation is made. Without compensation, the power factor of the unknown load may be a very small part of the total reading, and therefore any errors may have a disproportionately great effect upon the accuracy of the power factor measured.

II. Neutralization of Capacity to Ground, C_1

Considerable errors may develop in the measurement of power factor if a large part of the reading is due to capacity to ground, C_1. For that reason, there is often a real necessity for compensating for the greater portion, if not all, of the capacity to ground. This can be done in large part by raising the potential of the shield surrounding the low-voltage electrode of the test specimen to the same potential as that of the electrode itself. For example, in the measurement of small specimens of cable, the sheath must be surrounded by a grounded shield in order to avoid stray currents. If this shield is insulated and raised to the potential of the sheath, the capacity to ground of the sheath will be ineffective.

If desired, compensation may be even more perfect than that. If the quadrants consist of tinfoil pasted on glass, other sheets of tinfoil of the same size could be pasted on the other side of each piece of glass opposite the high quadrants and insulated from the instrument. All leads to the high quadrant are normally surrounded by grounded guards, which for this purpose should be insulated. The guards of the quadrants and of the leads may now be connected to the shield surrounding the low-voltage electrode of the test specimen, and all raised to the potential of this electrode. This will compensate for all capacity to ground except the distributed capacity to ground of the quadrant resistance which is normally very small. When n equals 2, under these conditions practically all of the reading will be due to the power factor of the load.

Some experiments in compensation were performed where the load used was a short piece of cable. Fig. 1 gives the diagram of connections. The conductor of a similar piece of cable was connected to the high voltage and its sheath grounded through a resistance whose value was such that the potential drop across it was the same as that across the quadrant resistance. The sheaths of both specimens were therefore at the same potential. Compensation was then accomplished by connecting the sheath of the auxiliary specimen to the guard surrounding the load specimen.

The accuracy of compensation can be checked by a method suggested by R. W. Atkinson. A key and condenser in series are inserted between the sheath of the auxiliary specimen and the guard surrounding the load specimen. A rough adjustment of the resistance in series with the auxiliary specimen is then made and a balance or deflection taken. If compensation is correct, no change in the balance or deflection will result on closing the key. If any change does occur, the resistance in series with the auxiliary specimen can be adjusted until the reading is independent of the position of the key. If a key were used without the series condenser, the balance would probably be too sensitive, due to possible differences in power factor of the load and auxiliary specimen.

Compensation for capacity to ground may be very advantageously applied to the method outlined in Section 5 of the former paper, where two balances are required, one on a zero-loss standard S and one on the unknown X, the total capacity to ground being kept constant. This can be accomplished in the following

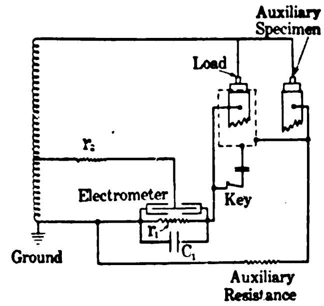

Fig. 1—Diagram of Connections for Compensation for Capacity to Ground in Quadrant Electrometer

way. Insulate the guards of both S and X and connect them to the low-voltage electrode of the auxiliary specimen. Connect S to the high voltage, and the high-voltage lead of X to the low-voltage electrode of the auxiliary specimen. Balance on S, compensation being made by means of the auxiliary resistance, series condenser and key. Then connect X to high voltage, connecting the high-voltage electrode of S to the low-voltage electrode of the auxiliary specimen. Balance on X, compensating again. A different value of auxiliary resistance, of course, will be required if the charging currents of X and S are not the same. The difference between the two $r_2 C_2 \omega$'s will give the power factor of X. The great advantage of this method lies in the fact that the capacity to ground of the instrument and leads does not have to be compensated for, and the difficulty of the shunting capacities, C_a and C_b is entirely eliminated.

III. Neutralization of the Needle Charging Current, I_h

The method used to neutralize the effect of I_h is shown in the diagram of connections, Fig. 2. The essential difference between this and the ordinary connection is that a graduated variable condenser C_3 and a variable resistance r_3, are inserted in parallel between

the low quadrant and ground. The procedure follows:

1. Connect the low-voltage electrode of the test specimen to the high quadrant, leaving the high-voltage electrode floating, a convenient quadrant resistance r_1 being inserted as usual. An equal resistance, r_3 is then inserted between the low quadrant and ground and sufficient capacity C_3 is cut in until the instrument reads zero.

2. Apply high voltage to the specimen. Inasmuch as during the previous balance the total capacity to ground of the high quadrant was higher by C_{ab} (see Section 6 of first paper), this amount of capacity must be deducted from C_3. The deflection is now brought back to zero by the potential resistance r_2 as usual (or a deflection taken), and the power factor may be obtained by the following formula:

$$\cos\phi + r_1 C_1 \omega - \frac{n-2}{2} \cdot \frac{I r_1}{E} + r_1 C_q \omega + \frac{I_h r_1}{E} = r_2 C_2 \omega \qquad (1)$$

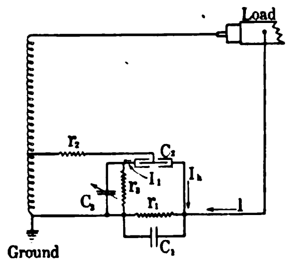

Fig. 2—Diagram of Connections for Neutralization of I_h

in which C_q *is the capacity between the high and low quadrants themselves,* and C_1 is as usual the capacity to ground of the high quadrant and all connected parts, when the low quadrant is grounded. C_1, therefore, includes C_q. C_q is in most cases absolutely negligible, especially if the quadrants are made of tinfoil on glass, and the last term on the left is usually negligible. It will therefore be seen that equation (1) is practically identical with equation (6) of Part II of the previous paper, and that all effects of the charging current I_h have been neutralized. Furthermore, the equation is entirely independent of the load current if n equals 2, and therefore, if the compensation is made, the method of balancing first on a standard condenser and then on an unknown condenser could be made regardless of the relative sizes of the two condensers, except as influenced by the changes in capacity to ground as explained in the previous paper.

Another obvious method of avoiding the effects of I_h might be briefly mentioned. If the charging current to the high quadrant is approximately equal to that of the low quadrant, and the losses are the same on both sides, all effects due to them should be removed if the ground were placed at the midpoint of the quadrant resistance, instead of grounding one set of quadrants. We believe that there is one great difficulty with this method. The low-voltage terminal of the test transformer would, of course, have to be insulated. All stray currents therefore from the high-voltage end of the transformer to ground would return to the low-voltage terminal of the transformer through the ground connection and therefore through the lower half of the quadrant resistance, thereby introducing an indeterminate and, possibly, large correction.

IV. Derivation of Equation for Neutralization of I_h

In the previous paper, an analytic method using the symbolic notation has been used. As stated in each case, the equations have also been derived geometrically from the vector diagrams with a perfect check. It appears that the present derivation is considerably simpler by the geometric method. At first thought, some of the geometry may appear too free, but it is believed to be justified because the actual vector diagram, if drawn to scale for a high-voltage measurement, especially with n equal to 1 or 2, would be so elongated that, for instance, all the vectors from the needle potential points, R, T, etc., to either quadrant are practically identical in absolute value. It is believed that practically all the substitutions about to be made are equivalent to the assumption that the angles are all so large or small that their sines or cosines, as the case may be, are equal to unity. An additional reason for confidence is that practically this same process and same assumptions completely checked the other equations derived analytically after the assumption that certain sines and cosines were equal to unity.

The vector diagram is shown in Fig. 3. $A B$ is the transformer voltage. $A N$ is the load voltage, the load current being the vector of reference. Angle $X A N$ = angle $A N M = \cos\psi$, the load power factor. B is the grounded point. The potential resistance, r_2 in Figs. 1 and 2 is connected to the transformer at any point, T.

In these first two figures r_1 and C_1 are as usual the quadrant resistance and the unavoidable shunting capacity and r_2 and C_2 are as usual in the potential circuit. It will be assumed that a resistance r_3, shunted by a capacity C_3, has been inserted between the "low quadrant" (the one usually grounded) and ground, no assumptions being made as to their present values. Let I_h and I_l be the charging currents from the needle to both the high and low quadrant respectively, and let $\cos\psi$ and $\cos\psi'$ be the power factors of these two currents respectively, as referred to the voltage between needle and quadrant.

Returning to Fig. 3, $N J'$ is the resultant voltage across the quadrants to be mentioned later. O is the midpoint of the transformer high-voltage winding, and T is the point at E/n to which r_2 is connected. $T R$ is the voltage drop across r_2, and $R D$, perpendicular to it is the effective needle voltage—assuming that

C_2 is the capacity of the instrument itself, though actually an auxiliary potential condenser is used as explained in Section 3 of the earlier paper.

If there were no capacity to ground from the high quadrant and connected parts ($C_1 = 0$) the drop across the quadrant resistance r_1 due to the load current I would be in the direction $N\,I$, parallel to $A\,X$. Due to the capacity C_1, the drop lags by an angle α and may be represented by $N\,J$. $R\,N$ is the voltage between the needle and the high quadrant, angle ψ being angle $R\,N\,H$. The direction of I_h is therefore $N\,L$, $H\,N\,L$ being a straight line. The drop across the quadrants due to I_h lags behind this by the same angle α, and therefore the drop due to this current is $N\,E$. Supposing r_3 and C_3 to still be zero, the drop across the quadrants is $N\,B$, the vector sum of $N\,J$ and $N\,E$. If resistance and capacity are now added between the low quadrant and ground, namely r_3 and C_3, the diagram changes. $R\,J'$ is the voltage between the needle and low quadrant, angle $R\,J'\,H'$ is angle ψ', and $J'\,G$ is the direction of I_l the charging current to the low quadrant. The drop across the resistance r_3 due to I_l lags behind this by an angle α'' (not equal to α, unless $r_1 = r_3$, and $C_1 = C_3$). The total quadrant voltage due to I and I_h in r_1, and I_l in r_3 is the resultant of $N\,B$ and $B\,J'$, or is equal to $N\,J'$ as stated above, making the angle α' with $N\,J$.

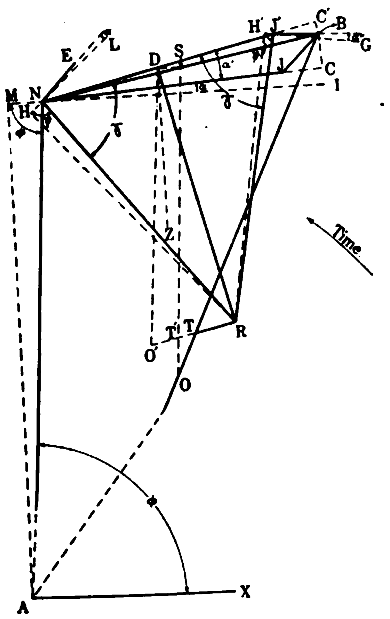

FIG. 3—VECTOR DIAGRAM FOR THE NEUTRALIZATION OF I_h

The condition of zero deflection of the instrument is that the voltage across the quadrants shall be perpendicular to the voltage from the needle to the midpoint of the quadrants, *i. e.*, $R\,D$ is the perpendicular bisector of $N\,J'$, and the proof centers about the triangle $O'\,D\,R$, including the condition mentioned above and the fact that $O'\,R$ is perpendicular to $R\,D$.

Take S as the midpoint of $N\,B$, and draw $D\,S$, which will equal one-half of $J'\,B$. Draw $O\,S$, cutting $T\,R$ produced in T'. Draw $D\,O'$ parallel to $O\,S$.

$$O\,B = E/2$$
$$T\,B = E/n$$

Therefore,

$$O\,T = O\,B - T\,B = \frac{n-2}{2\,n}\,E$$

Therefore,

$$\frac{O\,T}{O\,B} = \frac{n-2}{n} = \frac{T'\,T}{S\,B}$$

Now,

$$S\,B = N\,B/2 = \frac{(I + I_h)\,r_1}{2}$$ (if cos $B\,J\,C$ and cos $B\,N\,C$ are taken as unity)

Therefore,

$$T'\,T = \frac{n-2}{n} \cdot \frac{(I + I_h)\,r_1}{2} \qquad (2)$$

Now,

$T\,R = r_2$ times current in potential circuit

$$= \frac{E\,r_2\,C_2\,\omega}{n} \qquad (3)$$

(Since the potential voltage T to D may be confused with $T\,B$ or E/n in scalar value)

Now,

$$O'\,T' = D\,S = J'\,B/2 = \frac{I_l\,r_3}{2} \qquad (4)$$

($O'\,D$ and $O\,S$ are parallel by construction, and in the actual diagram $D\,S$ and $O'\,T'$ are practically parallel)

$$\text{Angle } O'\,D\,R = 90 \text{ deg.} - \phi + \alpha + \alpha' \qquad (5)$$

(This may be seen by drawing a line $D\,Z$ from D perpendicular to $N\,I$. $O\,S$ is parallel to $A\,N$ because O and S are the midpoints of $A\,B$ and $N\,B$ by construction, and $D\,O'$, drawn parallel to $O\,S$, is also parallel to $A\,N$. Angle $O'\,D\,Z$, therefore, $= 90$ deg. $- \phi$. $D\,R$ is perpendicular to $N\,J'$, and $D\,Z$ to $N\,I$ by construction. Therefore, angle $Z\,D\,R = \alpha + \alpha'$):

$$\text{Sin}\,O'\,D\,R \doteq \frac{O'\,R}{O'\,D} = \frac{O'\,T' + T'\,T + T\,R}{E/n} \qquad (6)$$

Substituting, (2), (3), (4), and (5) in (6), we obtain

$$\sin\,(90 - \phi + \alpha + \alpha') = \cos\phi + \sin\alpha + \sin\alpha'$$

$$= \frac{n\,I_l\,r_3}{2\,E} + \frac{n-2}{2} \cdot \frac{(I + I_h)\,r_1'}{E} + r_2\,C_2\,\omega \quad (7)$$

$\sin\alpha = r_1\,C_1\,\omega$, and therefore only $\sin\alpha'$ remains to be determined.

An auxiliary angle γ will be introduced. $\gamma =$ angle $R\,N\,J' =$ angle $N\,J'\,R$.

$$\sin\alpha' = \frac{CC'}{N\,C'} = \frac{C\,B + B\,C'}{N\,B}$$ ($N\,B = N\,C'$ if cos

$B\,N\,C'$ is unity and $C'\,B\,C$ is practically a straight line)

$$= \frac{J\,B \sin C\,J\,B + J'\,B \sin C'\,J'\,B}{N\,B}$$

But $N\,B = (I + I_h)\,r_1$, $J\,B = I_h\,r_1$, and $J'\,B = I_l\,r_3$
Angle $C\,J\,B$ = angle $C\,N\,E = 180 \text{ deg.} - \psi - \gamma + \alpha + \alpha'$
Angle $C'\,J'\,B$ = angle $R\,J'\,C'$ $-$ angle $R\,J'\,B$ = $(180 - \psi' + a'') = \psi' - \gamma - \alpha''$
Therefore,
$\sin \alpha'$ =

$$\frac{I_h\,r_1 \sin(180 - \psi - \gamma + \alpha + \alpha') + I_l\,r_3 \sin(\psi' - \gamma - \alpha'')}{(I + I_h)\,r_1} \quad (8)$$

Simplifying, dropping the sines of large angles and cosines of small ones, and rearranging terms, we obtain:

$$\sin \alpha' = \frac{I_h}{I} \cos \psi + \frac{I_h\,r_1 + I_l\,r_3}{I\,r_1} \cos \gamma$$

$$+ \frac{I_h}{I} \sin \alpha - \frac{I_l\,r_3}{I\,r_1} \cos \psi' - \frac{I_l\,r_3}{I\,r_1} \sin \alpha'' \quad (9)$$

Since ψ and ψ' are circuit constants, and $\sin \alpha = r_1\,C_1\,\omega$, and $\sin \alpha'' = r_3\,C_3\,\omega$, the only unknown is the auxiliary angle γ, which must be evaluated.

From the figure,

$$\cos \gamma = \frac{N\,D}{R\,N} = \frac{(I\,r_1 + I_h\,r_1 - I_l\,r_3)/2}{E/n} \quad (10)$$

Substituting (10) in (9), and (9) in (7) and algebraically simplifying:

$$\cos \phi + \left(1 + \frac{I_h}{I}\right) r_1\,C_1\,\omega + \frac{I_h}{I} \cos \psi$$

$$- \frac{n-2}{2} \cdot \frac{(I + I_h) r_1}{E} = r_2\,C_2\,\omega + \frac{I_l\,r_3}{I\,r_1} \cos \psi'$$

$$+ \frac{I_l\,r_3}{I\,r_1}\,r_3\,C_3\,\omega - \frac{n\,(I\,I_h\,r_1^2 + I_h^2\,r_1^2 - I_l^2\,r_3^2)}{2\,E\,I\,r_1} \quad (11)$$

This is the general equation for $\cos \phi$ in terms of the circuit constants including a resistance and capacity between the low quadrant and ground, no assumptions having been made as to their relative values.

In the actual process of neutralizing the charging current I_h as described in Section 3 of this paper, the first step was to insert r_3 between low quadrant and ground, making $r_3 = r_1$. Thus r_3 is then shunted by C_3 until the electrometer reads zero, the high-voltage electrode of the load not being connected. This means that the electrometer is measuring two equal loads, one through each set of quadrants at full voltage E/n on the needle. The losses measured on each side must, therefore, be equal. Therefore, from equation (3) of the previous article:

$$\frac{E}{n}\,I_h \cos \psi + \frac{E}{n}\,I_h\,r_1\,C_1\,\omega + \frac{I_h^2\,r_1}{2}$$

$$= \frac{E}{n}\,I_l \cos \psi' + \frac{E}{n}\,I_l\,r_1\,C_3\,\omega + \frac{I_l^2\,r_1}{2} \quad (12)$$

Dividing by $E\,I/n$:

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I}\,r_1\,C_1\,\omega$$

$$= \frac{I_l}{I} \cos \psi' + \frac{I_l}{I}\,r_1\,C_3\,\omega + \frac{n(I_l^2 - I_h^2) r_1}{2\,E\,I} \quad (13)$$

And, since $r_3 = r_1$, (11) reduces to:

$$\cos \phi + r_1\,C_1\,\omega + \frac{I_h}{I} \cos \psi + \frac{I_h}{I}\,r_1\,C_1\,\omega$$

$$- \frac{n-2}{2} \cdot \frac{(I + I_h)\,r_1}{E} = r_2\,C_2\,\omega + \frac{I_l}{I} \cos \psi'$$

$$+ \frac{I_l}{I}\,r_1\,C_3\,\omega - \frac{n\,r_1\,(I\,I_h + I_h^2 - I_l^2)}{2\,E\,I} \quad (14)$$

If (13) be subtracted from (14), the equation reduces to equation (6) of the other article, except for a practically negligible term $I_h\,r_1/E$.

If this were so, our object would be accomplished, inasmuch as all terms containing the charging currents from the needle and the power factor of these currents would be removed. It was tried out experimentally on a known load and *did not check*. Finally, the error in reasoning was discovered. It has been assumed that C_1 and C_3 are the same in equations (13) and (14) respectively and also that C_1 is as usual the total capacity to ground of the needle and all connected parts. This is true *if the capacity between the quadrants themselves is negligible*, and only in that case. If this capacity, which is an essential part of the total capacity to ground, in the usual connection, is not negligible, then raising the potential of the low quadrant will diminish the capacity to ground of the high quadrant by a certain fraction of the capacity between quadrants, which will be called C_q. The fraction of C_q which will be taken away is inversely proportional to the potential of the quadrants, or since equal resistances r_1 and r_2 are used, inversely proportional to the currents flowing in these resistances.

We will, therefore, define C_1 as the total capacity between high quadrant and ground, when the low quadrant is grounded, and C_3 as the total capacity between low quadrant and ground, when the high quadrant is grounded. C_1 will therefore be the same as in all our other equations. The values of C_1 and C_3 given in the equations of this appendix are, therefore, different from this definition as explained above, inasmuch as they are capacities when equilibrium is reached.

Equations (13) and (14), as shown below, must, therefore, be rewritten and obtain equations in which these capacities agree with their definition in the beginning of this paragraph.

(**13**) becomes

$$\frac{I_h}{I}\cos\psi + \frac{I_h}{I} r_1 \left(C_1 - \frac{I_l}{I_h} C_q \right) \omega + \frac{I_h^2 r_1}{2}$$

$$= \frac{I_l}{I}\cos\psi' + \frac{I_l}{I} r_1 \left(C_3 - \frac{I_h}{I_l} C_q \right) \omega + \frac{n\,(I_l^2 - I_h^2)}{2\,E\,I} \quad (15)$$

(**14**) becomes

$$\cos\phi + \frac{I_h}{I}\cos\psi + \left(1 + \frac{I_h}{I}\right) r_1 \left(C_1 - \frac{I_l}{I + I_h} C_q\right)\omega$$

$$- \frac{n-2}{2} \cdot \frac{(I + I_h) r_1}{E} = r_2 C_2\,\omega + \frac{I_l}{I}\cos\psi'$$

$$+ \frac{I_l}{I} r_1 \left(C_3 - \frac{I + I_h}{I_l} C_q\right)\omega - \frac{n\,r_1\,(I\,I_h + I_h^2 - I_l^2)}{2\,E\,I} \quad (16)$$

If (**15**) be subtracted from (**16**) the following is obtained

$$\cos\phi + r_1 C_1\,\omega - \frac{n-2}{2} \cdot \frac{I\,r_1}{E} + r_1 C_q\,\omega + \frac{I_h\,r_1}{E} = r_2 C_2\,\omega \quad (17)$$

This is the same as equation (**6**) of the former paper with the exception of the fourth and fifth terms, which in most instruments would be negligible, and therefore the effect of I_h has been practically neutralized by our method.

V. Experimental Proof of Neutralization of I_h

As mentioned in Section 4, it was thought at first that the method of neutralizing the effect of I_h outlined in Section 3 was practically perfect. It was tried out experimentally, a balance first being obtained on air condenser No. 1 in the usual manner, and then a balance was obtained after the procedure given in Section 3 was performed. It was expected that the balance after I_h had been neutralized would be smaller than before, primarily due to the elimination of the term $\frac{I_h}{I} r_1 C_1\,\omega$. Instead of that, however, the potential resistance required after the neutralization process had been performed was *larger*, which was puzzling. The effect of the capacity between the quadrants themselves, namely C_q was then realized, and the derivation was changed as in Section 4. Finally equation (**1**) was obtained, including the effect of the capacity between quadrants. In our instrument, the quadrants instead of being tinfoil on glass, as is often the case, were cast aluminum plates, about 3/16 in. thick, with a beading along both the outside and inside and a rib at one point, which altogether made a by no means negligible area between adjacent quadrants, the separation between quadrants being about 1/16 in. C_q was calculated on the basis of 1/16 in. separation and the effective area between quadrants, and was also calculated from the balance described by means of equation (**1**), all other quantities being known. These two values of C_q checked to within about 10 per cent, which seems quite satisfactory, inasmuch as the actual capacity between quadrants could not be calculated accurately.

It was not convenient to measure this actual capacity and the easiest method of checking equation (**1**) was actually to shunt a known condenser between quadrants and measure its capacity by a series of readings, including our procedure for neutralizing I_h.

The four following readings were taken, at 14,000 volts with half voltage on the needle, 100,000-ohms quadrant resistance, r_1 and at 60 cycles.

1. Air condenser No. 2 alone with no compensation.
2. Air condenser No. 2 alone with I_h neutralized.
3. Air condenser No. 2 with an additional condenser of capacity C_A shunted across the quadrants, no compensation.
4. Air condenser No. 2 with the *additional* condenser C_A *across the quadrants*, I_h neutralized.

By "with I_h *neutralized*" in the readings 2 and 4 above, is meant that the process outlined in Section 3 was performed, namely that the low-voltage electrode of the load was connected to the high quadrant with the high-voltage electrode point floating. A resistance of 100,000 ohms was then inserted between the low quadrant and ground, and shunting this a variable capacity was connected, which was so adjusted that the reading of the electrometer was equal to zero. This variable condenser which was graduated and calibrated, was reduced in capacity by an amount equal to the C_{ab} capacity of the load, and the high voltage was then connected to the load, and a balance performed by means of the potential resistance as usual.

Following are the values of potential resistance used, and also $r_2\,C_2\,\omega$

Reading	r_2	$r_2\,C_2\,\omega$
1	18,570 ohms	0.02950
2	19,600 "	0.03113
3	25,100 "	0.03988
4	31,600 "	0.05020

Remembering that the power factor of air condenser No. 2 is zero, the two following equations, according to equation (**8**) of the other and equation (**1**) of this paper, are obtained from the readings 1 and 2 respectively.

$$0 + \frac{I_h}{I}\cos\psi + \left(1 + \frac{I_h}{I}\right) r_1 C_1\,\omega$$

$$+ \left(1 + \frac{I_h}{I}\right)\frac{I_h\,r_1}{E} = 0.02950 \quad (18)$$

$$0 + r_1 C_1 \omega + r_1 C_q \omega + \frac{I_h r_1}{E} = 0.03113 \qquad (19)$$

Remembering that during readings 3 and 4 the total capacity to ground, as defined is equal to $C_1 + C_A$, and that the total capacity between quadrants is $C_q + C_A$, the two following equations are derived from both the equations (**8**) and (**1**) and the readings 3 and 4.

$$0 + \frac{I_h}{I} \cos \psi + \left(1 + \frac{I_h}{I}\right) r_1 (C_1 + C_A) \omega + \left(1 + \frac{I_h}{I}\right) \frac{I_h r_1}{E} = 0.03988 \qquad (20)$$

$$0 + r_1 (C_1 + C_A) \omega + r_1 (C_q + C_A) \omega + \frac{I_h r_1}{E} = 0.05020 \qquad (21)$$

Subtracting equation (**19**) from equation (**18**):

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I} r_1 C_1 \omega + \frac{I_h}{I} . \frac{I_h r_1}{I} - r_1 C_q \omega = -0.000163 \qquad (22)$$

Subtracting (**21**) from (**20**)

$$\frac{I_h}{I} \cos \psi + \frac{I_h}{I} r_1 (C_1 + C_A) \omega - r_1 (C_q + C_A) \omega + \frac{I_h}{I} . \frac{I_h r_1}{E} = -0.01032 \qquad (23)$$

Taking equation (**23**) from equation (**22**),

$$r_1 C_A \omega \left(1 - \frac{I_h}{I}\right) = 0.00969 \qquad (24)$$

Knowing that r_1 equals 100,000, I_h equals 30 microamperes, and I equals 0.568 milliamperes, and solving for C_A, the following is obtained.

$$C_A = 2.71 \times 10^{-10} \text{ farads}$$

It will be noted that C_A may also be obtained by subtracting equation (**18**) from equation (**20**), this being the ordinary method of measuring capacity as described in Section B of the previous paper. Making this subtraction

$$\left(1 + \frac{I_h}{I}\right) r_1 C_A \omega = 0.01038 \qquad (25)$$

From equation (**25**) we may calculate that $C_A = 2.61 \times 10^{-10}$ farads.

In order to check further their accuracy the authors sent the condenser C_A to an outside electrical laboratory whose measurements of the capacity were 2.53×10^{-10} farads. This check is not perfect, but it is believed to be quite satisfactory, especially in view of the difficulty with which the preliminary balance of the neutralization process with no voltage on the load was made, due to the lack of sensitivity of this instrument.

A NEW TYPE PORCELAIN PROTECTION TUBE

The choice of a proper protection tube for a thermocouple is nearly as important as the selection of the material for the couple. One of the most important properties of such a tube is low porosity to gases, since furnace gases usually attack the couple.[1] There are three general methods of attaining this low porosity: (*a*) By burning a refractory tube to a very high temperature (3000 deg. fahr.); (*b*) by adding a flux (such as feldspar) to a refractory body causing it to vitrify at a considerably lower temperature (2550 deg. to 2700 deg. fahr.); and (*c*) by coating a refractory body, which is not burned at a temperature sufficiently high to vitrify it, with an impervious glaze.

The first method is expensive and not generally practicable, and the second results in tubes which are apt to deform at operating temperatures. The third method produces tubes of satisfactory quality, is comparatively convenient, and has been adapted by this bureau to the production (by the "one-fire" method) of tubes for use in the ceramic laboratory. However, the "freezing" of the glaze to the wall of the furnace, or the ware with which it comes in contact, is a constant source of annoyance and loss of tubes by breakage. This is particularly true of laboratory work, the nature of which does not permit usually of permanent installations of tubes.

The Bureau of Standards has overcome this difficulty by the production of a "double tube" which is highly refractory, satisfactorily rigid at operating temperatures, and which is rendered impervious to gases by a coating of glaze between the double wall of the tube. The tube is formed by casting first a thin tube of the body composition, followed immediately by a cast (or coating) of the glaze, and then a third coating using the body composition to form the inner wall of the tube. When dry, this double-wall tube can be removed from the mold and burned in the usual manner.

THE FLATTEST FLAT

The United States Bureau of Standards has recently completed a flat surface which it claims has a deviation of one-ten-millionth of an inch of being perfectly flat. This is made out of quartz and will be available to American industry generally for test purposes. It is predicted that it will make for more accuracy of the development of intricate mechanical instruments employed in many manufacturing processes especially in the construction of machinery.

This "master quartz flat" will supplant the glass flats previously used by the bureau in testing micrometers and other measuring gauges used by manufacturers. With the glass flats previously used the same degree of accuracy could not be obtained because of its tendency to expand unequally due to heat.

1. Bureau of Standards Tech. Paper No. 170, p. 89

Remote-Controlled Substations
of the New York and Queens Electric Light and Power Company

BY W. C. BLACKWOOD[1]

Member, A. I. E. E.

Synopsis.—*This paper describes a unit type of distribution substation which has been designed for a Metropolitan district. Although of much lower capacity than other stations on the same system, its cost per kv-a. is approximately the same as the larger stations. The station is unattended and all operations are controlled from a distant attended station. The cost of operation per unit of capacity is no greater than for a much larger attended station. Remote-control was adopted rather than automatic operation because of the nature of the load and territory served where service with minimum interruption is demanded.*

THE New York and Queens Electric Light and Power Company serves four wards in the Borough of Queens, New York City, covering approximately 100 sq. mi. This territory is developing very rapidly both with industrial establishments of all types and sizes and residences varying from small one-family houses to very large apartment buildings.

Energy is purchased from the United Electric Light and Power Company at 13,200 volts and 26,400 volts and is stepped down for 2300/4000 volts., four-wire, distribution in substations located in Long Island City, Flushing, Maspeth and Jamaica, the ultimate capacity of these stations being 75,000 kv-a., 40,000 kv-a., 60,000 kv-a. and 30,000 kv-a. respectively.

In 1925 it was necessary to provide additional substation capacity in the district supplied by the Jamaica Substation, and three means of accomplishing this were considered—first, to increase the size of the present substation at Jamaica; secondly, to build another similar attended station; and thirdly, to build a smaller unattended station for automatic operation or remote control, and to provide for future growth by the erection of other similar unit unattended stations.

A study of these plans indicated that the cost per kv-a. of a large attended station and a small unattended station with automatic features or remote control was approximately the same due to the greater simplicity of the smaller station and the possibility of using switches of lower interrupting capacity than would be required in a large substation where the concentration of power would be greater. It was also found possible to resort to bus regulation in the smaller station, because of the shorter distribution feeders which would be supplied by it, while in the large station it would be necessary to install regulators on the individual feeders with the attendant complication of spare feeder equipment and transfer bus.

If operators were employed the operating cost per kv-a. of the smaller station would, of course, be greater than that of a large station but, if unattended, the operating cost per kv-a., considering periodic inspections which must be made, is estimated to be less than that in the large attended station.

In considering whether an automatic or a remote-controlled substation would be built, the governing factor was the quality of service to be supplied. As demanded in a metropolitan section, it has always been the company's policy to furnish service as nearly free from interruption as possible. Also, the increasing demands upon electric service for such devices as oil-burning equipments, electric clocks, operation of radio and other uses are beginning to make the furnishing of service with 100 per cent continuity imperative. An automatic substation without supervision and control from an attended station would not give the quality of service demanded, and, in order to supply such service, it was decided that all of the operations in the substation

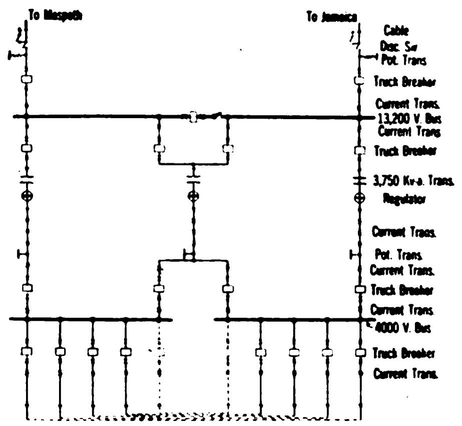

FIG. 1—ONE-LINE WIRING DIAGRAM WOODHAVEN SUBSTATION

should be under the direct and immediate control of an attendant at some point on the system. With such supervision, it was not considered necessary to install automatic features in the station, and the final decision was to build a station with all switches remote-controlled from the nearest attended station and with all operations indicated at that station.

The first substation of this type was erected in Woodhaven at a location about 2½ mi. from the Jamaica substation. Three 3750-kv-a., three-phase, oil-insulated, self-cooled transformers were installed and the rated capacity of the station is 7500 kv-a., one transformer being a spare. The station is fed by a 13,200-volt., three-phase 500,000-c.m. underground cable from the Jamaica substation and a similar cable from

1. Of the New York and Queens Electric Lt. & Power Co., Long Island City, New York.

To be presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

the Maspeth substation approximately 5½ mi. away.

Referring to the wiring diagram, Fig. 1 will show that each incoming cable is connected through oil circuit breakers to a 13,200-volt bus, which is sectionalized at its mid point by an oil circuit breaker. One

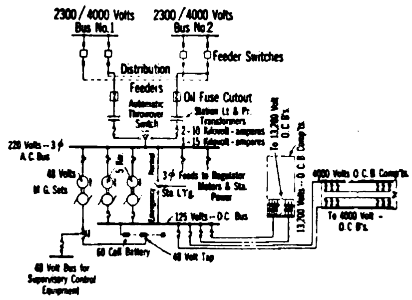

FIG. 2

transformer is connected to each section of this bus through oil circuit breakers, and the third transformer is arranged with double breakers for connection to either section of the bus. The switching connection on the 4000-volt side of the transformers is similar to

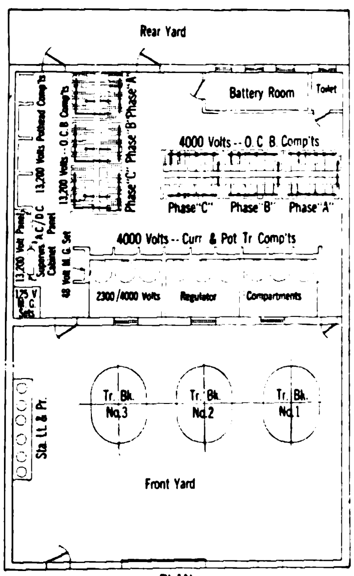

FIG. 3—PLAN OF WOODHAVEN SUBSTATION

that on the primary side, with the exception that the 4000-volt bus is operated in two sections without a tie breaker. There are four 4000-volt loop distribution feeders, the two ends of each feeder being connected to opposite sections of the 4000-volt bus. Three 135-kv-a., single-phase, automatic induction voltage regulators are connected in the secondary leads of each transformer. The distribution feeders are rated at 400 amperes for a loop feeder, although the switches on each end of the loop have a capacity of 600 amperes.

Each transformer bank is protected by differential relays and the bus sections are similarly protected so that any fault on the bus or its connections will open all breakers connected to the section in trouble. With the loop arrangement of feeders, this will cause no interruption to service.

The bus and switch structures were greatly simplified by the installation of single-phase, truck-type, oil circuit breakers, grouped according to phases both on the 13,200-volt bus and the 4000-volt bus. The transformer switches and 13,200-volt switches are controlled

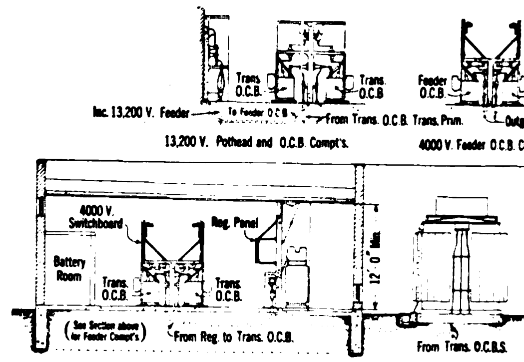

FIG. 4—SECTIONS OF WOODHAVEN SUBSTATION

as three-phase units, by electrically connecting the solenoids.

The 4000-volt feeder breakers are operated single-phase. As will be noted from the sectional drawings of the switch compartments, the grouping of all the switches on one phase makes it unnecessary to install three buses and avoids the usual connections from the

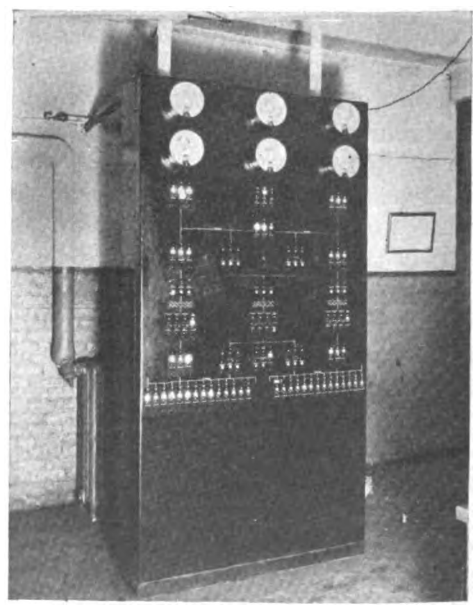

FIG. 5—PANEL OF JAMAICA SUBSTATION FOR WOODHAVEN CONTROL

bus to the switches which must, in the case of two of the phases, cross other buses if they are arranged in vertical formation.

Fig. 2 is a diagram of the control connections, in the design of which consideration was given to the fact that the station would be unattended and that therefore

continuity of the d-c. supply was essential. Two banks of station light and power transformers are fed from two 4000-volt feeders, tied to opposite bus sections. The secondaries are connected through an automatic throw-over switch to a 220-volt., three-phase bus from which two 5-kw. motor generator sets are fed. Normally,

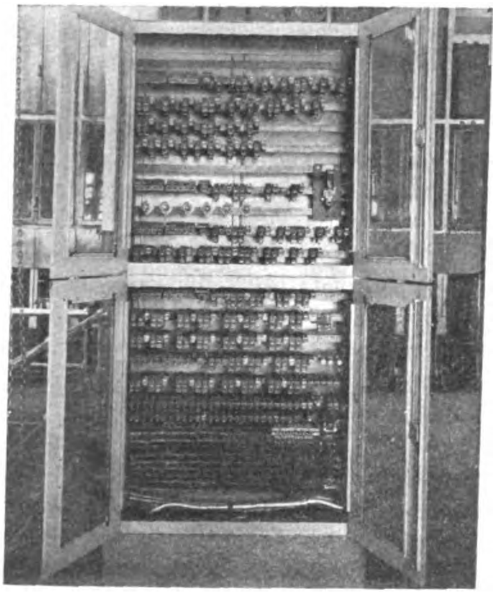

Fig. 6—Supervisory Control Relay Cabinet at Jamaica Substation for Woodhaven Control

one set is in operation, trickle-charging the battery, and relays are provided which, in case of failure of this set, will immediately place the other set in operation.

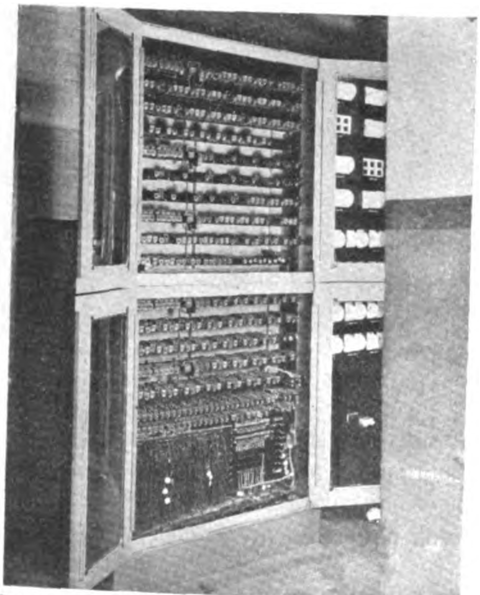

Fig. 7—Supervisory Control Relay Cabinet at Jamaica Substation for Woodhaven Control

A one-kw. motor generator is provided to supply the 48 volts, direct current, required to operate the supervisory control system. In case of failure of this set, connection is automatically made to a 48-volt tap on the station battery. The motor generator set is used for normal operation instead of the battery tap to avoid unequal discharge of the battery.

Sectionalizing switches, but no fuses, are used in the d-c. connections to the oil circuit breaker compartments and all wiring is insulated with 5/32-in. special rubber compound, so installed that grounds or short circuits are practically impossible. This plan was adopted because the blowing of a fuse in an unattended station would probably not be discovered until an attempt was made to operate a breaker and a serious interruption

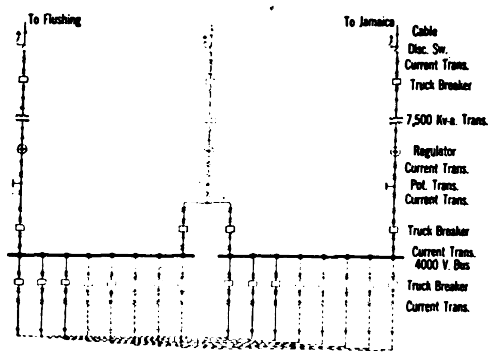

Fig. 8—One-Line Wiring Diagram—Hollis Substation

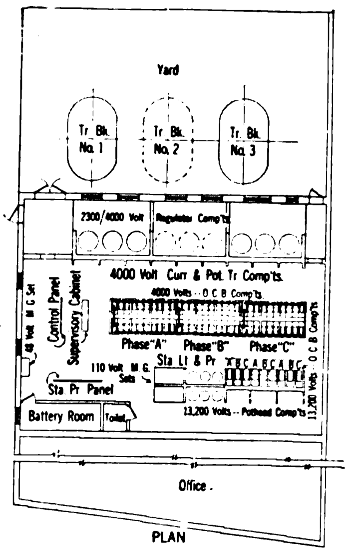

Fig. 9—Plan of Hollis Substation

might result if the d-c. supply to a trip coil was open at the time of a feeder short circuit.

All operations in the station are controlled from a panel in the Jamaica substation shown in Fig. 5. This panel is made of furniture steel and the control keys and indicating lamps are arranged in accordance with the wiring diagram of the Woodhaven station. The control is the Westinghouse Synchronous Relay Visual System, which was described in a paper by Mr. Chester Lichtenberg, presented at the Midwinter Convention in New York, February 8-11, 1926. The relay cabinets at the Jamaica and Woodhaven stations are shown in Figs. 6 and 7. The control cable, which is installed in

under ground ducts throughout, is ten pair No. 19 B&S, paper-insulated and lead-encased.

The supervisory equipment controls 21 single-pole, 13,200-volt breakers and 12 single-pole, 4000-volt breakers, in groups of three, but with single-pole indication at the Jamaica station and 24 single-pole, 4000-volt feeder switches with single-pole indication at the Jamaica station.

It is also possible to read at Jamaica, the current and voltage of each transformer in the Woodhaven station and to operate the regulators from Jamaica to equalize the voltage on the transformers when one is being cut into service.

FIG. 10—WOODHAVEN SUBSTATION 4000-VOLT OIL CIRCUIT BREAKERS AND CONTROL PANELS

Indication is given at Jamaica of high temperature in the transformer windings, ground on the d-c. control system, the operation of the battery charging motor generators and the opening of the station door.

The Woodhaven station has been in operation only a few months and therefore, no definite conclusions can be drawn as to the operation of the supervisory equipment. The installation is probably the most extensive and complicated that has yet been placed in service and there were naturally a number of difficulties encountered in starting it. These were mostly matters of relay adjustment and changes in connections which were found to give back feeds or sneak paths which caused incorrect relay operations. These have been corrected and it is believed that the reliability of operation will be at least equal to that of an attended station.

Construction of a similar station at Hollis approximately eight miles from Jamaica has been started and while the connections and arrangement are substantially the same as at Woodhaven, certain changes have been made which are considered improvements in the design.

The Hollis station will have twice the capacity, or 15,000 kv-a. supplied by two 7500-kv-a. transformers with one 7500-kv-a. spare unit. The diagram of connections is shown in Fig. 8. Each transformer will be supplied by a 13,200-volt incoming feeder with no high-tension bus. With this exception the connections are the same as at Woodhaven. There are of course eight instead of four-loop, 4000-volt feeders.

The arrangement of the bus and switch structures shown in the plan Fig. 9, is slightly different and a control board has been provided at the end of the 4000-volt bus structure on which are located the control switches for the feeder breakers which at Woodhaven are located on the panels directly above the breakers. The relays for each feeder are located on panels above the breakers as at Woodhaven but these panels have been faced in the opposite direction so that access is had from the top of the bus structure instead of from ladders in the switch aisle.

The supervisory control equipment is identical with that used at Woodhaven and the control panel will be placed alongside the Woodhaven panel in the Jamaica substation.

The growth of load in the Borough of Queens is taking place in a number of communities or centers some of which are widely separated and it is probable that the growth will be served by the erection of stations similar to those described above at or near the load centers. Supervisory control equipment, although it has pro-

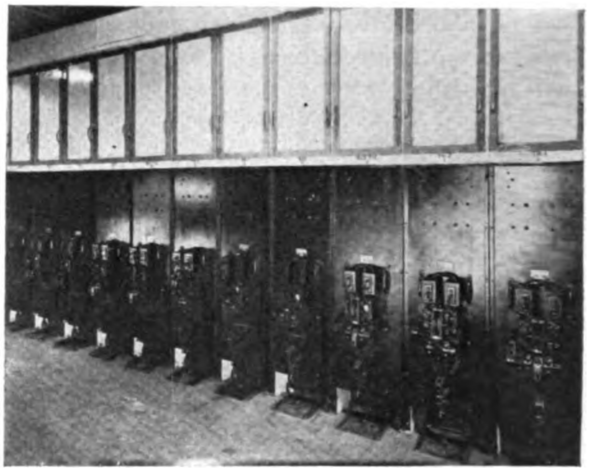

FIG. 11—WOODHAVEN SUBSTATION, 13,200-VOLT OIL CIRCUIT BREAKERS

gressed rapidly in the past few years, has been developed principally along the lines of supervision and indication of the operations of automatic stations and has not been depended upon entirely for the complete operation of stations. Much more reliable equipment is needed when the station is not arranged to operate itself automatically in case of failure of the supervisory equipment and while the equipment now available may prove to be satisfactory it will probably be found necessary to change its design in some respects to make it more rugged before the reliability of operation which is demanded in metropolitan districts, is fully realized.

Abridgment of

Refraction of Short Radio Waves in the Upper Atmosphere

BY WILLIAM G. BAKER[1]
Non-member
and
CHESTER W. RICE[2]
Associate, A. I. E. E.

***Synopsis.**—The paper shows that the striking phenomena of short-wave radio transmission (i. e., below 60 meters) can be quantitatively accounted for on a simple electron refraction theory in which the effect of the earth's magnetic field and electron collisions may be neglected as a first approximation. The distribution and number of electrons per unit volume in the upper atmosphere required on this theory to account for the meager experimental data appear to be in general accord with the values required in the explanation of the diurnal variations of the earth's magnetic field, aurorae and long-wave radio transmission.*

The paths taken by the waves from an antenna to distant points on the surface of the earth are calculated. The path calculations give a definite picture of the now familiar skip distance effects. Ideal signal intensity curves (i. e., neglecting absorption and scattering) are given, which show how the energy sent out by a transmitter is distributed over the surface of the earth. A focussing of energy just beyond the skip distance, and again just inside the point where the ray tangent to the ground at the transmitter comes back to earth is clearly shown. The reflection of waves at the surface of the earth is also considered.

The results of these calculations make it possible to estimate the most suitable wave lengths for night and day communication between any two points on the earth's surface. It is also pointed out that there will be a minimum wave length, in the vicinity of 10 meters, below which long distance communication becomes impossible. It is shown that from the point of view of long distance communication low angle radiation is most effective. The ray paths and energy flux density in the wave front of the sky waves are independent of the plane of polarization of the transmitter. The effects of polarization on the reception problem are not discussed.

I. Introduction

SHORT-wave (*i. e.*, 60 to 15 meters) transmission experiments during the past two years have definitely brought to light many peculiarities which were entirely unexpected as extrapolations from our many years of long-wave experience. Until recently any announcement of long-distance short-wave transmission was put down as an unexplained freak by the average radio man, and dismissed from his mind. As the number of such reports increased, we could no longer be content to dismiss them as freaks and were forced to abandon our preconceived notions as to what normal short-wave transmission should be, and extend our theory in such a way as to give these remarkable results a definite place in the new scheme of things.

In Fig. 1 we have attempted to summarize the available data on short-wave transmission characteristics. Most of the data are from the valuable papers by Taylor[3] and Taylor and Hulburt[4] with a few check points kindly supplied by Young.[5] We have also obtained considerable help, in drawing the smooth curves through the few scattered points, from the valuable work published by many amateurs.[6] The curves assume that 5-kw. are being supplied to an average antenna and that the practical limit of reception is reached at 10 microvolts per meter. The curves further assume full daylight or night conditions at both the transmitter and receiver in order to eliminate sunset and sunrise effects as well as peculiarities which arise when one station is in darkness and the other in daylight. This, of course, limits the diagram to practically north and south transmission; nevertheless, it may be used to estimate the general trend for other conditions.

As a typical example of the peculiarities of short-wave transmission, let us describe the experience obtained with a 5-kw., 30-meter transmitter. Here the signal rapidly descreases as we leave the transmitter and reaches the lower useful limit of 10 microvolts per meter at about 70 miles. This short range is what might be called the expected value as viewed from our long-wave experience and is represented in Fig. 1 by passing to the right of the line marked *Limit of Ground*

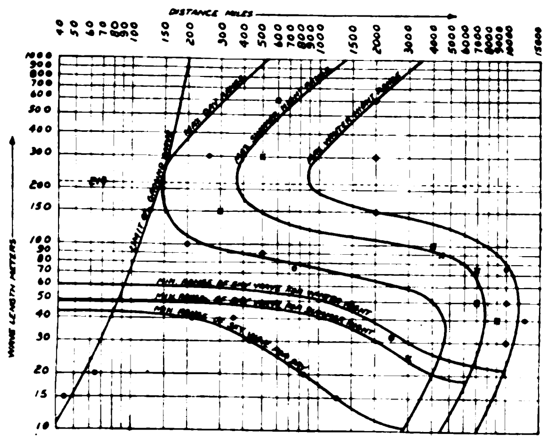

Fig. 1—Approximate Transmission Characteristics Mainly from Data by A. H. Taylor for 5 Kw. in Antenna and Limit of Reception, 10 Microvolts per Meter. North and South Transmission

1. W. and E. Hall Fellow of the University of Sydney, New South Wales, Australia. Research Laboratory, General Electric Co., Schenectady, N. Y.
2. Research Laboratory, General Electric Co., Schenectady, N. Y.
3. A. Hoyt Taylor, *Inst. Radio Eng.*, Vol. 13, p. 677, 1925.
4. A. Hoyt Taylor and E. O. Hulburt, *Q. S. T.*, p. 12, Oct. 1925.
5. C. J. Young, Unpublished reports on Short-Wave Transmission Tests by the General Electric Co. at Schenectady, N. Y.
6. See for example *Q. S. T.*, 1924 and 1925.

Presented at the Midwinter Convention of the A. I. E. E., at New York, N. Y., February 8-11, 1926. Copies of complete paper available upon request.

Wave. If we now continue to greater distances the signal remains out until we reach approximately 450 miles where th day signal unexpectedly becomes strong again. This is represented in the figure by crossing to the right of the curve marked *Minimum Range of Day Sky Wave.* Continuing to greater distances we find the signal gradually falling off in intensity, reaching the useful limit of.10 microvolts per meter in the vicinity of 4500 miles by day. This is represented in Fig. 1 by passing to the right of the curve marked *Maximum Day Range.* On a summer night the signal does not reappear after the 70 mile extinction until we are approximately 2000 miles from the transmitter, after which the signal falls off gradually to a very low value at 7500 miles.

The present explanation of the above peculiar phenomena is as follows: Assume, for simplicity, that energy is radiated equally in all directions by the transmitter. As we go away from the source. the signal strength will decrease in the usual manner due to spreading and energy absorption by the ground, with the result that the 30-meter signal practically vanishes in the vicinity of 70 miles. In other words, the ground wave component of the 30-meter signal behaves as we should expect from our long-wave experience, *i. e.*, is rapidly attenuated. The unexpected thing happens when we go out to 450 miles and find that the signal by day has reappeared. This reappearance of signal is accounted for by electronic refraction of a portion of the energy which is radiated towards the sky. A reflection theory of this effect has been proposed by Reinartz.[7] More recently a refraction theory has been developed by Taylor and Hulburt.[4] The calculations in the present paper are based on the electron theory of optical dispersion in metallic media as developed by Lorentz,[8] Drude,[9] etc. We are also greatly indebted to Eccles,[10] Larmor,[11] Appleton[12] and Nichols and Schelleng[13] who have worked out many important conclusions which follow from an application of the optical theory to various phases of the radio transmission problem.

The present calculations show that by making certain reasonable assumptions as to the number and distribution of the free electrons in the upper atmosphere the main characteristics of the relatively meager experimental results can be accounted for.

The calculated paths for rays going out from the transmitter at different angles to the horizontal show the following general characteristics: A ray starting out at a low angle will be only slightly refracted and come to earth again at a great distance from the transmitter. For higher angles the rays will return to earth progressively nearer the transmitter. Finally a critical angle is reached for which the refracted ray comes down at the nearest distance to the transmitter. For higher angles the points of return recede from the transmitter until finally a second critical angle is reached where the ray does not return to earth. but instead goes out into space and is lost.

The distance from the transmitter to the nearest point at which the refracted sky wave returns to earth has been called the "skip distance." For a given wave length the skip distance is a minimum in the middle of the day and a maximum on a winter night, the summer night value being somewhat less than the winter night skip. This variation is theoretically accounted for by a change in the height, thickness and maximum value of the electron density in the upper atmosphere.

The experimental summary given in Fig. 1 shows that the skip distance for a given time of day or night decreases with increasing wave length. This observation is in agreement with the increase in refraction on the longer wave lengths. If we neglect the effect of collisions between the electrons and gas molecules which prevent the refraction index from going to zero, we obtain a sharp upper limit in wave length above which skip distances fall to zero. For the ionization values assumed in the paper, this occurs for a wave length of 60 meters on a winter night as shown in the calculated skip distance curves of Fig. 16.

If the effect of collision frequencies were taken into account, this sharp upper limit would disappear and we would obtain skip distances on wave lengths greater than 60 meters for the assumed winter night ionization values. The effect of the earth's magnetic field will also require consideration in the vicinity of the upper limiting wave length. The experimental determination of skip distances on the longer wave lengths will be difficult owing to the masking effect of a relatively strong ground wave.

On the present theory we may expect severe fading near the transmitter under certain circumstances. For example, consider the case of 60-meter transmission on a winter night. Here a refracted or sky wave will fall inside of the ground wave limit and at a certain distance may be approximately equal in magnitude to the ground wave value. Under these conditions severe interference effects between the two waves will result. If the ground absorption is high this effect may be found quite close to the transmitter. Over salt water the effect should occur at a greater distance.

On shorter waves where the skip distance is well beyond the ground wave limit, severe fading is exp cted in the region just beyond the skip distance, where the two sky waves of approximately equal intensity overlap.

Appleton[12] and a little later Nichols and Schelleng[13] independently pointed out that the earth's magnetic

7. John L. Reinartz, *Q. S. T.*, p. 9, April 1925.
8. H. A. Lorentz, The Theory of Electrons, Teubner, 1909.
9. Paul Drude, The Theory of Optics (Engl. Trans. by Mann and Millikan) Longmans, 1917.
10. W. H. Eccles, *Proc. Roy. Soc.*, Lond., Vol. 87, p. 79, 1912.
11. Joseph Larmor, *Phil. Mag.*, Vol. 48, p. 1025, 1924.
12. E. V. Appleton, *Proc. Phy. Soc.*, Lond., Vol. 37, Part 2, p. 16D, 1925.
13. W. H. Nichols and J. C. Schelleng, *The Bell System Technical Journal*, Vol. IV, p. 215, 1925.

field should produce some very interesting effects on radio transmission, especially in the vicinity of 214 meters and above. It is interesting to note, in this connection, that Fig. 1 shows a marked absorption in the 214 meter region. A very interesting study of transmission phenomena in the broadcast wave length band, has recently been reported by Bown, Martin and Potter[14]. The present paper is confined to the propagation phenomena on the short-wave side of 214 meters where the effective electron restoring force due to the earth's magnetic field will cease to be important compared with the electron inertia force, and may, therefore, be neglected as a first approximation.

The subject matter contained in the body of the complete paper will be summarized here, by listing the section headings.

II. REFRACTIVE INDEX OF A MEDIUM CONTAINING FREE ELECTRONS

III. GENERAL EQUATION FOR THE PATH OF A RAY IN A MEDIUM OF VARYING REFRACTIVE INDEX

IV. CONSTITUTION AND DISTRIBUTION OF IONIZATION IN THE UPPER ATMOSPHERE

V. CALCULATION OF THE PATH OF A RAY IN A MEDIUM IN WHICH THE ELECTRON DENSITY IS A SINE SQUARE FUNCTION OF THE HEIGHT

VI. TYPICAL PATH CALCULATIONS

VII. DISCUSSION OF SKIP DISTANCE CALCULATIONS

VIII. CALCULATION OF THE POWER RECEIVED AT THE SURFACE OF THE EARTH FROM A DISTANT SHORT WAVE TRANSMITTER, NEGLECTING ENERGY ABSORPTION

IX. INTENSITY CALCULATIONS

Appendix I

EFFECT OF ELECTRON COLLISIONS WITH MOLECULES ON THE REFRACTIVE INDEX OF AN IONIZED MEDIUM

Appendix II

GENERAL EQUATION FOR THE PATH OF A RAY IN A MEDIUM OF VARYING REFRACTIVE INDEX IN POLAR COORDINATES

Appendix III

DIFFERENTIATION OF THE RANGE EQUATION WITH RESPECT TO θ FOR THE CASE OF A CURVED EARTH

Appendix IV

FOCUSING EFFECTS AT THE SKIP DISTANCE AND INSIDE OF THE TANGENT RAY

X. SUMMARY AND CONCLUSIONS

We have seen that the striking phenomena of short wave radio transmission (*i. e.*, below 60 meters) can be quantitatively accounted for on a simple electron refraction theory in which the effects of the earth's magnetic field and collisions of electrons with molecules may be neglected as a first approximation. The distribution and number of electrons per unit volume in the upper atmosphere required on this theory to account for the meager experimental data appear to be in general accord with the values required in the explanation of the diurnal variations of the earth's magnetic field, aurorae and long wave radio transmission[28].

Thus the large increase in the skip distance on a given wave length at night compared with that by day is a natural consequence of the greater ionization produced on the sunlit hemisphere by the streamers issuing from the sun. The ideal field intensity calculations given in Fig. 25 show that we may make an ample allowance for scattering and absorption and still account for the strong signals observed at great distances. The high field intensities indicated in the ideal curves of Fig. 25 at the skip distance and where the tangent ray strikes the earth are due to the focussing effect discussed in Appendix IV. The intensities at the two foci will, of course, be limited by the finite size of the source as well as by absorption and scattering.

Let us now discuss the problem of maintaining night and day communication between two points 5000 kilometers apart from the point of view of the present theory. For full winter night conditions (*i. e.*, night at both transmitter and receiver) Fig. 16 indicates that the selection of a 30-meter wave length would put the receiver right at the skip distance. Such a wave length selection would result in the arrival of two intense sky waves and consequently severe fading. Inspection of the field intensity calculations of Fig. 25 show that the field intensity produced by the ray leaving the transmitter at the higher initial angle dies out very rapidly compared with that produced by the ray having the lower initial angle. Therefore, if we pick a somewhat longer wave length than 30 meters we will receive a reasonably strong signal from one ray only and consequ ntly be less likely to find severe and rapid fading effects. We would, therefore, probably choose a wave length in the vicinity of 32 meters for winter night operation.

An alternative would be to select a wave length in the vicinity of 55 meters, with the idea of taking advantage of the focussing which occurs just inside of the distance at which the ray leaving the transmitter tangent to the ground comes back to earth. For full day conditions this wave length would be weak since 5000 kilometers is too far from the day skip distance. If we applied the above reasoning in selecting the best value for full day operation from Fig. 16 we would probably be led to select a wave length in the vicinity of 11 meters. This, however, would bring us down very close to the lower wave length limit which would mean a very weak signal. The reason for the weak signal near the low wave length limit will be readily appreciated when we remember that under these conditions we are working close to the value at which

14. Ralph Bown, De Loss K. Martin and Ralph K. Potter. *The Bell Syst. Tech. Jour.*, Vol. V, No. 1, p. 143, 1926.

28. H. J. Round, T. L. Eckersley, K. Tremellen and F. C. Lunnon. *Journ. Inst. Elec. Engg.*, Vol. 63, No. 346, p. 933, Oct. 1925.

a ray leaving the transmitter tangent to the earth's surface strikes the lower boundary of the ionized medium at the second critical angle. Under these conditions there is only a small fraction of the emitted radiation which returns to earth.

It would, therefore, be better to select a wave length in the vicinity of 15 meters and operate on the ray which is reflected from 2500 kilometers to 5000 kilometers. Under these conditions we would, of course, face the possibility of considerable fading due to interference between the weak direct ray and the reflected ray. Another method would be to use a still longer wave length, for example around 25 meters, and depend upon the reflection of the energy falling at 2500 km. which is already beginning to pile up towards the focus at 3500 km.

In this connection it is interesting to note that the reflected 25 meter signal should be much stronger at 6400 km. than at 5000 km. since the focus is in the vicinity of 3200 km. In other words, it is apparently easier to get a good day signal at 6400 km. than at 5000 km. This point of view indicates that in short wave transmission problems, there will be certain favored distances. Another point of interest is that a 28 meter wave length should give good day and night communication between two points about 6400 km. apart due to the direct ray by night and the reflection from the tangent ray focus by day.

The numerical values deduced for this example are, of course, very uncertain since the ionization constants for the upper atmosphere which are required before a set of radio transmission characteristics like Fig. 16 can be calculated were figured backward from the very meager radio data. In other words it is probably fair to say at the present time that short wave radio transmission experiments are the most direct method we have of estimating the ionization conditions in the upper atmosphere. We should not lose sight of the fact that the skip distances, etc., which depend upon the ionization conditions in the upper atmosphere are probably not constant but will vary from year to year following the 11 year sun spot period, the last minimum of which occured in 1922.

When both the transmitter and receiver are not in the sunlit or darkened hemisphere the ray paths will no longer be symmetrical about the middle point, and due allowance will have to be made for the variation of ionization conditions between the two stations. Sunset and sunrise effects will also require special treatment. It is also probable that transmission to or from the polar regions will require special study of this kind, due to the high concentration of ionization over the polar regions as compared with that over the middle belt of the earth. We can conclude in a general way that transmission from the sunlit into the darkened hemisphere will result in longer skip distances than would result if daylight extended over the whole path. For example, a ray entering the ionized medium from the sunlit side will at first meet the normal day refraction, which starts bending the ray back towards the earth and, as it moves into the darkened hemisphere, the bending by refraction will become less and less until normal night conditions exist. Thus the ray will strike the ground at a greater distance from the transmitter than it would have, if full day conditions extended over the entire path. Here the general conditions for reciprocity[29] are satisfied, so that if a ray were started back along the same path it would retrace the entire path back to the starting point.

Inspection of the day curve of Fig. 16 shows that it will be impossible to maintain communication between two distant stations on less than a 10-meter wave length. This limitation is due to the fact that the tangent ray will strike the lower boundary of the ionized medium at an angle greater than the second critical angle and will therefore not return to the earth, but be refracted out into empty space.

The precise value of this minimum wave length is, of course, not 10.6 meters, as indicated in Fig. 16, because of the meager data upon which the figure is based. There is a similar limit for full winter night conditions given as 22.5 meters in Fig. 16. Near sunset or sunrise we can, however, use a wave length less than the above full winter night limiting value, when transmitting from the dark into the light hemisphere, since the refraction is increasing in the direction of travel of the ray and may be sufficient to bend the ray back to earth.

It is now interesting to see what type of antenna directive curve will be most effective for long distance communication from the point of view of the present theory. We have seen that all of the energy which strikes the lower boundary of the ionized medium above the second critical angle is refracted out into space and is lost. The initial angle at the transmitter which corresponds to this condition is obtained from equations (80) and (97) as

$$\theta = \cos^{-1} \left\{ (1 + b/r_0) \sqrt{1 - \sigma N_0 / \omega^2} \right\}$$

which may be written for convenience as

$$\theta = \cos^{-1} \left\{ (1 + b/6300) \sqrt{1 - 9 \times 10^{-9} N_0 \lambda^2} \right\}$$

The summer day and winter night conditions on long wave lengths yield the largest useful values of the initial angle. For our assumed ionization condition we obtain $\theta = 67.8$ deg. for 40 meters on a summer day and $\theta = 64.5$ deg. for 55 meters on a winter night. For shorter wave lengths the critical values for the initial angles will be much less, as will be seen from Figs. 23 and 26. Here $\theta = 25.9$ deg. for 21 meters on a summer day and $\theta = 11.2$ deg. for 25 meters on a winter night. Thus we may conclude that on these

29. Cases where two way communication on the same wave length will not hold, due to the effect of the earth's magnetic field, or because of an electron drift velocity, have been discussed respectively by E. V. Appleton, *Nature*, p. 382, March 7, 1925, T. L. Eckersley, *Nature*, p. 466, Sept. 26, 1925.

short wave lengths all of the useful radiation is emitted between the horizontal and approximately 70 deg., and the greatest distances are reached by the low-angle radiation. We therefore conclude that for long-distance work, on short waves, maximum efficiency is obtained by low-angle radiation. This also means that nearby obstructions which cut off the low angle radiation will be detrimental to long distance working. It is therefore desirable to place the transmitter on a hill or mountain, so as to obtain an unobstructed path to the horizon in the desired direction. Raising the antenna system well above the ground will also assist by reducing ground losses and lowering the horizon.

For long distance work the plane containing the electric vector at the transmitter may make any angle whatever with respect to the ground without appreciably affecting the ray paths or energy flux density in the wave front.

In any case the earth's magnetic field will produce enough rotation of the plane of polarization to make the angle of polarization of the received ray at the surface of the ground purely a question of chance. The best type and orientation of receiving system (loop or antenna) will depend upon the direction and polarization of the arriving wave as well as upon the conductivity of the ground and height of the receiving system above the earth. Some interesting work on determining the direction of arrival of signal waves has recently been done by Appleton and Barnett[30].

The best polarization of the transmitter can therefore be considered from the point of view of ground losses, mechanical construction and such questions as nearby interference, due to the ground wave, etc.

It should be pointed out in closing that electron collisions and the effect of the earth's magnetic field will modify the shape of the skip distance curves in the vicinity of the upper asmptotic wave length. Here absorption and double refraction (*i. e.*, splitting of a ray into two components having different velocities of propagation) will require consideration in a complete theory of short wave transmission.

The above theory is based on continuous wave theory and will not apply directly to very highly damped waves. In highly damped spark transmission we are dealing with a wide band of frequencies and therefore skip distance effects, etc., will be considerably blurred. Here methods similar to those used by Eckersley[31] in his very interesting explanation of the familiar "trolley car noise" often heard by radio men, would have to be applied.

The relatively small effect of molecular refraction, due to density and temperature gradients in the lower atmosphere, discussed by Fleming[32] and Larmor[11] has been neglected.

It should also be kept in mind that only an approximate allowance has been made for the curvature of the ionized medium on the ray effect of the paths.

ACKNOWLEDGMENT

The writers owe a great deal to Mr. E. W. Kellogg for the many illuminating suggestions which he contributed during the preparation of the paper.

30. E. V. Appleton and M. A. F. Barnett, *Proc. Roy. Soc. A*, Vol. 109, p. 621, Dec. 1925.

31. T. L. Eckersley, A Note on Musical Atmospheric Disturbance, *Phil. Mag.*, Vol. 49, p. 1250, June, 1925.

32. J. A. Fleming, *Proc.* Phy. Soc. Lond., Vol. 26, p. 318, 1913-1914.

GERMAN-LUXEMBURG POWER SCHEME

The sites for two plants of the Ours River hydroelectric scheme, are to be such that one plant will be in Germany and the other just across the border in Luxemburg. At the point where the dam is to be built, the valley is narrow and the conditions favorable. The dam will be 106 meters high, and the average flow is 30 cubic meters per second. The impounded water will back up a distance of 28 kilometers, and flood 20 square kilometers, as well as six towns. In order to obtain more water than the Ours River itself supplies, water will be carried by pipe line from the Kyll River at Birresborn (elevation 335) to the Prum River (elevation 325) at Waxweiler, thence to the Irsen River (elevation 318) and finally to the Ours River. Water will also be drawn from the Sauer River.

Plans for Supplying Power

The new company intends to supply power only during the day and to store the water at night. During the night they may purchase cheap power and pump water back into the lake, as the day power rate is about 4½ times the night rate. A reserve supply of 200,000,000 cubic meters of water can be stored in the reservoir.

The power will be used in Luxemburg and the Rhine Provinces. Transmission lines will be built to Cologne (107 kilometers, 200,000 volts), connecting with the Goldenburg company at Duren, Trier (45 kilometers, 100,000 volts), Eteburck (50 kilometers), and Luxemburg City. When the work is completed, the company will be able to generate 400,000 kilowatt hours per day, which may be increased to 600,000. Should the demand for power increase, another plant can be erected below the present dam, giving a further capacity of 60,000 kilowatts. There are a few small power plants in the neighborhood which now produce together about one-fortieth of what the new company will be able to generate.

Current Transformers with Nickel-Iron Cores

BY THOMAS SPOONER[1]

Member, A. I. E. E.

Synopsis.—*There has been developed recently a nickel-iron alloy called hypernik which has especially low hysteresis loss and high permeability at low inductions. Due to these properties the material is particularly suitable for the cores of current transformers. A ring-type series transformer with a core of hypernik has approximately one-third of the ratio and phase-angle errors exhibited by a similar transformer having a core of ordinary silicon steel.*

The relative performance of transformers with cores of the two kinds of material are shown by test and by calculation for various burdens and ratios. The minimum ratio for which satisfactory performance can be obtained with a through-type transformer having a hypernik core is about 200 to 5.

This new material is relatively expensive but its use will undoubtedly be warranted for certain applications.

The accurate metering of power supplied at high voltages is difficult due to limitations in the performance of through-type current transformers. With a single turn for the primary the available m. m f. for low currents is very small. For a standard five-ampere secondary winding the number of secondary turns is fixed by the ratio, therefore, for a given burden inductions in the cores are high which means relatively large core losses and magnetizing currents. As the transformer ratio decreases the phase-angle errors rise very rapidly due to losses and the low permeability at low inductions for the ordinary silicon-steel core materials.

Some years ago L. W. Chubb recognized the possibility of improving the performance of current transformers by the use of certain nickel-iron alloys which have especially high permeability at low inductions.[2] Such a material has now become commercially available through the efforts of T. D. Yensen and P. H. Brace.

The purpose of this paper is to show some of the advantages which may be gained by the use of a particular nickel-iron alloy called hypernik for the cores of through-type transformers.

Current Transformer Characteristics

If the magnetic properties of the core of a current transformer and the leakage reactances of the windings are known, the ratio and the phase-angle errors for any secondary current or burden on the transformer; may be calculated quite accurately. Since this particular discussion is limited to through-type transformers, the effect of leakage reactance will be neglected since this is practically negligible for this type of transformer.[3]

In order to calculate the performance of ring-type transformers, it is necessary then to know only the watt and wattless components of magnetizing current for the particular core at the desired frequency and induction as determined by the secondary current and burden. A method of measuring the core characteristics will be discussed later.

The relation between the magnetic properties of the core and transformer performance has been shown very clearly by Agnew.[4] Fig. 1 shows the vector diagram of a current transformer supplying an inductive load.

E_2 is the secondary voltage.

I_1 and I_2 are the primary and secondary currents, respectively.

n is the ratio of the number of secondary to primary turns.

φ is the phase angle of the secondary current.

M is the magnetizing component of the core exciting current necessary to produce the flux Φ.

F is the corresponding loss component of exciting current (due to hysteresis and eddy losses in the core).

Because of the magnetizing and loss components of

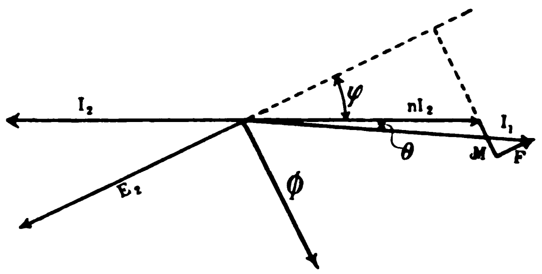

FIG. 1—VECTOR DIAGRAM OF CURRENT TRANSFORMER

the exciting current there will result (unless the exciting current is in phase opposition with the secondary current) a phase angle between the primary and secondary currents which will differ from 180 deg. by the angle θ. This is the phase-angle error of the transformer. The ratio error is proportional to the difference between I_1 and $n\,I_2$.

Agnew gives the following simplified formulas for calculating the errors in current transformers.

$$\text{Ratio } (R) = n + \frac{M \sin \varphi + F \cos \varphi}{I_2} \qquad (1)$$

1. Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

2. U. S. Patent Number 1,277,384.

3. Effect of Magnetic Leakage in Current Transformers. H. W. Price, C. K. Duff.

Papers on Current Transformers. *Bull.* No. 2, Section No. 4, University of Toronto, 1921, p. 169-171.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

4. A Study of the Current Transformer with Particular Reference to Core Losses. P. G. Agnew, *Bull.* Bureau of Standards, Vol. 7, 1911, pp. 423-474.

$$\text{Tan } \theta = \frac{M \cos \varphi - F \sin \varphi}{n I_2} \quad (2)$$

Obviously if φ is 0, namely, if the burden on the secondary of the transformer is non-inductive,

$$R = n + \frac{F}{I_2} \quad (3)$$

$$\text{Tan } \theta = \frac{M}{n I_2} \quad (4)$$

In other words, for this case and a given secondary current the ratio depends only on the ratio of the secondary to primary turns and the loss in the core. The phase angle depends only on the same turn ratio and the magnetizing current or permeability of the core material.

A material is desired, therefore, which has low losses

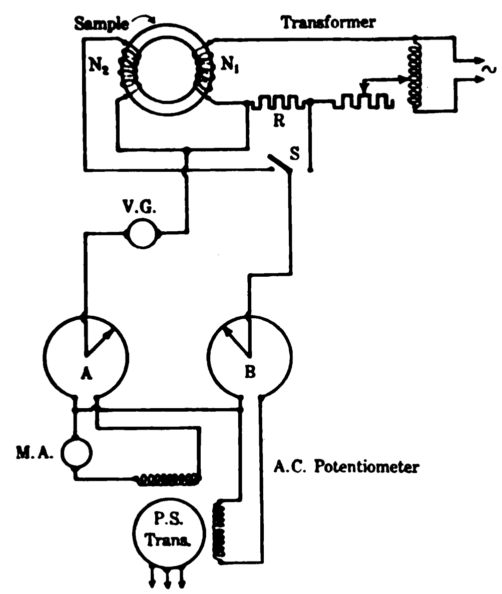

Fig. 2—Diagram of Connections for Ring Testing

and high permeability at low inductions. It is such a material which has now become available.

Determination of Magnetic Properties of Core Materials

In order to predetermine the performance of a given design of a current transformer under definite conditions of load, it is desirable to have curves for the specific kind of core material which is to be used, giving the watt and wattless components of the exciting current plotted against induction. Such data can be obtained by supplying a sample of core material with a winding or windings, applying different voltages of the desired frequency and measuring the current and watts by means of sensitive indicating instruments. For very low inductions this is rather a difficult and tedious process since the wattmeter must be very sensitive and corrections must be made for the instrument losses.

A much quicker and simpler method is to use a Tinsley-Gall, a-c. coordinate potentiometer.[5] The use of this instrument for such a purpose has been described recently.[6] The method of test is shown in Fig. 2.

The a-c. potentiometer, itself, is shown schematically. It consists of two distinct potentiometers supplied with currents which are equal in magnitude but differ 90 deg. in phase. These currents are obtained from a phase-shifting transformer having a two-phase secondary winding. Voltage balance is indicated by means of a vibration galvanometer. The sample, which is shown in ring form, is provided with primary and secondary windings N_1 and N_2. A-c. current of the desired frequency is supplied from a convenient source through a regulating transformer and a series resistance. This source is the same as that which supplies the primary of the phase-shifting transformer. The primary current I_1 is first adjusted to some convenient value and switch S is thrown to the left, thus connecting the potentiometer to the secondary winding N_2. Potentiometer B is set to O and the phase-shifting transformer and potentiometer A are then adjusted for O reading of the vibration galvanometer $V G$. When this adjustment is completed, A gives the magnitude of the secondary voltage and from it the induction in the sample can be calculated as follows, assuming a sine wave of voltage, which is nearly true for low and moderate inductions assuming approximately a sine-wave supply of current. This assumption is far from true, however, for high inductions.

$$B = \frac{E_2 \times 10^8}{A \times N_2 \times f \times 4.44} \quad (5)$$

where,

B is the induction in gausses
E_2 is the voltage induced in the secondary
A is the cross section of the specimen in sq. cm.
N_2 is the number of secondary turns
f is the frequency.

Next, S is thrown to the right connecting the potentiometer across the terminals of the shunt R. Then potentiometers A and B are adjusted for a vibration-galvanometer balance. The reading of A is now proportional to the loss component of the current in the primary and the reading of B is proportional to the wattless or magnetizing component of the current. If R equals 1 ohm, the readings of A and B are directly in amperes. This operation may be repeated for as many inductions as is desired. If more convenient a single winding only may be used on the sample, provided it has a negligible resistance.

If now the magnetizing current is multiplied by the

5. A New A-c. Potentiometer, by D. C. Gall, *Electrician*, Vol. 90, April 6, 1923, p. 360.

6. Some Applications of the A-C. Potentiometer, T. Spooner, *Journ.* Optical Society of America and Review of Scientific Instruments, March 1926, p. 217.

voltage and divided by the weight of the sample in pounds, there will result the wattless volt-amperes per pound for the material. Similarly the watt component of current gives the watts per pound. This is on the assumption that N_1 and N_2 are equal. By using a sufficiently large sample, data have been obtained by this method for a range of inductions from a few gausses to several thousand gausses, both at 25 and 60 cycles.

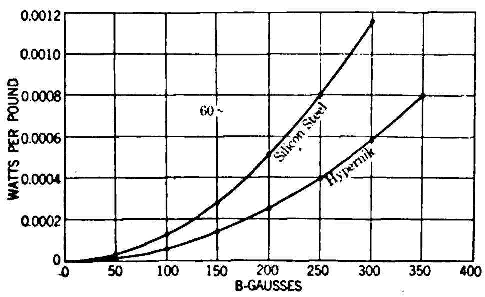

FIG. 3—CORE LOSS OF RING PUNCHINGS

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

Figs. 3 to 6 show the watt and wattless volt-ampere for 60 and 25 cycles for a good grade of four per cent silicon steel as compared with a rather poor specimen of hypernik. The thickness of laminations was 0.014 in. (0.0356 cm.). These particular curves cover a rather limited range of inductions but indicate clearly the difference in the properties of the two kinds of material. The marked superiority of the hypernik is obvious. For actual design purposes it is more convenient to

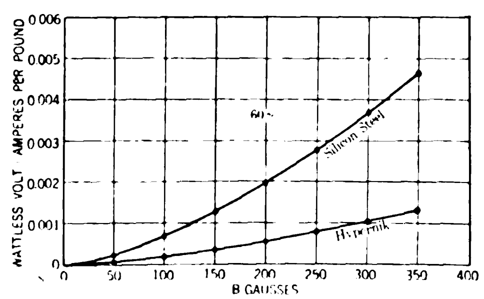

FIG. 4—MAGNETIZING CURRENT OF RING PUNCHINGS

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

plot the results on double-log paper since a much larger range of inductions can be covered with less confusion of scales.

The Calculation of Performance. Using the magnetic characteristics of the material as given by such curves as shown in Figs. 3 to 6, and by using formulas (1) and (2), it is a very simple matter to predetermine the characteristics of a through-type transformer. The method will be illustrated by an example and the results compared with actual test values. The following constants apply to a transformer actually built and tested at 60 cycles.

Core Material.

Hypernik

Rings: 5⅞ in. (14.9 cm.) outside diameter; 3⅝ in. (9.2 cm.) inside diameter

Weight: 10 lb. (4.54 kilograms)

Cross section of core (density 8.3) = 14.22 sq. cm.

Secondary Windings.

Turns: (N_2) = 100

Resistance = 0.109 ohms

Burden

15 volt-amperes at 80 per cent power factor (resistance 0.480 ohms)

Inductance = 956 microhenries.

The total resistance to be considered in calculating the

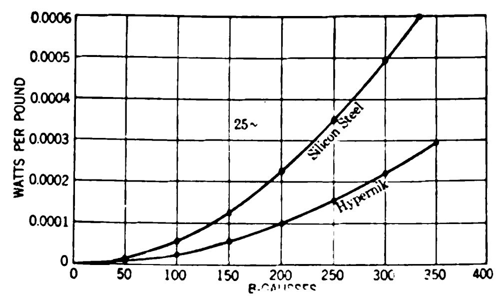

FIG. 5—CORE LOSS OF RING PUNCHINGS

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

performance must include the secondary resistance of the transformer winding, therefore,

$R = 0.109 + 0.480 = 0.589$ ohm.

$X = 2\pi f\, 956 \times 10^{-6} = 0.360$ ohm.

$\sqrt{R^2 + X^2} = 0.690$ ohm

$\tan \varphi = 0.611$

$\sin \varphi = 0.521$

$\cos \varphi = 0.853$

One ampere in the secondary, therefore, corresponds

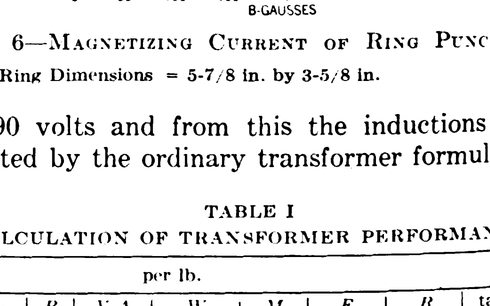

FIG. 6—MAGNETIZING CURRENT OF RING PUNCHINGS

Ring Dimensions = 5-7/8 in. by 3-5/8 in.

to 0.690 volts and from this the inductions can be calculated by the ordinary transformer formula (5).

TABLE I

CALCULATION OF TRANSFORMER PERFORMANCE

			per lb.						
I_2	E_2	B	VA	W	M	F	R	$\tan\theta$	θ
0.5	0.345	91	0.00015	0.000049	0.435	0.142	1.0069	0.00590	20′
1	0.690	182	0.00047	0.00021	0.681	0.304	1.0060	0.00422	14′
2	1.380	364	0.00140	0.00086	1.014	0.624	1.0053	0.00270	9′
3	2.070	546	0.00259	0.00200	1.250	0.966	1.0049	0.00188	7′
4	2.760	728	0.00393	0.00348	1.424	1.261	1.0045	0.00141	5′
5	3.450	910	0.00540	0.00530	1.566	1.537	1.0042	0.00107	4′

The wattless volt-amperes per pound, $V A$, and the watts per pound, W, were obtained from curves similar to those given by Figs. 3 and 4, but covering a greater range of inductions. In order to obtain M and F, it is simply necessary to multiply $V A$ and W, respectively, by $\frac{N_2 W_t}{E_2}$ where W_t is the weight of the core material in pounds. R and $\tan \theta$ are then obtained directly from formulas (**1**) and (**2**).

This detailed analysis has been followed through

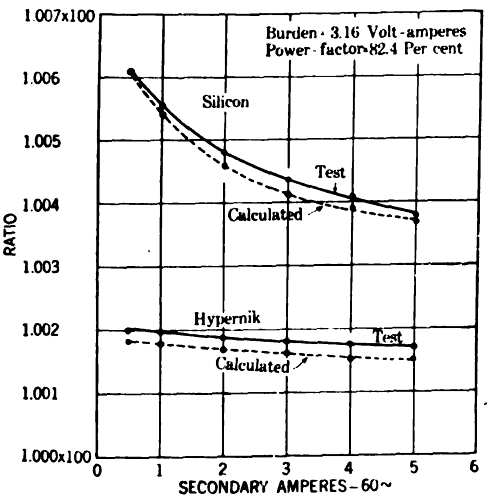

Fig. 7—500-5 Ring-Type Current Transformers
Burden = 3.16 volt-amperes
Power factor = 82.4 per cent

since it has been observed that a person not familiar with this type of calculation is very likely to make a mistake in applying the various formulas.

Check Values

Two transformers exactly alike, except that one had a silicon-steel core and the other a core of hypernik,

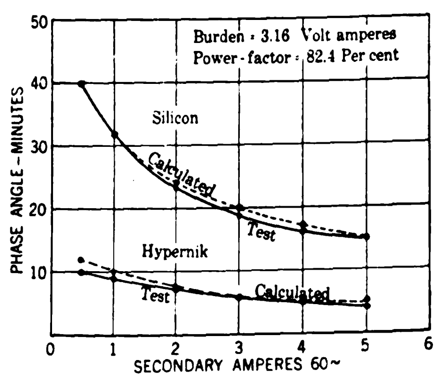

Fig. 8—500-5 Ring-Type Current Transformers
Burden = 3.16 volt-amperes
Power factor = 82.4 per cent

were constructed according to the above specifications, each core weighing 10 lb. They were sent to the Bureau of Standards for check at 60 cycles and two burdens, namely 3.16 volt-amperes and 15 volt-amperes. It may be noted that the net inductions in the two cores were slightly different although the fluxes were identical since silicon steel has a density of about 7.5 and hypernik of about 8.3.

The test and calculated results are given by Figs. 7 to 10. The checks are probably about as close as could

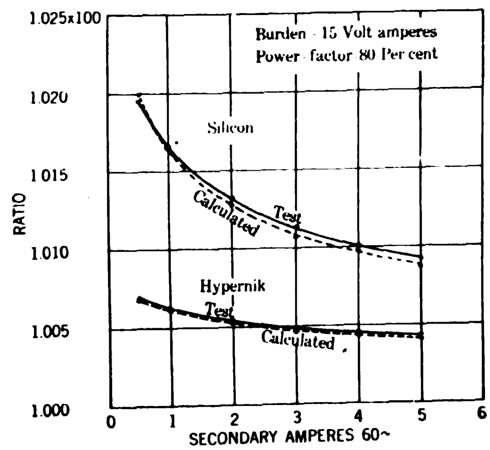

Fig. 9—500-5 Ring-Type Current Transformers
Burden = 15 volt-amperes
Power factor = 80 per cent

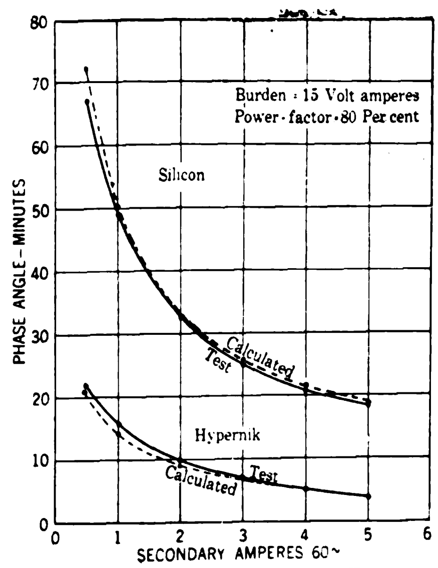

Fig. 10—500-5 Ring-Type Current Transformers
Burden = 15 volt-amperes
Power factor = 80 per cent

be expected and are in general very good. Before calculating the performance, the magnetic quality of the core material was checked on a completed transformer at two or three inductions by means of the a-c. potentiometer and where the results departed appreciably from the curves of Figs. 3 and 4, parallel curves were drawn from which the magnetic data were obtained.

Relative Performance of Transformers for Various Ranges

Having shown that it is possible to calculate the performance of this type of transformer with approximately the same accuracy as it can be tested, we are now in a position to show by calculation what can be expected

for various ranges. Figs. 11 to 15 give the comparative ratio and phase-angle curves for silicon and hypernik transformers for various ranges of secondary current from 200 to 1500 amperes, using various burdens and weights of core material. The very considerable superiority of hypernik over the silicon steel is seen for these conditions. In comparing the ratio curves it should be remembered that by means of turn compensa-

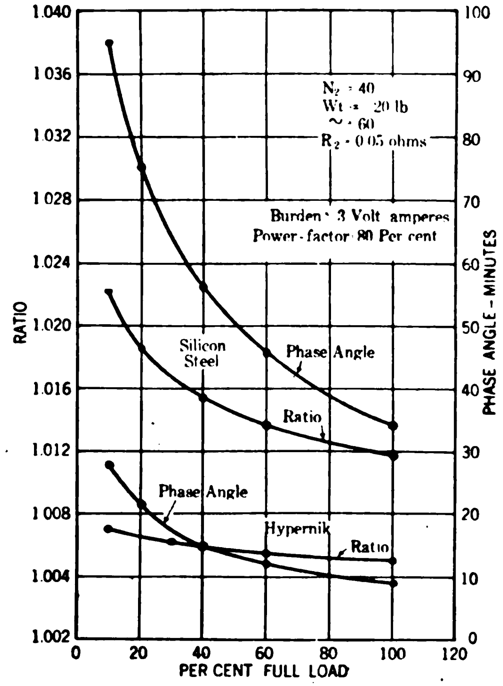

FIG. 11—200-5-CURRENT TRANSFORMERS

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 40
$Wt.$ = 20 lb.
~ = 60
R_2 = 0.05 ohms

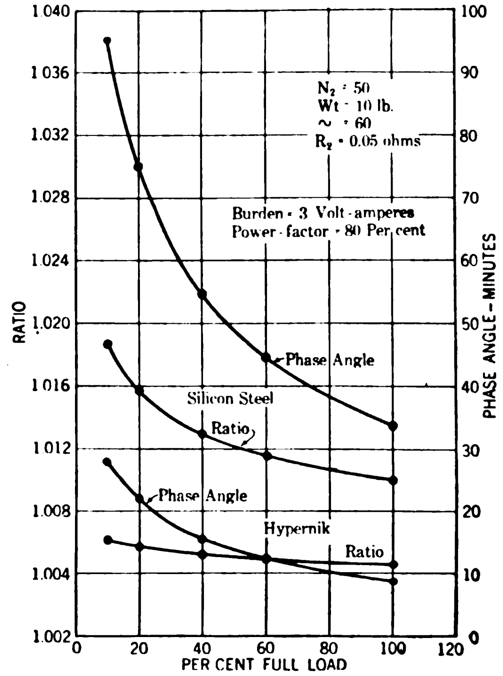

FIG. 12—250-5 CURRENT TRANSFORMERS

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 50
$Wt.$ = 10 lb.
~ = 60
R_2 = 0.05 ohms

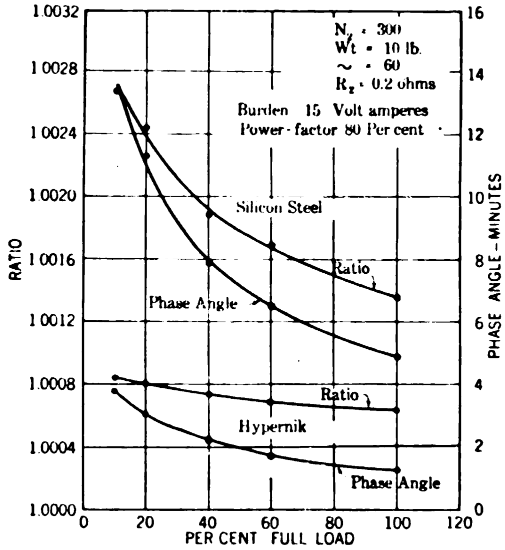

FIG. 13—1500-5 CURRENT TRANSFORMERS

Burden = 15 volt-amperes
Power factor = 80 per cent
N_2 = 300
$Wt.$ = 10 lb.
~ = 60
R_2 = 0.2 ohms

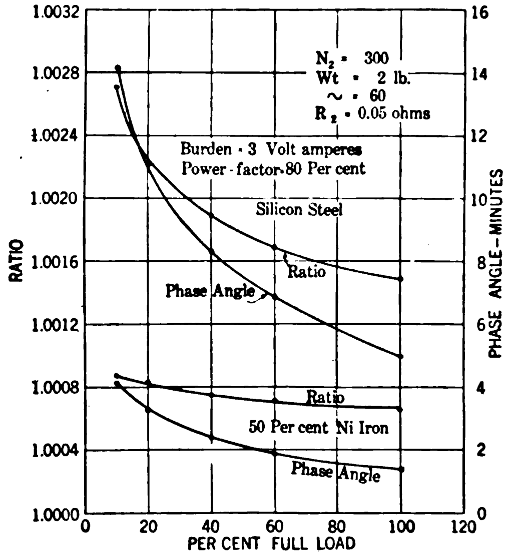

FIG. 14—1500-5 CURRENT TRANSFORMERS

Burden = 3 volt-amperes
Power factor = 80 per cent
N_2 = 300
$Wt.$ = 2 lb.
~ = 60
R_2 = 0.05 ohms

tion the actual ratio curves may be reduced much closer to unity by this means. It will be noted, however, that this compensation will not be nearly as effective for the silicon-steel transformers since the ratio curves are not nearly as flat as for the hypernik. The phase-angle

errors will not be affected much by turn compensation. Of course, compensation for phase-angle and ratio errors can also be effected by means of parallel non-inductive or capacity shunts, but this is rather unsatisfactory since an adjustment has to be made for each burden.[2]

As an indication of the burdens which may be im-

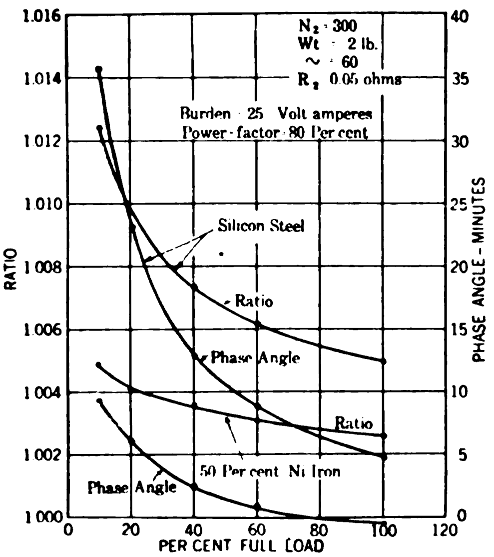

FIG. 15—1500-5 CURRENT TRANSFORMERS

Burden = 25 volt-amperes
Power factor = 80 per cent
N_2 = 300
$Wt.$ = 2 lb.
~ = 60
R_2 = 0.05 ohms

posed on a current transformer it may be mentioned that a watthour meter requires from one to two volt-amperes at full load and a switchboard ammeter about three volt-amperes. Relays and recording instruments may take 15 volt-amperes or more.

CONCLUSIONS

A new core material for current transformers has been made available which for the same weight of core reduces the ratio (assuming no compensation) and phase-angle errors to approximately one-third of those resulting from the use of ordinary silicon steel. This material is much more expensive than silicon steel but for large installations, where considerable blocks of power need to be measured accurately, the extra cost would be insignificant as compared with the value of the improved accuracy of measurement. Where there are space limitations, if desired, a smaller amount of core material could be used giving the same performance as for the silicon steel and at approximately the same cost, but resulting in a smaller transformer.

The gain to be expected by the use of hypernik for the cores of transformers, using L-shaped punchings, would not be as great as for ring-type punchings, due to the decreased permeability resulting from the gaps. Even here, however, for the same size of transform are considerable improvement by the use of the new iron would result. The use of hypernik in through-type transformers will perhaps be the most important application since it is in this case that the transformer designer finds his chief difficulty in obtaining good performance. In this connection, however, it may be mentioned that hypernik is of no value for the cores of through-type transformers operating very heavy-burden relays since it saturates at a considerably lower induction than silicon steel. It is only at the lower inductions, namely, for meter loads, that its superiority manifests itself.

The application of this material for improving current-transformer performance is extremely simple since it involves no changes in the general transformer design and no changes in the existing meters.

MUSCLE SHOALS

The Joint Congressional Committee on Muscle Shoals has decided to recommend acceptance of the bid of the Muscle Shoals Fertilizer Company and the Muscle Shoals Power Distributing Company. The terms of the proposal submitted by the above bidders have been written into House Bill 11602 which is awaiting action in the House of Representatives. It is also understood that the acceptance of this proposal has the approval of the President and the Secretary of War.

It will be recalled that the Muscle Shoals Fertilizer Company and the Muscle Shoals Power Distributing Company represent a combination of fourteen public utility companies which have previously been interested in the use of the Muscle Shoals power.

No estimate is possible at this time as to how soon this proposed legislation will be acted upon although it is now felt no action will be taken during this session of the 69th Congress.

FEDERAL POWER COMMISSION WILL NOT INTERFERE WITH STATES RIGHTS

The case of the New York State in its control of the waters of the Niagara River, being handled before the Federal Power Commission by former Secretary of State, Charles Evans Hughes, has brought a pointed statement from the Federal Power Commission in which the members reiterated their desire not to interfere with the rights of states in the regulation or development of navigable waters in their boundaries. The project calls for the development of hydroelectric power in the Gorge below the Falls of Niagara and below the "Maid of the Mist" pool, in Niagara County, where the above named company plans to erect its power house and dam.

Mr. Hughes, in his letter, discusses at length the commission's proposed license and states that the Attorney-General of New York holds that its provisions "would constitute an invasion of authority of the State."

The Retardation Method of Loss Determination
as Applied to the Large Niagara Falls Generators

BY J. ALLEN JOHNSON[1]

Associate, A. I. E. E.

***Synopsis.**—Institute literature is apparently lacking in information regarding retardation tests. The purpose of this paper is to point out certain advantages of the method and to describe the procedure followed in testing the Niagara generators.*

The basis of the method is first given with the fundamental formula upon which it depends. Since it requires the use of the moment of inertia, or "fly-wheel effect," $W R^2$, methods of determining this value are given, and it is pointed out that it can be determined by test.

The methods of determining the speed of rotation and its rate of change are given, with a description of the devices used for automatically recording the necessary data and the method of interpreting such data. It is shown how the determination of losses over a range of speeds increases the accuracy of the determinations.

General methods of testing are described, with a connection diagram and an outline of the necessary precautions. The detail procedure for tests for different losses is given.

It is shown how this method of test furnishes data for the separation of the friction from the windage. The division of mechanical losses between generator and turbine in a specific case is also described.

The procedure in determining the electrical losses from the test data is given and some observations made regarding the apparent desirability of the further refinement of the method.

WHILE the retardation method of determining generator losses has long been known and is recognized by the Institute Standards, the Institute records are peculiarly lacking in literature on the subject, a search of the Index having failed to disclose a single paper on, or specific reference to, retardation tests. It seems rather strange that a method of testing which has found its way into the Institute Standards should have received so little attention in its literature. The explanation probably lies in the inherent simplicity of the method and the comparative rarity of its use in past times. It would appear that the method has been, and is yet, considered as a "last resort" method, to be used only when no other method is possible. It is the writer's purpose to show that the method has advantages and virtues of its own, not possessed by the usual and better known methods. It has, in the writer's opinion, never received the attention or publicity it deserves, nor been subjected to the intensive study for the perfection of its technique that is warranted by its possible accuracy and its ease of application.

The writer's attention has been focussed upon this method by the necessity of determining the conventional efficiencies of a considerable number of large water-wheel driven generators. The usual or standard method of determining generator losses is by driving the generator with a motor of known efficiency, and measuring the input to the motor under the various desired conditions. This method is usually impracticable in the case of large water-wheel generators. The most practicable and available method of making loss tests on such installations is by means of the retardation method.

The lack of repute which has apparently been attached to this method is probably due to two factors: first, that it depends upon the fly-wheel effect, $W R^2$, of the rotating parts, the determination of which has been considered to lack accuracy since it has been assumed that this value had to be calculated from the design: second, that the accurate measurement of speed and time are attended with certain difficulties which require the use of more refined methods and instruments than the usual stop-watch and indicating tachometer.

As a matter of fact, the fly-wheel effect can be determined by test; and the rate of retardation can be determined by automatic recording devices far more accurately than by the tachometer and stop-watch. In fact, the method lends itself naturally to automatic graphic recording methods, which may be made of almost any degree of accuracy desired.

This paper, therefore, will describe the procedure followed in the determination of the losses in the large generators of the Niagara Falls Power Company in an attempt to demonstrate thereby the practicability of the retardation method for the determination of the losses in such units.

The Retardation Method of Loss Test. The retardation method is based upon the fundamental law for the kinetic energy of a rotating mass, *i. e.*:

$$E = 1/2 \frac{W R^2 \omega^2}{g} \tag{1}$$

Where E is the energy.

$\frac{W}{g}$ is the mass of the rotating body

R is the radius of gyration, and

ω is the angular velocity.

If energy is added, the angular velocity or speed of rotation must increase, and if energy is abstracted, the speed must decrease. Obviously the rate at which the speed decreases must be a function of the rate of abstraction of energy, that is, of the power loss, and will be given mathematically by the first differential of

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Presented at the Regional Meeting of District No. 1, of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

equation (1) with respect to time. The equation for power loss then takes the form:

$$\frac{d\,E}{d\,t} = \frac{W\,R^2 \,.\, 2\,\omega\,d\,\omega}{2\,g\;\;d\,t} \qquad (2)$$

Putting $\omega = 2\,\pi\,s$ (where s is speed rev. per sec.)

$$\frac{d\,E}{d\,t} = \frac{W\,R^2}{2\,g} \,.\, 8\,\pi^2\,s \,.\, \frac{d\,s}{d\,t} \qquad (3)$$

Expressing this equation in convenient units for the purpose of generator-loss measurements, we have:

$$\text{Loss in kw.} = \frac{4\,W\,R^2\,\pi^2\,S}{32.2\,(3600 \times 33000 \times 1.34)} \cdot \frac{d\,s}{d\,t} \qquad (4)$$

Where

W is weight in pounds

R is radius of gyration in ft.

S is rev. per min.

$\frac{d\,s}{d\,t}$ is rate of retardation in rev. per min. per min.

32.2 is the acceleration of gravity in ft. per sec. per sec. and the expression in parenthesis in the denominator contains the necessary conversion factors to convert from sec. to min. and from ft-lb. per sec. to kw.

Assuming $W\,R^2$, the "fly-wheel effect," to be known it is then only necessary to determine the speed (S) and the corresponding simultaneous value of the rate of retardation $\left(\frac{d\,s}{d\,t}\right)$ to determine the corresponding instantaneous value of power loss.

For convenience it is desirable, for each generator tested, to combine all of the constants into a single constant which may be called the "retardation loss coefficient" and which may be designated by the letter D. The loss in kw. for that particular generator will then be:

$$\text{Loss in kw.} = D\,S\,\frac{d\,s}{d\,t} \qquad (5)$$

Determination of $W\,R^2$. The usual method of determining $W\,R^2$ is by calculation from design, or from design corrected by actual measurement of weights. This is a rather laborious process, but one which can, if necessary, be carried out to almost any desired degree of accuracy. The usual method is to divide the mass up into simple forms, the weights and radii of gyration of which can be easily calculated, the summation of all the parts giving the desired value for the whole. The generator manufacturers are usually required to state this value for use in the governor design, and it is therefore usually available.

The value of $W\,R^2$ can, however, be determined by means of a retardation test in connection with the direct measurement of the friction, windage and iron loss by input. In this test the generator is driven as a synchronous motor by a second generator connected to its terminals. Readings of input to the driven machine are made, also of the corresponding values of current, voltage and speed. From these readings, the values of combined friction windage and iron losses are determined. Upon the completion of these tests, the driving generator is disconnected, after raising the speed slightly, and a retardation test carried out while values of voltage, speed and rate of retardation are carefully obtained. By substituting in formula (4) above, the corresponding values of loss, speed and rate of retardation obtained from these two tests, the value of $W\,R^2$ can be readily calculated. It will usually be found, if the work is carefully performed, that the value of $W\,R^2$ so found, will check very closely with that obtained by calculation from design.

Determination of speed (S) *and rate of retardation* $\left(\frac{d\,s}{d\,t}\right)$. In the earlier tests, these quantities were measured by means of the tachometer and stop-watch, but it was found by experience that such methods are apt to give inaccurate results, particularly at the higher speeds where the speed is most rapidly changing, due to the inaccuracies of tachometers and the difficulty of accurate timing by such means.

In the later tests, automatic means were employed for recording graphically the quantities from which the speed and rate of retardation are deduced. These means comprised three devices, namely:

1. A contact-making revolution counter
2. A contact-making timer
3. A two-element chronograph

The revolution counter consisted merely in a train of gears arranged to be driven directly by the rotor of the generator under test, and with a contact-making device arranged to make contact every 10 revolutions of the generator. Any other number of revolutions per contact could, of course, be chosen if desired.

The timer used in these tests was one driven by a clock and arranged to make contact once every five sec. omitting a contact once every minute. Any other time interval within reasonable limits could likewise be provided by suitable means.

The chronograph used in these tests was a rather crude device in which the paper used for record was wrapped about a cylinder and glued to make a continuous cylinder of paper. The two pens were mounted upon the armatures of two small solenoids, so arranged that upon making circuit through the coils the pen is moved a millimeter or two, parallel to the axis of the cylinder, returning to its original position upon breaking the circuit. The cylinder is mounted upon a coarse screw thread and driven by a small synchronous motor, and advances along its axis one in. (25.4 mm.) with each revolution which it makes. In the tests to be described, the paper was driven at a speed of about three in. (75 mm.) per min. Experience has shown, however, that

a greater speed would be preferable in order to give greater accuracy in determining the generator speed.

Fig. 1 shows, *a* Timer, *b* Chronograph, and *c* Revolution Counter. The chronograph shown is not the one used in the tests herein described, but one built for future use. Fig. 2 is a reproduction of a typical chronograph record of a retardation test.

Interpretation of Chronograph Records. By drawing straight lines across the record at suitable equal time intervals, the number of revolutions occurring in each

FIG. 1—THE CHRONOGRAPH BY WHICH TESTS WERE MADE
a. Timer
b. Chronograph
c. Revolution counter

of such time intervals can be accurately measured, thereby determining the average speed of rotation during each such interval. Tabulating these and taking the differences between successive readings, gives the average rate of retardation occurring between such successive speeds. If the time intervals are taken sufficiently short the average speeds for each interval can, with sufficient accuracy, be taken as occurring at the middle of the intervals, and the corresponding values of $\frac{d\,s}{d\,t}$ as simultaneous with the times dividing the intervals. Also the speed at the division points can with sufficient accuracy be taken as the average of the preceding and succeeding intervals. In illustration, the following tabulation, Table I, is from the chronograph record of a test for friction, windage and iron loss, on a 65,000-kv-a. generator.

The curve shown in Fig. 3 is a plot of these losses against speed, from which the desired value at normal speed can be read. These results are quite consistent, and no great error can be made by this method, since errors in one direction in one or more readings must be compensated by errors in the other direction in succeeding ones. Hence, the individual errors can confidently be eliminated by plotting the results graphically.

TABLE I
FRICTION, WINDAGE AND IRON LOSS BY RETARDATION

Time Minutes	Av. rev. per min.	(S) Rev. per min.	$d\,s/d\,t$ Rev. per min. per min.	Kw. (0.525 S $d\,s/d\,t$)	Remarks
0					
	17.6				
1		111.00	13.2	769	These values of kw. are obtained by using the value of $W\,R^2$ as calculated from design, *i. e.*, 68,255,000 lb.-ft. (Retardation loss coefficient = 0.525)
	104.4				
2		98.40	12.0	620	
	92.4				
3		87.35	10.1	463	
	82.3				
4		77.85	8.9	363	
	73.4				
5		69.35	8.1	295	
	65.3				
6		61.60	7.4	239	
	57.9				
7		54.70	6.4	184	
	51.5				

In the usual application of the retardation method, as set forth in the handbooks, its has been customary to determine $d\,s/d\,t$, the slope of the retardation curve, at normal speed only. This has resulted in a lack of accuracy and is undoubtedly in part responsible for the lack of confidence in the method. By the method of determination here set forth, this inaccuracy is eliminated by the device of using the entire curve to eliminate the errors in individual points, which is particularly applicable in this case since the curve as a whole cannot depart far from the truth.

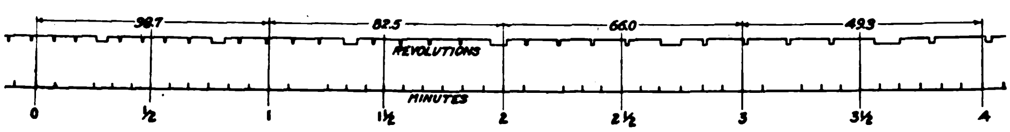

FIG. 2—CHRONOGRAPHIC RECORD OF RETARDATION TEST FOR FRICTION, WINDAGE AND LOAD LOSSES ON 65,000-KV-A. GENERATOR

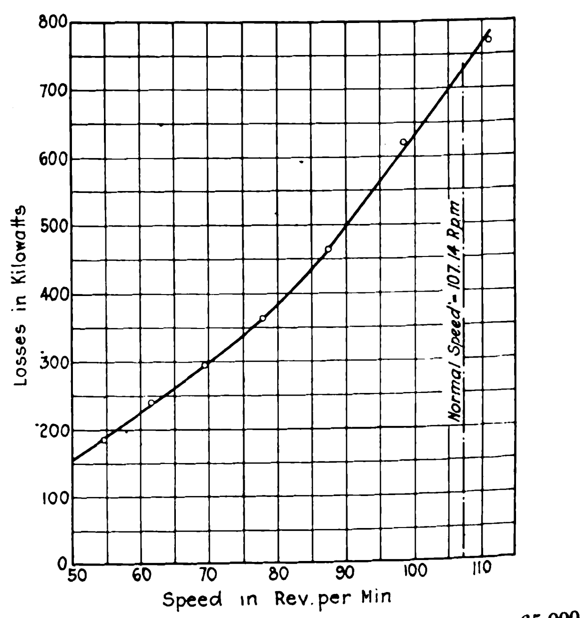

FIG. 3—FRICTION, WINDAGE AND IRON LOSSES OF 65,000-KV-A. UNIT WITH EXCITATION CORRESPONDING TO 11,100 VOLTS AT 107.14 REV. PER MIN.

This same test will illustrate the method, mentioned above, of determining by test the value of $W R^2$. The same machine showed friction, windage and iron losses as measured by input, at normal speed of 107.14 rev. per min., and at the same voltage as obtained at normal speed during the retardation test of 695 kw., see Fig. 4. The value of $d s/d t$ at the same speed, from the retardation test is 12.99 rev. per min. per min. Therefore, from equation 4:

$$W R^2 = \frac{695 \times 36000 \times 33000 \times 1.34 \times 32.2}{4 \times 9.87 \times 107.14 \times 12.99}$$

$$= 64{,}700{,}000$$

$W R^2$ as calculated from design	68,255,000
Difference	3,555,000

or about 5 per cent. Much closer agreement than this is usually found, in many cases the test value checking exactly with the calculated, see Fig. 6. However, in a machine of this size, even an error of this magnitude could only affect the efficiency determination by less than one-tenth of one per cent.

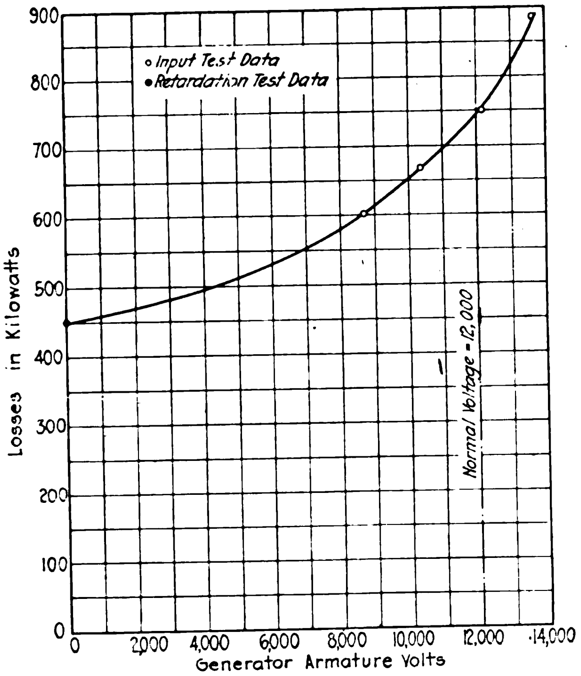

FIG. 4—FRICTION, WINDAGE AND IRON LOSSES OF 65,000-KV-A. UNIT—NORMAL SPEED 107.14 REV. PER MIN.

General Methods of Test. Before starting a series of retardation tests, it is necessary that the unit be properly prepared. It is desirable that the generator be separated from the turbine, if possible. In horizontal-shaft units and in vertical-shaft units where the generator has a lower guide bearing, the coupling can usually be separated and the generator operated without the turbine. In vertical units where the generator has no lower guide bearing, or where, for some other reason, the coupling cannot be separated, it becomes necessary to permit the turbine to rotate with the generator. This introduces losses which cannot be charged to the generator and considerable judgment and ingenuity is then required to apportion the observed losses between generator and turbine.

When it is necessary to include the turbine rotor with the generator, precaution should be taken to guard against injury to the turbine by overheating bearings or glands or runner rim by possible rubbing at the latter point, due to too close clearance. A small amount of water can usually be supplied to such points to keep them cool. In such a case, however, it is essential that conditions of water flow, etc., be kept constant during the tests in order to eliminate any variable factors from this source.

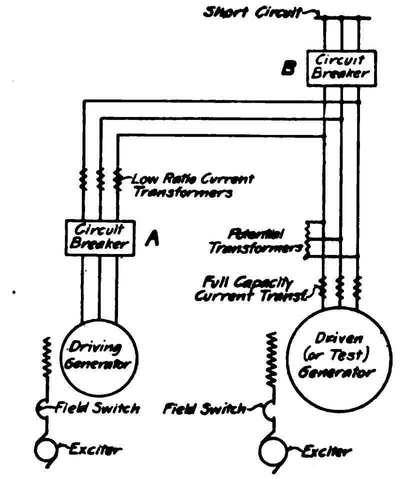

FIG. 5—DIAGRAM OF CONNECTIONS FOR RETARDATION TESTS

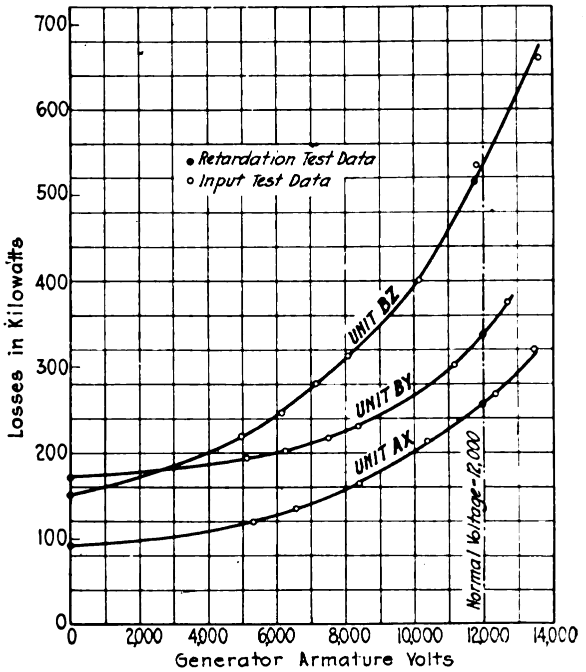

FIG. 6—FRICTION, WINDAGE AND IRON LOSSES OF THREE 32,500-KV-A. UNITS—NORMAL SPEED 150 REV. PER MIN.

The simplest and most practical method of bringing the generator up to speed is to drive it as a motor from

another generator of the same voltage. The driving generator can be of considerably smaller capacity than the one to be driven, no difficulty whatever having been experienced with a ratio of ratings of one to four. The driving and driven machines are synchronized from rest in a manner now well understood. Fig. 5 shows the connections as usually employed for all tests.

In the leads from the driving machine there should be an oil circuit breaker, and current transformers. For the latter, a primary ampere capacity of about 6 per cent of the rated current of the driven machine, with 5-ampere secondary, has been found satisfactory. Such a size is large enough to carry the current required to accelerate the driven machine (if not accelerated too rapidly), and is small enough to give good readings on standard 2.5- to 5-ampere ammeters and wattmeters when measuring the input to the driven machine. In any specific case the required size should be calculated from the estimated friction, windage and iron losses. Suitable means should also be provided for measuring voltage and power input. It is assumed that proper calibrations of all instruments and instrument transformers will be taken care of in the standard manner.

It is preferable that the machine under test be separately excited in order to eliminate complications. However, if a direct-connected exciter is used, allowance must, of course, be made for the output and losses thereof.

Procedure. It has been found most convenient to make tests in the following order:

1. Friction, windage and iron loss by input
2. Friction, windage and iron loss (or $W R^2$) by retardation
3. Friction and windage by retardation
4. Friction and windage and load loss by retardation

1. Friction, Windage and Iron Loss by Input.

Close fields of both machines and circuit breaker *A* (leaving *B* open,) Fig. 5, and synchronize from rest. Bring machines up to normal speed gradually so as not to dangerously overload current transformers. Raise voltage to 10 or 15 per cent above normal for first reading. Take readings of voltage, current, power input, field current and speed at successive voltages down as low as field controls will permit. Usually readings can be carried down to about half voltage. Take at least 10 readings at each point at 15 sec. intervals. Before each series of readings see that field current of driving machine is adjusted so that armature current is a minimum, with driven machine field adjusted for desired voltage.

2. Friction, Windage and Iron Loss by Retardation.

At completion of input test, as above, raise speed to about 15 to 20 per cent above normal, adjust field current for normal open circuit voltage at normal speed, as per saturation curve, and open circuit breaker *A*, Fig. 5. As speed decreases record revolutions and time by means of chronograph as described above. Read volts, field current and speed by tachometer, (for check only, if a reliable one is available) at time intervals synchronized with chronograph. Field current should remain constant throughout test. Records should continue until speed has decreased at least to half normal value.

This test can be repeated for as many values of field current or generator voltage as desired. However, a single test at rated voltage will usually be sufficient to check the input test and the value of $W R^2$. Should a good check not be obtained, however, it is desirable to repeat and correct the value of $W R^2$ if the value calculated from design appears to be persistently in error.

3. Friction and Windage by Retardation.

Synchronize from rest and bring to 15 or 20 per cent above normal speed. Open oil circuit breaker between machines and immediately open field switch of test machine. As speed decreases, record revolutions and time on chronograph and read speed on tachometer (if available) at times synchronizing with chronograph record. Record should be continued to well below half speed in order to obtain as much of this curve as possible for a purpose to be explained later. A single test should be sufficient to determine friction and windage.

4. Friction, Windage and Load Losses by Retardation.

With circuit-breaker *B* open, close circuit breaker *A* and synchronize from rest as usual. Raise speed to above normal as before. Quickly open circuit-breaker *A*, open field switch, close circuit-breaker *B*, close field switch and quickly adjust field current to give desired armature current as per closed circuit saturation curve. These operations can and should be completed before speed has come down to 10 per cent above normal, in order that steady conditions may exist while speed is passing through normal value. Record revolutions and time by chronograph, and make synchronized readings of speed and of field and armature currents. This test should be repeated at various armature currents in order to obtain data for a curve of stray-load loss versus armature current.

Separation and Determination of Friction and Windage. The nature of the friction and windage losses and the consequent laws governing the form of the friction and windage retardation curve furnish a means of separating the "apparent friction" from the "apparent windage" losses.

With a constant coefficient of friction, the friction loss should vary directly as the first power of the speed.

The windage loss, however, in accordance with the well-known laws governing the movement of air, should vary directly as the third power of the speed. It would seem, therefore, that the curve of windage and friction losses against speed, should have the form:

$$\text{Total friction and windage loss} = F\,S + W\,S^3 \qquad \textbf{(6)}$$

Where F may be called the coefficient of friction loss and W the coefficient of windage loss, S being the speed in rev. per min.

Upon plotting such a curve from the record of a fric-

tion and windage retardation test, it is found to conform exactly to this law.

TABLE II
FRICTION AND WINDAGE BY RETARDATION

Time Minutes	Av. rev. per min.	(S) Rev. per min.	($d\,s/d\,t$) Rev. per min. per min.	Loss kw.	Remarks
0					
	115.4				
1		111.25	8.3	485	
	107.1				
2		103.20	7.8	423	
	99.3				
3		96.25	6.1	309	$W R^2$ (from design) 68,255,000 lb.-ft.^{2}
	93.2				
4		90.20	6.0	285	(Retardation loss coefficient = 0.525)
	87.2				
5		85.50	5.4	240	
	81.8				
6		79.30	5.0	209	
	76.8				
7		74.65	4.3	169	
	72.5				
8		70.55	3.9	145	
	68.6				
9		66.75	3.7	130	
	64.9				
10		63.05	3.7	123	
	61.2				
11		59.95	2.5	78.7	
	58.7				
12		57.00	2.8	84.0	
	55.6				
13		54.45	2.3	66.0	
	53.3				
14		52.15	2.3	63	
	51.0				
15		49.85	2.3	60.2	
	48.7				
16		47.60	2.2	55	
	46.5				
17		45.60	1.8	42.2	
	44.7				
18		43.75	1.9	43.6	
	42.8				
19		42.05	1.5	33.1	
	41.3				
20		40.35	1.9	40.1	
	39.4				

Table II is the data from the graphic record of such a test, and Fig. 7 shows the values plotted from Table II.

The coefficients are readily found by substituting in equation (6) the values of total loss and speed for two points of the curve and solving simultaneously. For example, taking the values at 100 and 60 rev. per min. from a trial curve drawn for the test points of Fig. 7 and substituting in equation (6) we have the simultaneous equations:

$$372 = 100\,F + 1{,}000{,}000\,W$$

$$94 = 60\,F + 216{,}000\,W$$

Solving for F and W we have:

$$F = 0.355$$

$$W = 0.0003365$$

Recalculating for successive values of S, we have:

TABLE III
FRICTION AND WINDAGE LOSSES BY CALCULATION EQUATION (6)

(S) Rev. Per Min.	Friction Loss in Kw.	Windage Loss in Kw.	Total Loss in Kw.
40	14.2	21.6	35.8
50	17.7	42.0	59.7
60	21.3	72.7	94.0
70	24.9	115.5	140.4
80	28.4	172.0	200.4
90	31.9	245.0	276.9
100	35.5	336.5	372.0
110	39.1	347.0	486.1
120	42.6	581.0	623.6

Plotting these values we find the resulting curve, Fig. 7, to correspond with the test values with practical exactness at all speeds. This curve is quite sensitive to small changes in the values of the coefficients of friction and windage losses, and several trials are sometimes necessary before the correct coefficients are found to make the curve fit the test points at all parts of the

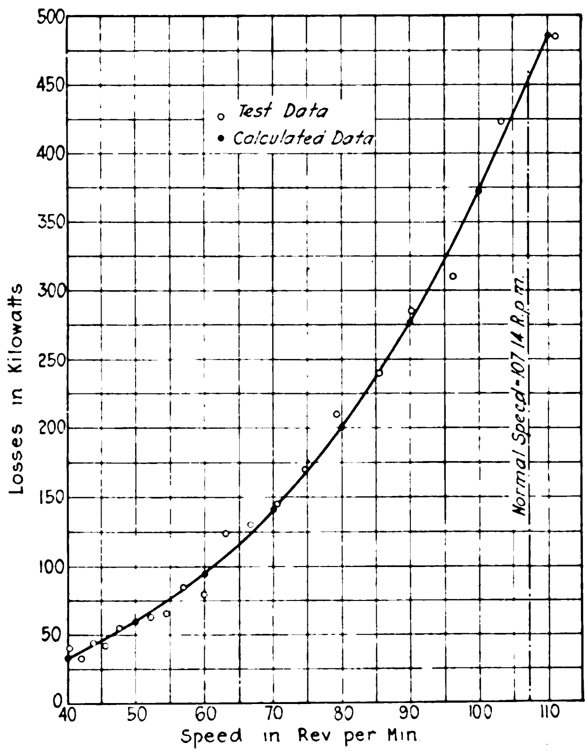

Fig. 7—Friction and Windage Losses of 65,000-Kv-a. Generator

curve. When this has been done, however, one can be quite confident that the resulting values of total losses are correct, whatever the separate values of "apparent friction" and "apparent windage" may represent, see Fig. 8.

It is indeed probable that even in the case of a test upon a generator alone, separated from its turbine, the "apparent friction" loss may include some of the windage and the "apparent windage" some of the bearing friction, since it seems probable that a small part of the

bearing losses are of such a nature as to vary with the third power of the speed. However, while there may be some doubt as to the exact composition of the two kinds of losses differentiated in this manner, their separation is nevertheless well worth while for the purpose (if for no other) of detecting the presence of any possible abnormal friction loss, such as a tight bearing or gland, or a rubbing turbine seal, which would surely show up in an abnormally large first power loss.

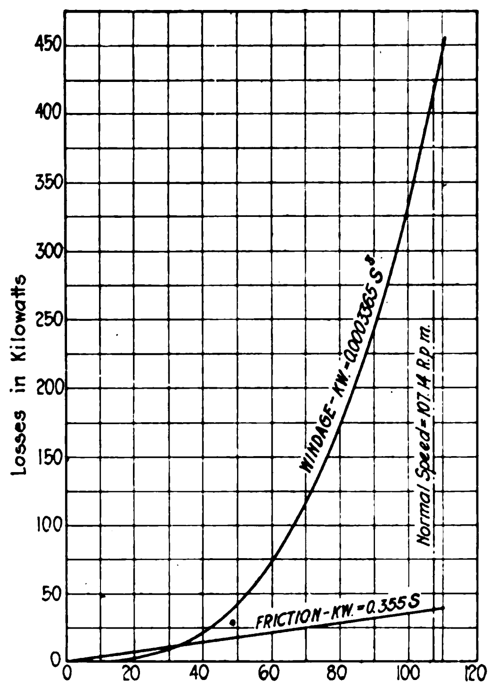

Fig. 8—Friction and Windage Losses of 65,000-Kv-a. Generator

However, the author believes, from experience in testing several different types and makes of generators by the above methods, that the separate "apparent friction" and "apparent windage" found by this method are very close to the actual friction and windage losses, when not complicated by other factors such as "disk friction" or "pumpage" losses in the turbine, due to the presence of water for cooling purposes.

Division of Friction and Windage Between Generator and Turbine. In those cases where tests are made with the turbine connected, the friction losses as above determined, will include turbine friction in bearings, glands and seals, and the "apparent windage" loss will include windage in the turbine and probably another loss due to the presence of a small amount of water in the turbine, which may be classed as "disk friction" or "pumpage." These losses can, at present, only be approximated, but by separating the first and third power losses by the method described above, these approximations can be handled with much more confidence than when the mechanical losses are all lumped together.

In an isolated case of a single unit, the division of the mechanical losses between generator and turbine is quite difficult, if not impossible. In a case, however, where several units of similar but different characteristics are being tested, it is often possible, by careful observations and comparisons, to make approximations which give results approaching the truth closely enough for practical purposes.

As an illustration of what may be done along this line, the steps taken in allocating the mechanical losses in three units of 32,500-kv-a. capacity, comprising three different combinations of turbines and generators will be described. If we designate the two turbine manufacturers by the letters *A* and *B*, and the three generator manufacturers by *X*, *Y* and *Z*, then we can designate the three units as *A X*, *B Y* and *B Z*.

The friction and windage losses of these three machines, all of the same capacity rating, and the steps by which they were allocated, are shown in the following tabulation:

TABLE IV
ANALYSIS OF FRICTION AND WINDAGE OF THREE 32,500-KV-A. UNITS

	Unit *A X*	Unit *B Y*	Unit *B Z*
Total Friction, Windage & Pumpage	91.65	171.5	151.05
Friction *H*	18.75	28.0	28.25
Windage and Pumpage	72.90	143.5	122.80
Analysis of Friction			
Weight of Generator Rotor and Shaft *A*	271,000	311,000	318,000
Weight of Turbine Runner and Shaft *B*	73,500	73,500	73,500
Weight on Thrust Bearing during Test *C*	344,500	384,500	391,500
Hydraulic Thrust	100,000	100,000	100,000
Weight on Thrust Bearing under Load *D*	444,500	484,500	491,500
Thrust Friction under Load $\left(\frac{D}{444500} \times 15\right)$ *E*	15.0 kw.	16.35 kw.	16.6 kw.
Thrust Friction during Test $\left(\frac{C}{D} \times E\right)$ *F*	11.62	12.95	13.25
Generator Share of *F* $\left(\frac{A}{C} \times F\right)$ *G*	9.15	10.46	10.76
Turbine Share of *F* $\left(\frac{B}{C} \times F\right)$	2.47	2.49	2.49
Total Friction from retardation test *H*	18.75	28.0	28.25
Total Thrust Bearing Friction during test *F*	11.62	12.95	13.25
Other Friction, guide bearings, etc., $(H - F)$ *I*	7.13	15.05	15.00
Generator Share of *I* *J*	2.0	2.0	2.0
Turbine Share of *I*	5.13	13.05	13.0
Total Generator Friction $(G + J)$	11.15	12.46	12.76
Analysis of Windage & Pumpage			
Total Windage and Pumpage (Ret. Test)	72.9	143.5	122.8
Generator Windage (Est.)	50.0	93.5	72.8
Turbine Windage (Est.)	10.0	10.0	10.0
Turbine Pumpage (Est.)	12.9	40.0	40.0
Total Generator Friction & Windage	61.15	105.96	85.56

That portion of the loss which is proportional to the third power of the speed was at first thought to be entirely windage, but upon further investigation it was found that there might be a loss in the turbine of the nature generally called disk friction which also varies as the third power of the speed, and, owing to the different construction of the two types of tubine, it is reasonable to expect that under test conditions these losses might differ very markedly between the two types. This

presumption is further corroborated by the very great discrepancy between the measured so-called windage losses of $A\ X$ and $B\ Y$ and $B\ Z$, these losses in the case of $B\ Y$ being just about double the corresponding losses of $A\ X$, see Fig. 6. It hardly seems reasonable to charge this discrepancy entirely to true windage.

The same sort of reasoning applies also to the friction losses. The thrust and guide bearings of the three units do not differ materially, but there is a considerable difference in the nature and area of the turbine seals between the A and B designs, and it would, therefore, seem reasonable to expect that that portion of the friction loss which takes place in the seals would be somewhat in proportion to the areas of the contiguous surfaces.

Analysis of Friction Loss. At the time when Unit $A\ X$ was placed in service, the bearing manufacturer's engineers made a determination of the loss in the thrust bearing of this unit and stated that this loss was apparently about 20 h. p., or 15 kw. This value has been used as a basis for the analysis of the friction loss, it being assumed that the loss in these thrust bearings will vary in direct proportion to the weight that they carry. This loss has also been.further divided between the generator and turbine in proportion to their weights.

Upon subtracting the value thus determined for the thrust bearing on Unit $A\ X$ from the total friction losses as determined by test, there remains but slightly over seven kw. to be divided between the generator and turbine-guide bearings and turbine seals. In consideration of the smallness of this loss, the nature of the parts which create it, and the relation which might be expected to exist between the generator guide and thrust-bearing losses, it was concluded that two kw. would be a reasonable portion of this loss to assign to the generator-guide bearings, the remainder being charged to the turbine.

In the case of the other two units, the total measured friction losses were considerably greater and the thrust-bearing friction was also somewhat greater, due to the increased weights of these machines over that of Unit $A\ X$. There appeared, however, no reason why the guide-bearing loss should be any greater than on Unit $A\ X$, and the assumption checks with the observed fact that the guide-bearing oil temperatures of the three units do not materially differ from each other.

There is then left chargeable to turbine friction approximately 13 kw. in Units $B\ Y$ and $B\ Z$, or about two and one-half times the corresponding loss in Unit $A\ X$, which ratio would appear reasonable from a consideration of the two turbine designs. This results in the friction losses of the three generators differing by only such amounts as are accounted for by their different weights.

Analysis of "Windage" Loss. In the case of the so-called windage losses—all those losses varying as the third power of the speed—the total of such losses in the case of Unit $A\ X$ was but 72.9 kw. As stated above there is too great a discrepancy between this value and those of similar losses determined for the other two units to be all charged to generator windage, and it is accordingly necessary to find some other difference between the two turbine designs to account for a part of this discrepancy. The value of this loss is about 20 kw. greater for Unit $B\ Y$ than for Unit $B\ Z$. This difference is believed to be reasonably accounted for by the fact that in Unit $B\ Y$ a large volume of air was allowed to discharge around the end windings of the armature, no attempt having been made to limit the discharge at these points to merely that necessary to maintain the temperature within safe limits, whereas, in the case of Unit $B\ Z$ the corresponding openings have been partially blocked for this purpose. The additional air moved in the case of Unit $B\ Y$ might account for the 20-kw. difference.

There then remains a difference of approximately 50 kw. between these losses on Units $A\ X$ and $B\ Z$. Part of this difference is undoubtedly in the generator and a part in the turbine. The designer of the Generator X was particularly careful to decrease to the greatest possible extent the windage loss by careful fan design and by the addition of sheet-metal shrouds on the generator-rotor spider and fan for the purpose of directing the air currents, while apparently such provisions are not carried out to the same extent in the case of Generator Z.

As to the turbines, an inspection of the respective runner designs indicates that in the case of Turbine B the lubricating water from the lignum-vitae bearing is much more apt to get away through the upper seals of the turbine than is the case of Turbine A, and this might readily account for a considerable part of the observed difference in losses.

A formula was given in the water-wheel test code for determining the turbine windage, but in this case this formula gave a value of approximately 50 kw., which, in the case of Unit $A\ X$ is obviously far too high, as it would leave but about 23 kw. for generator windage. There is, however, undoubtedly some windage loss in the turbines under test conditions, and this was approximated by reference to fan data. It was found that the shut-off power of a fan was in the neighborhood of 20 per cent of the full-load power, and it was assumed that the 50 kw. resulting from the above mentioned formula would represent the full-load power of the turbine runner as a fan, which appeared reasonable from a consideration of its dimensions and in comparison with fan data. It was then assumed that the shut-off power or windage with turbine gates closed would be 20 per cent of this, or 10 kw. This was assumed to be the same for all three turbines. There was then left, in the case of Unit $A\ X$, 62.9 kw. to be divided between generator windage and turbine disk friction. Of this 50 kw. was arbitrarily charged to generator windage, as this seemed a reasonable value, and left an amount of 12.9 kw. chargeable to turbine disk friction. In the

case of Units B Y and B Z, it was thought that the disk friction might be approximately three times that of Unit A X, and was accordingly put at 40 kw., leaving for generator windage 93.5 kw. in the case of Unit B Y, and 72.8 kw. for Unit B Z, as compared with the 50 kw. assumed on Unit A X. The value of 50 kw. (40 + 10) for turbine windage and disk friction happens to be the same as would have been assigned to turbine windage had the test code formula been used, hence, should not be open to serious criticism.

The final values of generator friction and windage then become for Unit A X, 61.15 kw.; Unit B Y, 105.96 kw.; and Unit B Z, 85.56 kw. We have two checks on these figures; first, the designer of Generator Z stated that he estimated the friction and windage of his generator at 80 kw., and second, the designer of Generator Y, that of his at about 109 kw. We have a further check on the accuracy of the resulting values of generator efficiency in that the efficiencies of the turbines of Units B Y and B Z, based on the values of generator efficiency thus arrived at, checked each other exactly.

Separation and Determination of Electrical Losses

Iron Loss. Obviously the iron loss is determined by subtracting the friction and windage from the iron-loss

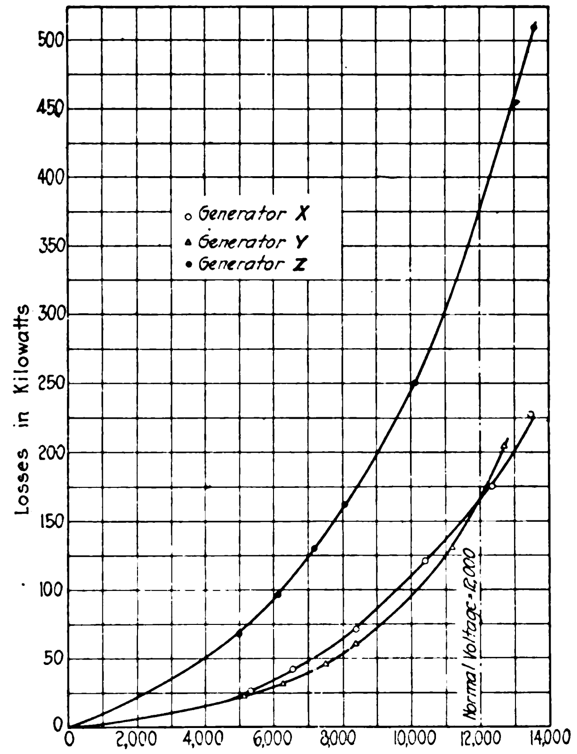

Fig. 9—Iron Losses of Three 32,500-Kv-a. Generators

friction and windage as determined either by the input or by the retardation test. Fig. 4 shows iron loss, friction and windage data for the 65,000-kv-a. unit, and Fig. 6 for the three 32,500-kv-a. units. The values of the friction and windage losses, of course, determine the termini of these curves on the zero voltage axis, thereby giving the necessary data for the completion of the lower part of the curves. Fig. 9 shows iron losses alone for the three 32,500-kv-a. generators and Fig. 10 for the 65,000-kv-a. generator.

Stray-Load Losses. Similarly the stray-load loss is

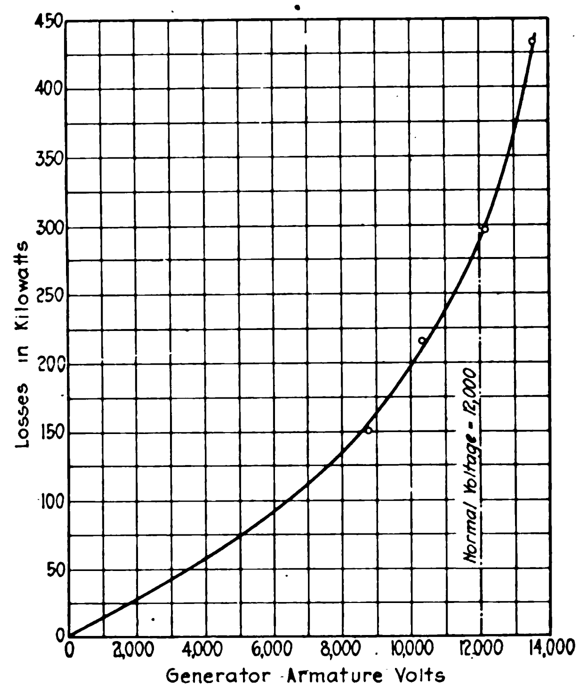

Fig. 10—Iron Losses of 65,000-Kv-a. Generator

determined by subtracting the friction and windage and armature $I^2 R$ loss from the appropriate test values. This has been done for the 65,000-kv-a. generator, the various steps by which the stray-load loss has been determined are indicated in Fig. 11.

Following the same general principles used in determining the friction and windage, and the iron loss, the test points are first determined and plotted for the delineation of a curve of loss against speed as obtained by the retardation test. In Fig. 11 these test points for armature currents of 1554 amperes, 2145 amperes, and 3156 amperes are shown respectively at a, b and c.

These points do not look very encouraging as almost any kind of a curve can, seemingly, be drawn through them. However, in delineating these curves, we are entitled to use all the information which we have, so, before drawing in the curves, it may be indicated on the sheet just what is known about the losses which are to be deducted. We, therefore, draw in the friction and windage loss curve, as per Fig. 7.

As to the $I^2 R$ loss, it is known both from theory and observation, that the short-circuit current remains practically constant at all speeds, hence, the $I^2 R$ loss is constant throughout the test. It is possible, therefore, to add a constant $I^2 R$ loss to the friction and windage-loss curve, obtaining the corresponding curves shown in Fig. 11.

The difference between this curve and the total-loss curve is the "stray-load" loss, and there should be some consistent relationship between the stray-load loss and speed. Three assumptions are possible:

1. Stray-load loss decreases as speed increases.
2. Stray-load loss constant as speed increases.
3. Stray-load loss increases as speed increases.

If the stray-load loss is caused mostly by eddy currents in the copper, as seems most likely, it would appear that it should increase with frequency, and the test points indicate in general that it does so. If so, three assumptions are again possible as to a possible

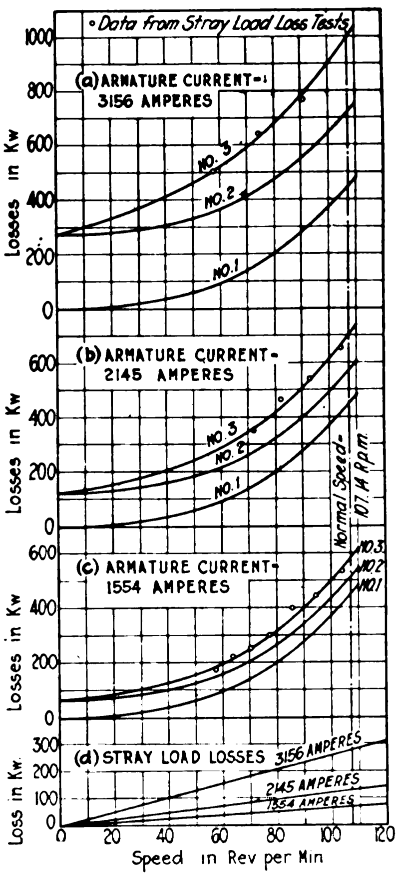

FIG. 11—RETARDATION TEST FOR STRAY LOAD LOSSES OF 65,000-KV-A. GENERATOR

Curve No. 1—Friction and windage losses
No. 2—Curve No. 1 plus $I^2\ R$ losses
No. 3—Curve No. 2 plus stray load losses

exponent of the power of the speed by which it varies, that is, if it is assumed that:

$$\text{Stray-load loss} = C\ S^n \qquad (7)$$

where C is a constant,
n may be

1. less than unity
2. equal to unity
3. greater than unity

In order to determine which of these assumptions most nearly agrees with the test data, trial curves were drawn and the speed-time curve reconstructed from points taken from the trial curves. The reconstructed curve based upon the assumption of $n = 1$ shows the better agreement, and this assumption was consequently used in drawing the final curve through the test points. The differences, however, between the results of the three assumptions are very slight, and none of them are probably scientifically true.

In drawing the curves, a point was selected on each of the trial curves through which it appeared the curve would have to pass whatever its form. From these values, the corresponding friction, windage and iron losses were deducted, the residual values being plotted on a rectangular scale and straight lines drawn through these points and the origin. These three lines, shown at *d* Fig. 11 are then the most probable curves of stray-load losses for different speeds at the three values of armature current. These three curves were then added to the friction, windage and $I^2\ R$ loss curves to produce the total-loss curves as shown. It was found that the stray-load loss at any given speed varied almost exactly as the square of the current, the chance agreement of the trial points in this respect being so close that the final curves were intentionally so drawn.

These results would *seem* to indicate the following conclusions:

1. The short-circuit stray-load losses are due (at least mostly) to an increase in the effective resistance of the armature conductors, due, no doubt, to a displacement of the current in the conductors—usually called "eddy currents."
2. This increase in effective resistance varies with the speed or frequency, and appears to be substantially proportional to the first power thereof.
3. The increase in effective resistance is apparently independent of the armature current.

From these results, it would appear that, practically, the effective resistance of the armature would be expressed by the formula:

$$R_f = R\,(1 + K\,f) \qquad (8)$$

where
R_f is resistance at frequency f
R is resistance for direct current
and
K is a constant.

While these conclusions *seem to be* indicated, it is, fo course, not safe to generalize from a single test, and further and more accurate determinations will be required to establish these relations definitely, if indeed, they actually exist at all.

However, in this case, it is apparently true that, for all practical purposes, the determination of the short-circuit stray-load loss for any current and any speed may be made from a single accurate test at one current and one speed. If formula (8), or one similar to it, should prove to be generally true, it would appear that some independent method of predetermining the coefficient (K) would be extremely useful.

Conclusions

1. The retardation method for determining certain of the losses in large generators is a useful, accurate, consistent and easily applied method, and deserves more extensive use and fuller official recognition.

2. The retardation method of measuring friction and windage losses contains within itself the means of separating these losses from each other. This is a very useful property when it is necessary to allocate such losses between the generator and its turbine. It is also useful for detecting abnormal friction or windage.

3. The determination of a loss at different speeds, which is a natural application of the retardation method, furnishes a means not only of more accurately determining such loss at normal speed, but also furnishes a means of throwing new light upon the nature of certain of the losses.

4. Development of apparatus and refinement of methods of carrying out retardation tests are desirable. An instrument to measure the rate of retardation directly, should be a possibility not difficult to realize.

Three Methods of Measuring Dielectric Power Loss and Power Factor

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Synopsis.—*The paper presents a brief description of the methods of measuring dielectric power loss and power factor in commercial use at the Electrical Testing Laboratories.*

The several methods are handled individually and their advantages and disadvantages listed.

Appendixes are included on the use of the shunted electrodynamometer as an ammeter, determination of compensation, effect of incorrect compensation in the wattmeter shunt, effect of slightly unbalanced voltages on three-phase measurements, a three-phase wattmeter switch and shielding, grounding, etc.

Introduction

The very fact that a symposium on methods of measuring dielectric power loss and power factor has been arranged is an indication that such measurements offer considerable difficulties, particularly when applied to present-day dielectrics. The purpose of this paper is to describe and discuss the methods now employed at the Electrical Testing Laboratories for such measurements.

Originality is not claimed for the methods described, but they have been improved and adapted as need for them has arisen. Experience has shown each to be satisfactory for the class of work for which it has been developed.

General

The three general methods to be described and the measurements for which they are adapted are as follows:

1. Compensated Wattmeter Method
   a. For single-phase measurements on cables
   b. For three-phase measurements on cables
2. Phase-Defect Compensation Method
   a. For high-voltage single-phase measurements on cables
   b. For single-phase measurements on low-voltage condensers of high capacitance
3. Transformer Bridge
   a. For single-phase measurements on very low capacitances (short pieces of cable, oils, compounds, sheet materials, etc.)

1a. The Compensated Wattmeter for Single-Phase Measurements.

This method consists in a direct measurement of the dielectric power loss in watts when an alternating potential is applied to the cable under test. As there is always a certain amount of "leakage" power in the test circuits and instruments, a measurement is first made of this "leakage" before the cable is connected for test. This "leakage" loss is then subtracted from the total loss with the cable or other dielectric in circuit in order to obtain the "net" or actual loss in the material under test.

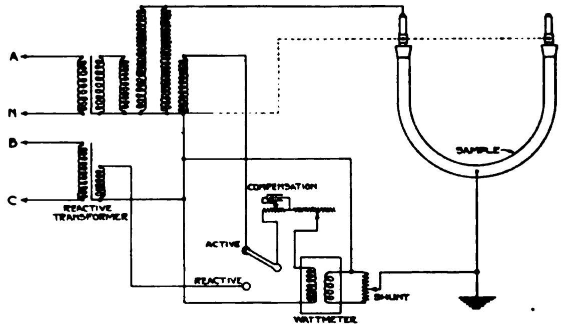

Fig. 1

This direct measurement is made using a shunted reflecting electrodynamometer wattmeter in connection with a potential transformer. The phase angle of the potential transformer and the self inductance of the

1. Both of Electrical Testing Laboratories, New York City.

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potential coil of the wattmeter are compensated for by the use of a shunted condenser of the proper value in the potential circuit of the wattmeter. The self inductance of the current element of the wattmeter is compensated for by the use of a shunted condenser in the wattmeter shunt.. A diagram of the complete circuit used is shown in Fig. 1.

The equipment used in making such measurements is as follows:

1 Insulating transformer
1 Testing transformer
1 Voltage transformer
1 Reflecting electrodynamometer wattmeter
1 Compensated wattmeter shunt
1 Voltage-circuit resistance with compensation
1 Calibrating load
1 Lamp and scale
1 High-resistance voltmeter
1 Frequency meter
1 "Reactive" insulating transformer

When using this method the wattmeter is calibrated on low voltage against a resistance load. In this

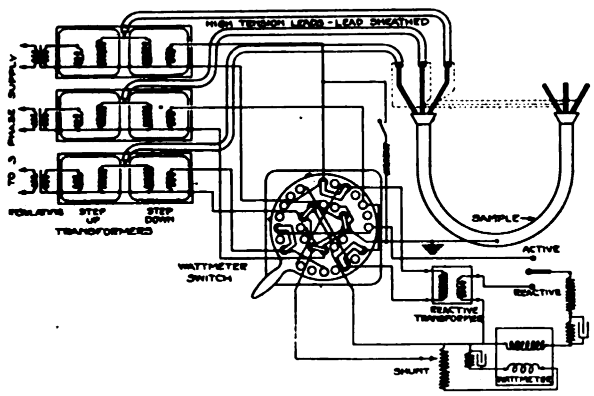

Fig. 2

operation the voltage circuit resistance is adjusted to give some even scale constant such as 0.001 watt loss in the high-voltage circuit per millimeter scale deflection.

After the calibration is completed the resistance in the compensation circuit is set for its correct value for the first test voltage. Since the burden on the potential transformer is practically constant from day to day, regardless of the sample under test, the value of compensating resistance necessary for various test voltages can be determined in advance by the methods described in Appendix II.

For speed in testing it is the usual practise to take a complete set of "leakage" readings covering the full range of test points and follow this immediately by "cable on" readings made at the same test voltages. These readings are referred to as "active" readings as distinguished from the "reactive" readings referred to below.

In order to determine power-factor it is then necessary to measure either the current, Appendix I, or the apparent power, reactive volt-amperes. It is the practise at these Laboratories to determine the reactive volt-amperes in this case rather than the current. With a three-phase, Y-connected supply and the test set operated on one phase, a transformer with a ratio of $\sqrt{3}$ to one connected across the remaining two phases furnishes a potential supply which makes it possible to read the reactive volt-amperes directly. In this case, as well as in the power readings, "leakage" readings and "cable on" readings are made for all test points. These readings are referred to as "reactive" readings.

A typical set of data is as follows:

	Active		Reactive
Voltmeter indication		20	
True voltage—kv		10	
Compensating resistance		249	
"Leakage" Measurements			
Dynamometer indication	−33		−67
Shunt	1		1
Total deflection	−33		−67
"Cable On" Measurements			
Dynamometer indication	112		168
Shunt	1		50
Total deflection	112		8400
Leakage deflection	−33		−67
Net deflection	145		8467
Net volt-amperes	0.145		8.467
Cotangent		0.0171	
Power factor, per cent		1.71	

The time required for an operator to take complete data on a test requiring six test voltages is about one-half hour. During this time he can make all computations as indicated in the sample data, these computations being made while waiting for the wattmeter to assume a steady deflection.

The sensitivity of this equipment is, of course, fixed in the calibration and remains constant throughout the test range.

The accuracy depends chiefly on the accuracy of compensation. With the present methods of determining compensation it is believed that an accuracy of $\pm$ 0.05 per cent in power factor should be obtained.

This type of equipment is sensitive to external conditions. The loss read by the wattmeter varies as the square of the applied voltage, so that small voltage variations multiply in their effect on the loss reading. The reactive volt-amperes vary directly as the frequency and as the voltage, hence these conditions must be constant and correct.

Dielectric power loss and power-factor measurements should be made using sine-wave potential. With this method, however, the power-loss is measured for the wave used, whatever its form may be.

Advantages:

1. Rapid operation—five minutes per test point including time for computations
2. Simple operation
3. Not affected by wave form of supply
4. High sensitivity

Disadvantages:

1. Accuracy of method depends on accuracy of compensation
2. Particularly susceptible to variations in supply voltage

1b. The Compensated Wattmeter for Three-Phase Measurements.

This method consists in a direct measurement of the dielectric loss in watts when a three-phase alternating voltage is applied to the sample of cable under investigation.

The method is essentially the three-wattmeter method for the determination of power in a three-phase, four-wire circuit. This method has been simplified by the use of one wattmeter in connection with a specially designed switch for connecting the wattmeter in each of the three circuits as desired. A complete diagram of this circuit is shown in Fig. 2.

The operation of this equipment is essentially the same as that described in Method 1a. Since it is very difficult to obtain balanced three-phase voltages, it has been found that best results are secured by holding the voltage constant on one phase, rather than trying to adjust to the correct voltage on each phase. The reasoning back of this is to maintain the conditions constant for each test point. When working on an unbalanced system this would not be true if the voltage were adjusted on each phase when the wattmeter is read.

The equipment used in making these tests is the same as that described in Method 1 *a*, except that three insulating, three testing and three potential transformers are required together with the special wattmeter switch, Appendix V.

A typical set of data from one of these tests is as follows:

Voltmeter indication		29	
True line-kv		10	
Compensating resistance		279	
	Active		Reactive
"Leakage" Measurements			
Dynamometer Indication Ph. I	−24		96
" " " II	0		141
" " " III	−52		120
" " Sum	−76		357
Shunt	1		1
Total deflection	−76		357
"Cable On" Measurements			
Dynamometer Indication Ph. I	−36		87
" " " II	107		81
" " " III	−42		79
" " Sum	29		247
Shunt	10		200
Total deflection	290		49400
Leakage deflection	−76		+357
Net deflection	366		49043
Net volt-amperes	0.366		49.043
Cotangent		0.0075	
Power factor, per cent		0.75	

The advantages and disadvantages of this method are essentially the same as those described in Method 1a.

2a. Phase-defect Compensation Method for High-Voltage Measurements.

This method consists in a determination of the power factor or phase angle of the sample under test by a direct comparison of its apparent phase defect angle with that of a "no-loss" air condenser.

In this method a reflecting type electrodynamometer wattmeter, connected as for measuring watts loss, is made to read zero by changing the phase of the current in the potential circuit by inserting inductance of known value. Such a balance is obtained, first, against a "no-loss" air condenser, and then against the sample.

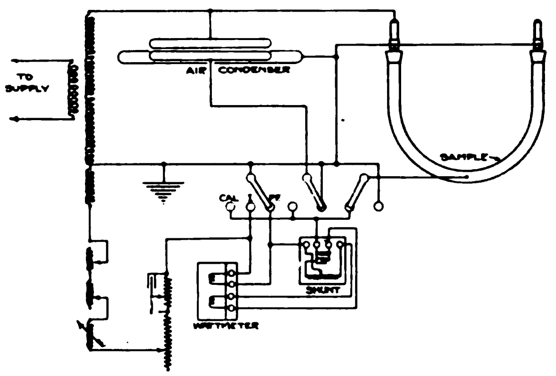

FIG. 3

From the difference in shift necessary the power factor or phase angle of the sample is obtained.

Complete connections used in this test are shown in Fig. 3.

The equipment used is as follows:

1 Testing transformer
1 Reflecting electrodynamometer wattmeter
1 Dynamometer shunt
1 Voltage circuit resistor with compensation
1 50- to 250-milhenry constant resistance tapped inductor
1 6- to 50-milhenry variable inductor
1 Lamp and scale
1 High-resistance voltmeter
1 Frequency meter
1 High-voltage variable air condenser, "no-loss"

In using this method the sample and the "no-loss" air condenser are kept connected to the transformer at all times in order to maintain the relative phase positions. For convenience in computing, the potential circuit resistance is kept constant at a value in ohms equal to 6 π times the frequency in cycles per second.

In order to determine the dielectric power loss the charging current is measured, using the electrodynamometer as an ammeter, Appendix I. Then from the charging current, the power factor and the test voltage, the dielectric power loss is computed.

A typical set of test data and computations is as follows:

Voltmeter indication	20
Test kv	
Cable (Condenser Connected Directly to Ground)	10
Potential circuit resistance	1131
Observed Inductance—Direct	44.0
" " —Reverse	43.8
" " —Average	43.9
Ammeter shunt	5
Ammeter reading	452
True milliamperes	2.74
Condenser (Cable connected directly to ground)	
Observed inductance—Direct	35.0
" " —Reverse	35.6
" " —Average	35.3
Difference in inductance	8.6
Power factor of sample, per cent	0.29
Dielectric power loss, watts	0.079

To determine the constant of the ammeter the electrodynamometer is calibrated against a resistance load. This connection is obtained with the selector switch on "calibrate."

Fig. 4 is the vector diagram for this method where

E = Test voltage
I_a = Current to air condenser
I_s = Current to sample
E_p = Voltage applied to potential circuit
I_1 = Current in potential circuit when balanced against air condenser
I_2 = Current in potential circuit when balanced against sample
ϕ_1 = Apparent phase defect angle of air condenser
ϕ_2 = Apparent phase defect angle of sample

The computation of the power factor is based on the following theory. If L_1 is the inductance setting for

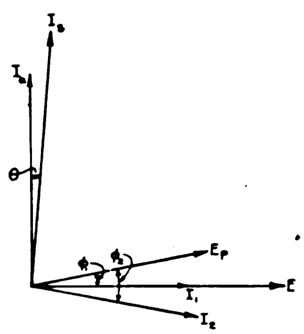

FIG. 4

zero reading on the air condenser, the phase shift of the current in the potential circuit in order to obtain the balance is

$$\tan \phi_1 = \frac{\omega L_1}{R} \tag{1}$$

Likewise, if L_2 is the inductance setting for balance against the sample, the phase shift of the current in the potential circuit is

$$\tan \phi_2 = \frac{\omega L_2}{R} \tag{2}$$

Since these are all small angles, the tangent is numerically approximately equal to the sine of the angle. Then, if θ is the phase-defect angle of the sample (difference between the actual angle and 90 deg.)

$$\sin \theta = \tan \phi_2 - \tan \phi_1 = \frac{\omega}{R}(L_2 - L_1) \tag{3}$$

or

$$\text{Power factor} = 100 \sin \theta = \frac{100\ \omega}{R}(L_2 - L_1) \tag{4}$$

But R has been made equal to 3 ω

Therefore,

$$\text{Power factor} = \frac{L_2 - L_1}{30} \tag{5}$$

when L_2 and L_1 are read in millihenries.

The computation of the power-factor is so simple that it is readily made while waiting for the ammeter to assume a steady deflection.

Computation of the charging current depends upon the ammeter connection used. See Appendix I for methods of using the electrodynamometer as an ammeter.

The time to take a set of readings covering six-test voltages is approximately one-half hour, during which time the power-factor values are also computed. The remainder of the computations may take as much as an additional 20 min.

The sensitivity of this equipment, when used for power-factor measurements, varies with the test voltage and the charging current to the sample under test. It is naturally more sensitive under higher currents and voltages.

When making the power-factor balance, voltage variations cause changing sensitivity, although at balance voltage variations have no effect (assuming no change in power factor with voltage). Likewise, frequency variations affect the sensitivity on power-factor measurements as well as change the apparent defect angle. On current measurements any variable causing a varying charging current (voltage or frequency) causes a variable reading, which is particularly objectionable since the deflection varies approximately as the square of the current.

The accuracy of this method is dependent chiefly upon the operator and upon the "no-loss" condenser. A careful operator should be able to make measurements to within ± 0.05 per cent power factor. The losses as computed from the current and power-factor should be well within ± 5 per cent accuracy.

In this equipment errors in wave form introduce an error in the power factor since it is computed on the basis of a sine wave. For harmonics which do not run above five per cent in value this is negligible.

Advantages:
1. Rapid operation
2. Simple operation

Disadvantages:
1. Variable sensitivity
2. Accuracy dependent on operator and on "no-loss" condenser
3. Frequency and voltage must be maintained constant

2b. Phase-Defect Compensation Method for Measurements on Low-Voltage Condensers of High Capacitance.

The measurement of losses in low-voltage condensers of high capacitance (such as are used for power-factor correction) may be accomplished by a modification of

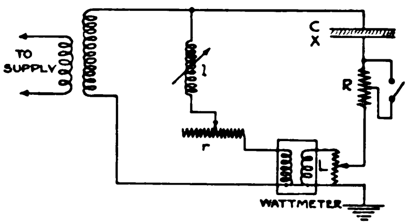

Fig. 5

Method 2a. The method then consists in a determination of the power factor of the test condenser by a comparison of the apparent phase-defect angles with different known values of resistance in series with it.

The diagram of connections is shown in Fig. 5. Here again a reflecting type electrodynamometer wattmeter is used, connected as for power measurement, and made to read zero by changing the phase of the current in the potential circuit by inserting inductance of known value. Such a balance is obtained for each of two or more known values of resistance in series with the test condenser.

In employing this method the following equipment is used:

1 Resistor having two or three steps
1 Reflecting electrodynamometer wattmeter
1 Lamp and scale
1 Variable inductometer
1 Voltage circuit resistor
1 Voltmeter
1 Frequency meter

Then, if

X = Series resistance of test condenser
C = Capacitance of test condenser
R = Resistance in condenser circuit (not including X)
L = Inductance of current circuit (usually that of current coil of wattmeter)
l = Total inductance of voltage circuit
r = Total resistance in voltage circuit
$\omega = 2\pi f$,

Fig. 6 shows that at balance

$$\frac{\omega l}{r} = \frac{X + R}{\dfrac{l}{\omega C} - \omega L} \tag{6}$$

When l_1, r_1 and l_2, r_2 are the inductance and resistance values at balance corresponding to R_1 and R_2, respectively, the following equations can be deduced.

$$X = \frac{r_2 R_2 l_1 - r_1 R_1 l_2}{r_1 l_2 - r_2 l_1} \tag{7}$$

$$C = \frac{l_1}{r_1 (R_1 + X) + \omega^2 L l_1} \text{ or } \frac{l_2}{r_2 (R_2 + X) + \omega^2 L l_2} \tag{8}$$

If r_1 can be kept equal to r_2, equation (7) reduces to

$$X = \frac{R_2 l_1 - R_1 l_2}{l_2 - l_1} \tag{9}$$

On the other hand, if a variable inductor is not available and r must be varied, equation (7) reduces to

$$X = \frac{r_2 R_2 - r_1 R_1}{r_1 - r_2} \tag{10}$$

This latter arrangement produces one peculiar condition in that the sensitivity of the meter may change more rapidly than the phase angle of the potential circuit thus causing the electrodynamometer indication to

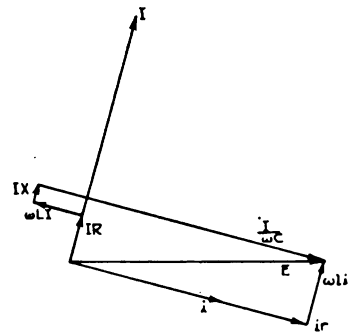

Fig. 6

become greater for a time as the balance point is approached.

A typical set of observed data and calculated results are shown below:

Test voltage, volts		440	
Frequency, cycles per sec		60	
Current-coil inductance, henrys		0.008	
Voltage-coil resistance, ohms		8000	
Resistance of current coil and leads, ohms		18	
"Test" resistance in current circuit, ohms	0		10
Total resistance in current circuit, ohms	18		28
Inductance of voltage circuit, millihenrys	400		588
Series resistance of test condenser, ohms		3.3	
Capacitance of test condenser, μ f		22.6	
Power-factor test condenser, per cent		2.81	
Loss in test condenser, watts		46.3	

Advantages:
1. No standard condenser needed
2. Settings only indirectly affected by frequency

Disadvantages:
1. Sensitivity variable
2. Constants of circuits must be known accurately

3a. The Transformer Bridge.

By this method the capacitance and equivalent shunting resistance are determined by comparison of the test sample with a "no-loss" air condenser. Each is inserted separately in one circuit of the bridge while the other circuit of the bridge containing known capacitances and resistances is adjusted until the currents in the two circuits are equal in magnitude and opposite in phase. From these values of capacitance and resistance the power factor and dielectric loss are computed.

A diagram of the circuit is shown in Fig. 7. The detector used consists of a synchronous commutator and a d-c. galvanometer. The rectifier is provided with two sets of brushes spaced 90 electrical degrees apart so that when properly set the bridge may be balanced for either component (active or reactive)—each practically independently of the other.

The balance circuit is unique in the use of a four-dial 100,000-ohm resistance box in connection with a

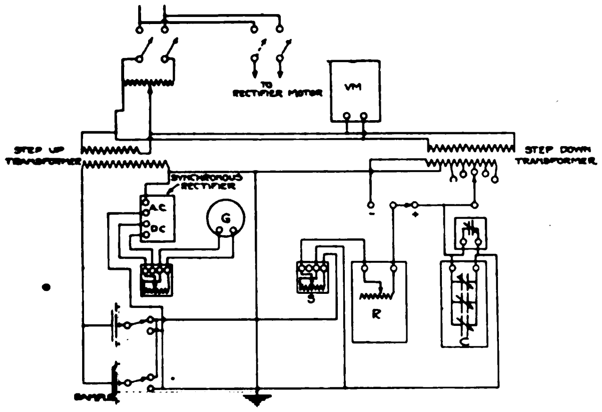

FIG. 7

universal shunt in order to simulate a continuously variable resistance of 0- to 500-megohm range. This is obtained by connecting the shunt across the detector and using the movable point as a connection for the resistance circuit.

Under certain conditions the resistance component required of the balance circuit is negative. Such a condition is provided for by an additional winding on the balance transformer as shown in Fig. 7.

The equipment used in this bridge consists of

1 D-c. reflecting galvanometer
1 Lamp and scale
1 Synchronous commutator
1 10,000-ohm galvanometer shunt
1 2000-ohm galvanometer shunt
1 4-dial, 100,000-ohm resistor
1 3-dial, 1 micro-microfarad mica condenser
1 1000-micro-microfarad variable air condenser
1 High-resistance voltmeter
1 Voltage regulator
1 Small step-down transformer
1 Testing transformer
1 High-voltage variable air condenser

In this method also, both the sample and the air condenser are kept connected to the testing transformer, each being connected directly to ground when not connected into the test circuit. This maintains circuit conditions constant at all times.

A set of typical test data is as follows:

	Air Condenser	Sample
Capacitance reading	0.2048	0.4378
Resistance reading	84000	42100
Shunt used	20	5
Tan ϕ	0.0077	0.0288
Power factor of sample, per cent		2.11

The tangent of the *apparent* defect angle, ϕ, is computed as for a parallel circuit

$$\tan \phi = \frac{1}{\omega C R S} \tag{11}$$

where

$\omega = 2 \pi f$
C = Capacitance read
R = Resistance read
S = Multiplying power of shunt

The defect angle of the sample is then the difference of these two angles, and since the angles are small,

Power factor $= \tan \phi_2 - \tan \phi_1$

where

ϕ_1 = the apparent defect angle of the air condenser

and

ϕ_2 = the apparent defect angle of the sample

The capacitance of the test sample is obtained from the capacitance read by

$$C_s = C \times r \tag{12}$$

where

C_s = Capacitance of sample
C = Capacitance read
r = Transformer ratio between test and balance circuits.

The time required for readings is about three minutes per test point. This includes the time for balances against both the air condenser and the sample.

Computations are not readily made during the test so that the time required for complete results on a test of six test points would be about one-half hour.

The sensitivity of this equipment is a function of the current in the test circuit and the galvanometer used. Since a d-c. galvanometer of medium high sensitivity (500 meg.) is used, the resultant sensitivity is high.

Accuracy is such that capacitances of the order of 50 micro-microfarads can be measured to within better than one per cent, while the power factor can be determined within $\pm$ 0.05 per cent (absolute value).

The bridge is extremely sensitive to leakages, so that all high-potential parts must be completely

shielded and all low-potential wiring metallically sheathed.

Frequency and voltage change affect the results only in so far as they change the properties of the test sample.

Potential waves of other than sine characteristics affect both the test and balance circuits alike and cause error only if neglected in the computations—the bridge

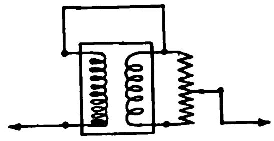

FIG. 8

determines the capacitance and resistance components for the wave applied.

Advantages:
1. Rapid operation
2. Simple operation
3. Very high sensitivity
4. Measurement range
   Capacitance 1-1000 micro-microfarads
   Power factor 0-100 per cent
5. Independent of frequency and voltage variations
6. Accuracy high

Disadvantages:
1. Very sensitive to leakages

Appendix I

THE USE OF THE REFLECTING ELECTRODYNAMOMETER AS A UNIVERSAL SHUNTED AMMETER

There are two methods of using the reflecting type electrodynamometer as a universal shunted ammeter. The first is that shown in Fig. 8. In this case only one coil is shunted and, providing the dynamometer has a uniform watt scale, the instrument follows the law,

$$\Delta S = K^2 I^2 \text{ or } I = \frac{\sqrt{\Delta S}}{K} \quad (13)$$

where

Δ = the deflection in millimeters
S = the multiplying factor of the shunt
K = the ammeter constant
I = the current

It is preferable under some circumstances to shunt

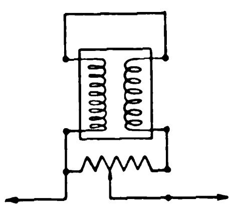

FIG. 9

both coils as shown in Fig. 9. The instrument then follows the law,

$$\Delta S^2 = K^2 I^2 \text{ or } I = \frac{S\sqrt{\Delta}}{K} \quad (14)$$

In this latter case, if the instrument can be calibrated to be direct reading on one shunt the product of the reading on this scale and the shunting value gives the current on any shunt. In the first case it is necessary to compute the constant over the range used and then the current which is a longer process.

Appendix II

DETERMINATION OF COMPENSATION

a. *Using a "no-loss" Air Condenser.*

To determine the correct wattmeter compensation for a given voltage, set air-condenser plates as close together as safe operation permits and read the wattmeter deflection for a series of values of "compensation resistance." These results when plotted, with wattmeter reading as abscissas and the square of the "compensation resistance" as ordinates, will give a straight line. Similar sets of data are then taken for a wider setting of the air condenser. These straight lines should then all cross at a point, corresponding to the correct value of compensation, at which point the wattmeter reading should be a constant regardless of the condenser spacing.

While this method is described as for a "no-loss" air condenser, it applies equally well for a "constant-loss" variable condenser. Leakages play no part, providing they are constant for each voltage.

This procedure, while applying to single-phase equipments in particular, is readily adapted to three-phase equipments. In this case, each phase is handled separately as for single-phase determinations and then the average of the three values used as the correct three-phase compensation.

b. *Using a Built-up Three-Phase Load.*

A second scheme, sometimes more convenient for determining three-phase compensation, is to take three single-phase loads of approximately the same capacitance and loss, say three pieces of single-conductor cable, on which determinations can first be made by single-phase test methods. These loads can then be combined into a three-phase load and the "compensation resistance" adjusted until the loss measured under three-phase potential equals the sum of the losses measured at a corresponding single-phase potential.

Appendix III

EFFECT OF INCORRECT COMPENSATION IN WATTMETER SHUNT

Incorrect compensation in the wattmeter shunt will introduce no error if the phase defect compensation method is used. Any such phase error will affect both balances of the wattmeter alike and hence be eliminated when the difference is taken.

In the straight wattmeter methods, however, incorrect compensation in the wattmeter shunt will cause an error unless the potential circuit compensation values are obtained as in Appendix II. Mathematical analysis and actual tests have shown that any error

caused by incorrect compensation in the wattmeter shunt appears as a constant angular error independent of shunt position.

Appendix IV

Effect of Slightly Unbalanced Voltages on Three-Phase Measurements

When making three-phase measurements the natural tendency is to adjust the voltage on each phase just before taking a reading. This, however, means that when the three-phase supply is slightly unbalanced the three readings are taken for three different voltages on the cable as a whole. It has been found a better practise to hold the voltage on one-phase constant during all the measurements on all phases and let the others remain slightly high or low in voltage. In this way, readings on the three phases correspond to a given condition though they will not correspond to a balanced condition.

Again, any unbalance in voltages means that there may be slight phase shifts sufficient to make it impossible to analyze the individual wattmeter readings and get any idea of conditions in the insulation of each of the three conductors forming the load. In fact, it is not unusual to get negative readings on one phase, though the total is positive in value.

Appendix V

The Three-Phase Wattmeter Switch

To determine the power loss and reactive volt-amperes in a three-phase test circuit, using one wattmeter, requires a large amount of switching. Fig. 10 shows the operations to be made. Points *X*, *Y* and *Z* must all connect to *G*, either directly or through the

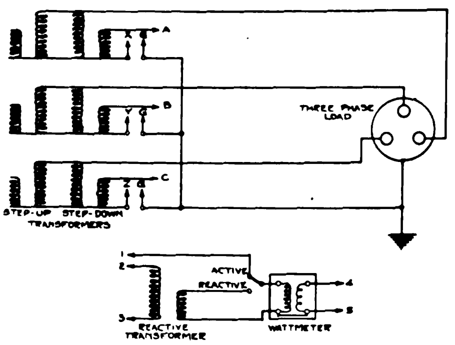

Fig. 10

current element of the wattmeter. With the current element of the wattmeter inserted between *X* and *G*, the potential element must connect to *A* and *X*, while the potential element for reactive volt-ampere measurements must connect to *B* and *C*. When the current element of the wattmeter is moved to connect between *Y* and *G*, the point *X* must again be connected to *G* and all the potential connections changed accordingly.

All of this switching with ordinary knife switches makes a very complicated and unwieldy arrangement. Accordingly, there has been developed at these Laboratories a simple-switching element which accomplishes in a single operation all of the necessary switching when changing from one phase to another. A diagrammatic view of this switch is shown in Fig. 11. The circles represent circular studs mounted in and insulated from the switch base. Connections are made to these studs as shown, the letters and numbers corresponding to those in Fig. 10. The upper or movable part of the

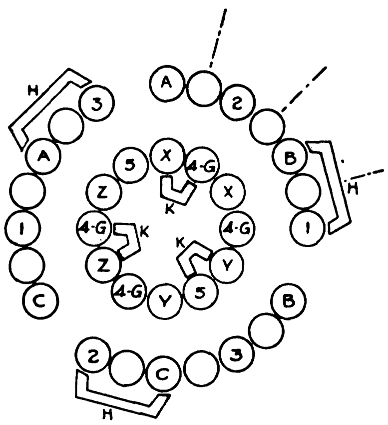

Fig. 11

switch rotates about the center and carries the spring contacts *H* and *K* which bear on the fixed studs. This switch in 60 deg. rotation provides correct connection of the wattmeter in each of the three phases.

Appendix VI

Shielding, Grounding, Etc.

In connection with all measurements made at high potential, shielding and guarding are important factors. In the three methods described in this paper, shielding is essential. All high-voltage parts, leads, etc., must be well shielded. All low potential wiring is best when done with metal-sheathed wire.

Shielding is most readily done when one side of the testing transformer and the transformer tank can be grounded. All the single-phase test equipments described in this paper are operated with one side of the testing transformer grounded. The grounding of the transformer and shielding protects the operator against contact with high-voltage parts.

As an additional protection to the operator, these testing equipments have been designed as "one-man sets," that is, they are built for complete operation by a single operator. All are equipped with safety switches which make it necessary for the operator to be in his place at the instrument table in order to put voltage on any of the equipment.

Abridgment of

Sag Calculations for Transmission Lines

BY H. B. DWIGHT[1]

Member, A. I. E. E.

Synopsis.—*A set of sag formulas is presented, in the form of convergent series which give accurately the results of the hyperbolic catenary formulas. The series are useful for calculating almost any practical transmission line span, long or short.*

Trial and error methods are not used. First, the sag or deflection is calculated for a given maximum tension in the cable. Then, changes in temperature corresponding to changes in deflection and loading are computed. This procedure is followed whether the supports are at equal heights or at unequal heights.

A formula is presented for the deflection from the line joining the supports, when the elevations are unequal. This is useful in sighting from tower to tower, as shown in Fig. 2.

A few examples are worked out and some derivations of formulas are given. In the last appendix instructions are given with regard to allowing for the change in weight per ft. with change in length of cable.

SAG calculations for transmission lines are frequently made by means of formulas based on the assumption that the curve of a cable in a span is a parabola. Formulas for the calculations are also published, which use the equation for the catenary, a curve so named because it is the shape of a suspended chain. This equation involves hyperbolic cosines.

In this article is presented a group of convergent series which will be found convenient and accurate for making sag calculations. Provided enough terms are computed, these give the results of the hyperbolic catenary formula as accurately as desired. Usually, two or three terms are all that are required. Since the series are convergent series derived from the expansions of hyperbolic functions, they can be said to be themselves hyperbolic formulas. The first term of the series is in many cases the same as the well-known parabolic formulas[2], the majority of which consist of only one term. The series herewith presented should therefore be easily understood and applied by those accustomed to the parabolic formulas.

The series moreover give directly and automatically the percentage error involved by using the parabolic formulas. Even where the latter have good accuracy, it is always worth while estimating the amount of their error in a given case. Often the worst feature of an approximate formula consists in the fact that the amount of its error is not indicated and remains unknown, so that in some more or less unusual case the error may be unexpectedly large. An approximate formula in the form of a convergent series is much safer to employ, since when the terms do not become smaller and smaller, the last one being negligibly small, it is obvious that the formula is not applicable to the case considered.

If, therefore, a formula is really the first term of a convergent series, it is practically always advisable to publish two or three terms of the series, so that the appropriateness of the formula for a given case may be quickly estimated.

The series are given in the form in which they can be most conveniently used for practical sag calculations. A few examples of their use are described, and in an appendix there is given the derivation of some of the series. The derivation of the others can be obtained by following the method of the examples given.

The description of the engineering problem is usually as follows: A certain maximum tension T is specified for a cable and it is desired to know what will be the sag corresponding to this tension under given conditions of temperature and wind and of ice loading. Further, it is desired to know what changes in temperature and tension correspond to given changes in sag or in loading. These results are required when the two ends of the span are supported at the same height or at unequal heights.

In preparing the formulas, the use of trial and error methods has been avoided. These involve more work than direct calculations, and have a greater liability of error. If values of temperature are assumed, such as 40 deg. or 60 deg., a trial and error process is required at some stage of the calculations. Accordingly, values of sag or tension are assumed, and temperatures are obtained by direct calculation.

This provides data for drawing a series of curves of sag plotted on temperature, separate curves being drawn for different lengths of span. These lengths of span may be the actual lengths for the transmission line being designed, or they may be even hundreds of ft., such as 200- 400- 600 ft., etc. In the latter case, new curves may be plotted from the first set, so as to show sag plotted against span, separate curves being plotted for specified temperatures such as 20 deg., 40 deg., 60 deg., etc., and for specified loadings.

These procedures do not involve trial and error processes. The drawing of the curves described above deals only with the final results, after temperatures have been calculated. This is not likely to produce errors in the same way as the use of curves for intermediate stages of the calculations.

Attention should be called to a paper by J. S. Martin,[3] containing a very complete table for calculating sags

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1. Professor of Electrical Machinery, Massachusetts Institute of Technology, Boston, Mass.

2. See articles on sag calculations by L. E. Imlay in the *Electric Journal* of February, 1925, and succeeding issues.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926. Complete copies available to members on request.

3. "Structural Engineering Problems in Transmission Line Construction," by J. S. Martin, *Proceedings* Engineers' Society of Western Pennsylvania, November 1922, page 309.

when the supports are at equal heights. Formulas are given for using the data in the table when the supports are at unequal heights but it is stated that the precision is not as great as for the case of equal heights, on which the calculations for the tabulated data were based. A method of successive approximations is described for obtaining sags at specified temperatures. While this involves some work, it is an orderly procedure leading to the desired result.

Sag Formulas

It is to be particularly remembered that in the formulas in this paper, l represents a half span only.

Supports at Equal Heights

$$\text{Sag or deflection} = d = l\left[\frac{1}{2}\frac{w\,l}{T} + \frac{7}{24}\left(\frac{w\,l}{T}\right)^3 + \frac{241}{720}\left(\frac{w\,l}{T}\right)^5 \ldots\right] \text{ft.} \quad (1)$$

where $l = \frac{1}{2}$ span $= \frac{1}{2}$ horizontal distance between supports in ft.

T = tension in pounds, in cable at supports, where the tension is greatest.

w = resultant loading in lb. per ft. of cable. Note that $w^2 = v^2 + h^2$ where v is the vertical force per ft. acting on the cable due to gravity on the cable itself and on the ice covering, if any, and where h is the horizontal pressure in lb. per ft. due to wind. The deflection d is not vertically downward. The distance vertically downward by which the lowest point of the cable is lower than the supports is $\frac{v\,d}{w}$ ft.

When the deflection, d, is given,

$$T = w\,l\left[\frac{1}{2}\frac{l}{d} + \frac{7}{6}\frac{d}{l} - \frac{4}{45}\frac{d^3}{l^3} \ldots\right] \text{lb.} \quad (2)$$

The unstressed length of cable in the span is

$$L_u = 2\,l\left(1 + \frac{2}{3}\frac{d^2}{l^2} - \frac{14}{45}\frac{d^4}{l^4} + \frac{278}{945}\frac{d^6}{l^6} \ldots\right) - \frac{wl^2}{A\,E}\left(\frac{l}{d} + \frac{5}{3}\frac{d}{l} + \frac{4}{9}\frac{d^3}{l^3} \ldots\right) \text{ft.} \quad (3)$$

where A = area of cross section of cable, in square inches and E = modulus of elasticity in pounds per square inch.

The first line of formula (3) gives the actual perimeter of the catenary, and the second line gives the stretch in the conductor.

To find the changes in temperature, t, corresponding to changes in deflection, d, and loading, w, find values of L_u corresponding to certain values of d and w. The changes in L_u are due to temperature, if the cable is assumed fastened to rigid supports, and

$$t = \frac{L_u - L_{u0}}{a\,L_{u0}} \text{ deg.} \quad (4)$$

where t is the change in temperature,
L_{u0} = value of L_u at the lower temperature,
L_u = value of L_u at the higher temperature, and
a = temperature coefficient of expansion per degree. If a is specified per degree Fahrenheit, then t is in degrees Fahrenheit. Note that

$$L_u = L_{u0}\,(1 + a\,t) \text{ ft.} \quad (5)$$

When a is defined as the increase per degree above a certain temperature, then L_{u0} should be that temperature, in using equation (4) or (5).

Curves can be plotted of d against t. Different curves for different values of w can be plotted.

To find changes in load, w, corresponding to changes in d at a given temperature, insert values of d in equation (3). The value of w which will give the value of L_u for the given temperature, is obtained directly. L_u is given by equation (5).

Changes in temperature corresponding to changes in tension T are given by the following equation, and by equation (4).

$$L_u = 2\,l\left[1 + \frac{1}{6}\left(\frac{w\,l}{T}\right)^2 + \frac{7}{40}\left(\frac{w\,l}{T}\right)^4 + \frac{241}{1008}\left(\frac{w\,l}{T}\right)^6 \ldots\right] - \frac{2\,w\,l^2}{A\,E}\left[\frac{T}{w\,l} - \frac{1}{6}\frac{w\,l}{T} - \frac{7}{120}\left(\frac{w\,l}{T}\right)^3 \ldots\right] \text{ft.} \quad (6)$$

Curves of tension, T, against temperature, t, can be plotted.

Supports at Unequal Heights

It is usually desirable to find first a solution of the catenary for a given maximum tension T at the higher support where the tension is the greatest, as was done in the case when the supports were at equal heights. Then, changes in temperature, loading and tension can be calculated, corresponding to changes in deflection.

Let v and h be the vertical and horizontal forces per foot acting on the cable, as previously defined. Then, $w^2 = v^2 + h^2$. Let p be the vertical height by which one support is higher than the other and let $2\,l$ be the horizontal distance between the supports.

$$q = \frac{p\,w}{v} \text{ ft.} \quad (7)$$

$$2\,k = \sqrt{4\,l^2 - q^2 + p^2} = 2\,l - \frac{(q^2 - p^2)}{4\,l} - \frac{(q^2 - p^2)^2}{64\,l^3} \ldots \text{ft.} \quad (8)$$

These dimensions are shown in Fig. 1, which is drawn in the plane of the cable and not in a vertical plane.

If h, the wind pressure, is zero, then $q = p$ and $k = l$

Equation (8) is based on the fact that the square of the distance between the supports is equal to $4\,l^2 + p^2$ and to $4\,k^2 + q^2$.

Let

$$b = \frac{q}{2\,k} \tag{9}$$

$$\begin{aligned} m = {} & k\left(1 - b^2 + \frac{2}{3}\,b^4 - \frac{8}{15}\,b^6 \ldots\right) \\ & + \frac{T}{w}\left(b - \frac{2}{3}\,b^3 + \frac{8}{15}\,b^5 - \frac{16}{35}\,b^7 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)\left(\frac{2}{3}\,b + 0 + \frac{2}{45}\,b^5 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)^2\left(\frac{2}{3}\,b^2 + 0 \ldots\right) \\ & - k\left(\frac{w\,k}{T}\right)^3\left(\frac{16}{45}\,b + \frac{8}{9}\,b^3 \ldots\right) \text{ft.} \end{aligned} \tag{10}$$

The deflection, $d + q$, is found from equation (1) putting $l = m$.

The distance vertically downward from the upper support to the lowest point of the cable is $\dfrac{v\,(d + q)}{w}$ ft.

For finding the effect of changes of temperature and loading, it would be possible to assume different values of T and find values of m and d as shown above. However, it will be a little shorter to assume values of H the horizontal tension and find m from the following:

$$\begin{aligned} m = {} & k + \frac{H}{w}\left(b - \frac{1}{6}\,b^3 + \frac{3}{40}\,b^5 - \frac{5}{112}\,b^7 \ldots\right) \\ & - \frac{k}{6}\left(\frac{w\,k}{H}\right)\left(b - \frac{1}{2}\,b^3 + \frac{3}{8}\,b^5 \ldots\right) \\ & + \frac{k}{30}\left(\frac{w\,k}{H}\right)^3\left(\frac{7}{12}\,b - \frac{17}{24}\,b^3 \ldots\right) \text{ft.} \end{aligned} \tag{11}$$

The deflection in this case is found from

$$d = n\left[\frac{1}{2}\,\frac{w\,n}{H} + \frac{1}{24}\left(\frac{w\,n}{H}\right)^3 + \frac{1}{720}\left(\frac{w\,n}{H}\right)^5 \ldots\right] \text{ft.} \tag{12}$$

$$\text{where } n = 2\,k - m \text{ ft.} \tag{13}$$

After m, n and d are found, using either (10) or (11) for m, the unstressed length of cable is found by applying equation (3) to each part of the span separately, as follows:

$$\begin{aligned} L_u = {} & m\left[1 + \frac{2}{3}\left(\frac{d + q}{m}\right)^2 - \frac{14}{45}\left(\frac{d + q}{m}\right)^4 + \frac{278}{945}\left(\frac{d + q}{m}\right)^6 \ldots\right] \\ & - \frac{w\,m^2}{A\,E}\left[\frac{1}{2}\left(\frac{m}{d + q}\right) + \frac{5}{6}\left(\frac{d + q}{m}\right) + \frac{2}{9}\left(\frac{d + q}{m}\right)^3 \ldots\right] \\ & + n\left[1 + \frac{2}{3}\left(\frac{d}{n}\right)^2 - \frac{14}{45}\left(\frac{d}{n}\right)^4 + \frac{278}{945}\left(\frac{d}{n}\right)^6 \ldots\right] \\ & - \frac{w\,n^2}{A\,E}\left[\frac{1}{2}\,\frac{n}{d} + \frac{5}{6}\,\frac{d}{n} + \frac{2}{9}\left(\frac{d}{n}\right)^3 \ldots\right] \text{ft.} \end{aligned} \tag{14}$$

Curves for sag, temperature, loading and tension can now be drawn, as described for the case of support as equal heights. If a value of H has been assumed, the tension at each support can be found by applying equation (2) or (21) to each part of the span. The tension at a support is somewhat greater than H, and is greater at the higher support.

If there is no horizontal part of the curve between the two supports, then m is greater than $2\,k$, and n is a negative quantity. See equation (13).

Where a value of H is assumed, a table, not too condensed, of hyperbolic sines can be used with equation (18) to find m. However, this would not give a direct calculation for m in terms of T, such as is given by equation (10). If the difference in elevation of the supports is unusually great compared with the length of the span, the series may not converge rapidly enough, and a table of hyperbolic sines and cosines may be required. In such a case, trial and error methods may be necessary in order to obtain the desired results.

An illustration of this type of calculation is given in Example V. Since it is a trial and error method, different values of H must be assumed until a satisfactory value of T is obtained.

When the supports are at equal heights, values of H may be assumed and a table of hyperbolic sines and cosines used in a somewhat similar manner to Example V. This usually requires more work than to use the series. This is a trial and error method if one is working to a specified value of T. It may be necessary to do this if the series do not converge rapidly enough, as with an unusually large ratio of sag to span, but this is not likely to occur with practical transmission-line spans having supports at equal heights. One should also refer to the table by J. S. Martin[4].

Deflection from Line of Supports

After the location of the lowest point O, Figs. 1 and 2, and, therefore, the complete equation of the catenary

4. *Loc. Cit.*

for one set of conditions, have been found, it is possible to find by a direct calculation the vertical distance, PQ, from the line of the supports A and C to a tangent BD which is parallel to AC.

In Fig. 2, $PQ = AB = CD$, and the two latter distances may be measured on the towers and the line BD be used for sighting to determine the correct amount of sag to give the cable when stringing it. For

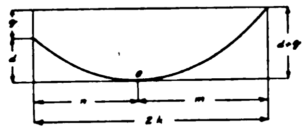

FIG. 1—SPAN WITH SUPPORTS AT UNEQUAL HEIGHTS

this purpose, assume that there is no wind or ice load, and so the cable hangs vertically. The calculation would be practically the same if wind load were included.

Let the equation of a line parallel to the line of the

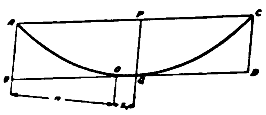

FIG. 2—DEFLECTION OF CABLE FROM LINE OF SUPPORTS

supports be $y = g\,x + f$ where g is known but where f is unknown. For this line, $\dfrac{d\,y}{d\,x} = g = \dfrac{p}{2\,l}$. The height of any point on the catenary above O is given by

$y = \dfrac{H}{w}\left(\cosh\dfrac{w\,x}{H} - 1\right)$. See Appendix I.

$$\frac{d\,y}{d\,x} = \sinh\frac{w\,x}{H}$$

If the line BD is tangent to the catenary at Q, which is the point (x_1, y_1),

$$\sinh\frac{w\,x_1}{H} = g$$

Then

$$\cosh\frac{w\,x_1}{H} = \sqrt{1 + g^2}$$

$$y_1 = \frac{H}{w}\left(\sqrt{1 + g^2} - 1\right) \qquad (15)$$

$$x_1 = \frac{H}{w}\sinh^{-1} g$$

$$= \frac{H}{w}\left(g - \frac{1}{2\times 3}g^3 + \frac{1\times 3}{2\times 4\times 5}g^5 - \frac{1\times 3\times 5}{2\times 4\times 6\times 7}g^7 + \ldots\right) \qquad (16)$$

Thus, numerical values of x_1 and y_1 can be obtained.

The height of P above O is $d + \dfrac{p\,(n + x_1)}{2\,l}$ and therefore,

$$P\,Q = A\,B = C\,D = d + \frac{p\,(n + x_1)}{2\,l} - y_1 \qquad (17)$$

all parts of which are known.

Example I. Find the difference in temperature for the following two sets of data for the same span:

$$2\,l = 800 \text{ ft.}$$

$$\frac{w\,l}{T} = 0.131\,28$$

$$\frac{w}{A\,E} = 0.000\,000\,757\,2$$

For the higher temperature, without wind or ice load,

$$\text{sag} = 23.176\,0 \text{ ft.}$$

$$\frac{w}{A\,E} = 0.000\,000\,297\,6$$

Temperature coefficient 0.000 0096

By formula (6),

$$\begin{aligned} L_{u0} &= 800\,(1 + 0.002\,872\,4 + 0.000\,051\,9 \\ &\qquad + 0.000\,001\,2\ .\ .\ .\ ) \\ &\quad - 800\,(0.002\,307\,0 - 0.000\,006\,6 \\ &\qquad + 0.000\,000\,04\ .\ .\ .\ ) \\ &= 800 \times 1.000\,625\,2. \end{aligned}$$

By formula (3),

$$\begin{aligned} L_u &= 800\,(1 + 0.002\,238\,1 - 0.000\,003\,5 \\ &\qquad + 0.000\,000\,01\ .\ .\ . \\ &\quad - 0.001\,027\,3 - 0.000\,005\,7 - 0.000\,000\,01\ .\ .\ .\ ) \\ &= 800 \times 1.001\,201\,6 \end{aligned}$$

By formula (4),

$$t = \frac{0.000\,576\,4}{0.000\,009\,6 \times 1.000\,625\,2} = 60.1 \text{ deg. fahr.}$$

This checks the result given in Mr. Martin's[5] paper.

Example II. Find the deflection for the following span[6]:

$2\,l = 2000$ ft.

Supports at equal heights.

$T = 70{,}000$ lb.

$w = 4.700$ lb. per ft.

$$\frac{w\,l}{T} = \frac{4.700 \times 1000}{70\,000} = 0.067143$$

$$\frac{l}{2}\left(\frac{w\,l}{T}\right) = 33.571$$

By equation (1), $d = 33.57 + 0.088 + 0.0005 = 33.66$ ft.

This agrees with the value of 33.6 ft. given in

5. Problem IV of the article by J. S. Martin, *Loc. Cit.*

6. Problem 2, p. 11, Transmission Line Design by F. K. Kirsten, 1923, Bulletin No. 17, University of Washington, Seattle, Wash

reference 6. It is seen that the series gives quickly and directly a precise solution of this problem, and the degree of precision of the calculation is indicated by the convergence of the series. The first term is the well-known parabolic formula.

Example III. Find the horizontal point for the following catenary[7]:

$2\,l = 2700$ ft.

Supports at unequal heights, $p = 179$ ft.

$T = 60\,587$ lb. at the higher support.

$h = 1.321$ lb. per ft.

$v = 2.870$ lb. per ft.

$w = 3.158$ lb. per ft.

$$q = \frac{p\,w}{v} = 197.0$$

$$2\,k = 2698.75$$

$$b = \frac{q}{2\,k} = 0.0730$$

By equation (**10**),

$m = 1342.2 + 1395.6 - 4.6 - 0.02 - 0.01 = 2733.2$ ft.

$n = 2698.7 - 2733.2 = -34.5$ ft.

The above paper gives $m = 2608.8$ ft. and $n = +91.2$ ft., but it neglects the fact that the cable lies in an oblique plane, and the dimension $p = 179$ ft. does not lie in that plane.

Example IV. Find the deflection for the following span[8]:

$2\,l = 4279$ ft.

Supports at unequal heights, $p = 185.5$ ft.

$T = 33000$ lb. at the higher support.

$h = 2.036$ lb. per ft.

$v = 2.623$ lb. per ft.

$w = 3.322$ lb. per ft.

$$q = \frac{p\,w}{v} = 235.0 \text{ ft.}$$

$$2\,k = 4276.57 \text{ ft.}$$

$$b = \frac{q}{2\,k} = 0.05495$$

By equation (**10**),

$m = 2132 + 545 - 17.0 - 0.2 - 0.4$

$= 2659$ ft.

By equation (**1**),

$d + q = 356 + 15 + 1$

$= 372$ ft.

The paper referred to above states that the deflection from the upper support is

$$9933.77 - 9615.44 = 318.33 \text{ ft.}$$

and that the deflection from the lower support is

$$9786.91 - 9615.44 = 171.47 \text{ ft.}$$

The difference between these deflections is 146.86 ft. which is less than the inequality in height of the supports, namely 185.5 ft. The difference of the deflections in the oblique plane should, however, be greater than 185.5 ft. In the appendix of the above paper, the equation $k_0 = k \cos\theta$ should be $k_0 = \dfrac{k}{\cos\theta}$, and formula (**3**) should be $k\left(\dfrac{1}{\cos\theta} - 1\right)$ instead of $k(\cos\theta - 1)$

$$\left[k = 185.5 \text{ ft. and } \cos\theta = \frac{2.623}{3.322}\right]$$

Example V. To illustrate the use of a table of hyperbolic sines and cosines,

Let $H = 31940$ in Example IV.

$$\frac{w\,k}{H} = \frac{3.322 \times 213\,8.28}{31940} = 0.222\,40$$

$$\sinh 0.222\,40 = 0.224\,24$$

$$\sinh \frac{w\,(k - n)}{H} = \frac{q\,w}{2\,H \times 0.224\,24}$$

$$= \frac{235.0 \times 3.322}{2 \times 31940 \times 0.224\,24}$$

$$= 0.054\,50$$

$$\frac{w\,(k - n)}{H} = 0.054\,47$$

$$n = 2138.28 - \frac{0.054\,47 \times 31940}{3.322}$$

$$= 1614.6 \text{ ft.}$$

$$m = 4276.57 - 1614.6 = 2662.0 \text{ ft.}$$

The value of T can now be calculated, and it will be slightly different from 33,000 since a value of H was assumed as part of the trial and error method.

The complete paper contains an appendix, here omitted, giving derivations of formulas.

7. Problem with cable loaded, Table VII, Transmission Line Design, by G. S. Smith, JOURN. A. I. E. E., Dec., 1925, p. 1352. See complete paper.

8. "Mississippi River Crossing," by H. W. Eales and E. Ettlinger, JOURN. A. I. E. E., Oct., 1925, first problem in the appendix. See complete paper.

LIGHTED STREETS

The lighting of public streets was originally a private undertaking, and the first city ordinance was passed in London in 1414, requiring all citizens to hang lamps before their doors at dark. Municipal street lighting originated in 1558 in Paris. Oil-burning lamps were used till 1813, when gas was adopted. In London electric street lighting is a development of the last forty years.

Discussion at Midwinter Convention

CARRYING CAPACITY OF 60-CYCLE BUSSES FOR HEAVY CURRENTS[1]

(LeClair)

New York, N. Y., February 9, 1926

H. B. Dwight: Usually it is found undesirable to place copper straps across lines of magnetic flux, but they should be placed parallel to the magnetic field as much as possible. Accordingly, where the phases are separated, I should suggest placing the straps parallel to the sides of an equilateral triangle, as in Fig. 1 of this discussion. If arrangement has not been tried out, it should be tested in comparison with the arrangements shown in Fig. 6 of the paper.

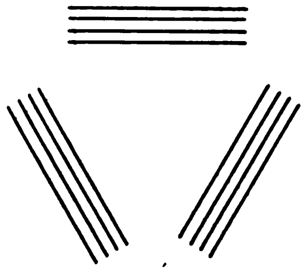

Fig. 1—Proposed Arrangement of Bus Bars

It is not always necessary to separate widely the conductors of different voltages. If the voltage is not over 250 volts, parallel straps connected + — + — etc., or A, B, C, A, B, C, etc., give extremely good results. In this way, currents up to 50,000 amperes at about 200 volts have been carried without trouble from skin effect, proximity effect, or reactance drop, as is well known in heavy electric-furnace work.

C. F. Wagner: The problem of current capacity of busses, by its very nature, is largely empirical. Mr. LeClair has contributed valuable experimental data to the general fund of knowledge on the subject.

I wish to question the statement made by Mr. LeClair on the fourth page of his paper which reads as follows: "In Mr. Wagner's article for single-phase busses he draws the curve from the outer edge to the center of the bar and assumes that the same condition holds from the center to the opposite edge of a bar. This is perfectly true in some cases but not at all true in others; and the electrical center, or the point of minimum current, in a bar may not be the physical center." While this statement is perfectly true, Mr. LeClair draws the inference that I would probably have made the same assumption, and, of course, been wrong, had I had a different set-up. The fact is that my assumption was correct for the particular case chosen, and for other cases in which the distribution was unsymmetrical I determined the distribution in the entire bar. Perhaps I am unjustified in interpreting the statement in this light and considering the matter merely one of an unfortunate choice of expression.

Regarding the use of magnetic steel for increasing the carrying capacity, the cut-and-try method of application does not appear to me to be an insurmountable difficulty. In connection with the magnetic balancers I should also suggest the use of radiating fins to carry away the iron loss in the balancers.

A. E. Kennelly: In the paper by Mr. LeClair, skin effect and proximity effect are fully referred to, but edge effect does not appear to be mentioned. If we take a flat strip of copper and allow it to carry direct current (the return conductor remote), we know, except for temperature variations, that the current density will be the same in all parts of the cross-section. However, when the strip carries an alternatng current, there may be negligible skin effect because the strip is thin. But the current density will not be uniform; it will tend to be much greater at the edges. That effect can be eliminated completely by bending up the strip edges so as to form a tube. The current density then becomes uniform everywhere, and the edge effect disappears.

That is a well known phenomenon and what we have in Mr. LeClair's paper is a mixture of edge effect and proximity effect. For example in the case of Fig. 2, you see that there is edge effect, but there are also proximity effects at the edges which are near to the other conductors. It is exaggerated, so to speak, by the vicinity of the neighboring conductors. But if the bus bars were removed or separated by a considerable distance, there would still be edge effect and the linear resistance of that conductor would be greater than that which would be obtained even though the skin effect were extremely small.

When the conductor is bent round, we tend to eradicate the edge effect, but we do not get rid of the proximity effect, and Curve 3, which represents Figure B, I think has an advantage in carrying capacity over Curves 1 and 2, corresponding to constructions where the edge effect is more pronounced. As Mr. LeClair has pointed out so well, it is very difficult to make measurements upon the resistance of bus bars owing to their size and cross-section. The linear resistance of the bars microhms per meter is so small that it is very often necessary, as he says, to infer the resistance from the temperature observations because where the point of resistance goes up including skin or edge effect, the temperature also will go up. On the other hand, we have to remember that all these effects of extra current density depend upon the resistivity and where the temperature goes up, the resistivity goes up too and modifies the effect. We thus get only an approximate measurement. The changes of temperatures involved will alter the distribution of current density.

S. W. Mauger: This subject began to interest the writer many years ago when rather exhaustive tests were made to determine a practicable and efficient method of carrying heavy currents. As Mr. LeClair states, the old standard of 1000 amperes per sq. in. and the practise of simply adding another parallel bar of copper to obtain increased capacity had become inadequate, especially for 60-cycle current. After trying many schemes, the writer suggested the plan now standard with the General Electric Company and referred to by Mr. LeClair in foot-note No. 5. One of the features of this scheme is the increased ventilation obtained and another is the so-called "box" arrangement which takes care of the skin effect. The first feature was very useful in carrying heavy d-c. currents and it was found that two sets of 4-in.-wide bars in vertical relation with 2-in. vertical space between them would carry at least as much current as one set of 10-in. bars, thereby saving 20 or more per cent of copper.

It may be inferred from Mr. LeClair's statement in the first paragraph on the fifth page of his paper that the General Electric Company scheme is suitable only for isolated phases and for currents not exceeding 7400 amperes at 60 cycles. Such an inference would be incorrect as the scheme allows the phases to be on close centers and by using wider bars with slightly more space between bars for increased ventilation, it has been possible to carry much greater currents than 7400 amperes, although this is as high as the published table goes. When there are long runs of bars for heavy a-c. current, transposition can be resorted to which overcomes any difficulty resulting from unequal distribution.

It would seem that with Mr. LeClair's proposed arrangement there would be difficulty in taking off connections from the bus bars except those of small capacity.

Mr. LeClair mentions the matter of permissible temperatures of bus bars. The rule of 30 deg. cent. rise is, of course, based on

1. A. I. E. E. Journal, January, 1926, p. 9.

an ambient temperature of 40 deg. cent. to give a maximum total of 70 deg. cent, the total being what we must have in mind. Naturally, if the ambient is lower, the rise may be higher, but for a standard rule, it is not safe to consider varying ambient temperatures. We must also remember that switching devices are designed on the basis of the A. I. E. E. Rule of 30 deg. cent. rise and bars connected to these devices must not have a higher temperature. Oxidation is much more rapid above 70 deg. cent. than below it, and it does not seem wise to consider an ambient of less than 40 deg. cent.

E. G. Bern (communicated after adjournment): In Mr. LeClair's contribution is a statement from which may be inferred that 7400 amperes is the feasible limit for a 60-cycle, three-phase bus with double-tier vertical laminations.

When dealing with currents of such magnitudes, the question of supporting the bus structure and its connections to withstand abnormal magnetic stresses usually demands a more liberal spacing of the bus phases. This is, of course, usually limited by available space, and by the permissible reactance, as mentioned

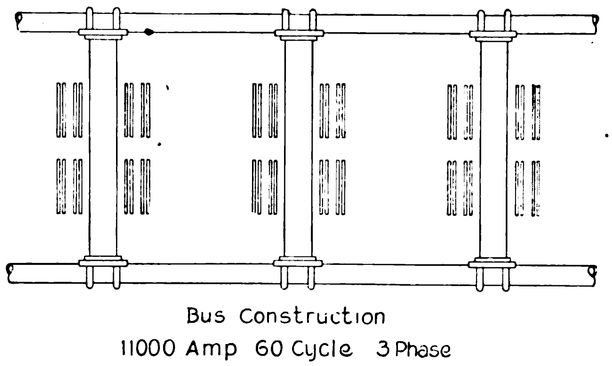

FIG. 2—BUS CONSTRUCTION, 10,000-AMPERE, 60-CYCLE, 3-PHASE

by Mr. LeClair. By properly proportioning the design, it has been found entirely practicable to use this construction for very much higher capacities without neglecting any of the above factors, and at the same time to make connections in a convenient manner. Fig. 2 herewith shows this construction successfully applied to a bus of 11,000-ampere capacity, which, however, should not be considered as the practical limit. Under some conditions a transposition scheme of equalizing the load in the different sections of the bus has worked out to good advantage without undue complications.

T. G. LeClair: At first thought it would seem undesirable to put copper straps across the lines of magnetic flux, and it would appear advisable to set up the three-phase bus with the bars arranged as shown in Fig. 3 herewith. However, after a

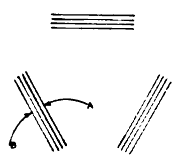

FIG. 3

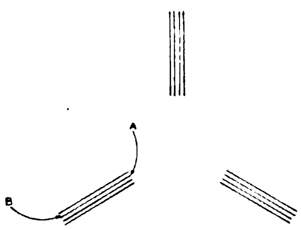

FIG. 4

careful examination of test results, we come to the conclusion that, with this arrangement, the ratio of currents at points A and B is practically the same as the ratio of currents at points A and B in Fig. 4 herewith. The particular case on which we have the most information from our test results is a bus consisting of four bars of 8-in. by ¼-in. copper, in arrangements which approximate Figs. 1 and 2. In this case, it appears that the current at point A is nearly three times the current at point B for either arrangement. This means that with the arrangements shown in Fig. 3 most of the current will be carried by the bar facing the center of the triangle and the other bars will carry very little. In Fig. 4, the outer edge of each of the bars will be carrying much less current than the inner edge, but they will reduce the temperature because they act in the nature of radiators, which is not the case with the unused copper of Fig. 3.

I do not wish to convey the impression that Mr. Wagner was making a mistaken assumption in his previous article. Some warning is, however, necessary because the majority of busses will be set up on an arrangement wherein the distribution of current will be unsymmetrical.

On the matter of balancing currents by means of magnetic balancers around the bars, there are two different points of view to take. One is that of the manufacturer of switchboards who has factory conditions to deal with and close contact with the men doing the work. In this case magnetic balancers may possibly be used to advantage. Out in the field we have different conditions, and usually the class of men doing the work is one unfamiliar with what is required. The contact between the engineer and the construction men is not so close, and the expense of the cut-and-try balancing is altogether out of reason. Some other method of balancing is much less expensive and more satisfactory for all cases.

Dr. Kennelly has brought up an important point in the use

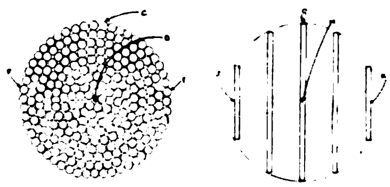

FIG. 5

of the terms "edge-effect" and "skin-effect." The difference in the significance of these terms should be made more clear. Fig. 5 herewith will probably explain my reasons for using the term skin-effect rather than the term edge-effect. This figure represents a single-phase circuit in which one of the busses is made up of laminated copper bars and the other of copper strands in the form of the cable. In the left-hand bus we all agree that due to skin-effect the current in the outer surface at C is much greater than the current at the center, D. Due to proximity effect the current at the point E is greater than the current at the point F, and by following the same reasoning in the right-hand bus, which, for the sake of clarity, I have made circular, we should still say that skin-effect is the cause of a greater current density at G than at H, and that proximity effect is the cause of the greater current density in bar J than in bar K. Now, if we arbitrarily take out the center bar of this bus and consider it separately we say that it is no longer skin-effect but edge-effect which causes the greater density at the point G than at point H. As I see it, edge-effect is a special application of the word skin-effect. Skin-effect should include any uneven distribution of the current in a bus or cable due to the flux created by the current in this bus, while proximity effect should include any uneven distribution caused by flux in an adjacent conductor. Regardless of the shape of the conductor, whether it be round, flat, or of any other shape, the uneven distribution due to the current in itself then causes skin-effect, and changing the shape changes the amount of this effect but does not change it from one type of effect to another. I do not wish to state that this is the best nomenclature to use for all cases, but I think it is time that we settle upon one definition by which we could all understand each other.

We did not make any test on an arrangement of bars exactly like that described by Mr. Mauger and by Mr. Bern, but it appears that they would have some trouble due to proximity

effect unless the busses were spaced a reasonable distance apart. Of course, so long as we can increase the spacing between phases and between individual bars of the phases, we may increase the carrying capacity indefinitely. When we come to the greater current, however, the weights of copper to be used become of considerable importance, and it becomes advisable to study carefully which arrangement will give the best copper economy. Perhaps it will pay to use a slightly more expensive support in order to use less copper. The type of construction illustrated in Mr. Bern's discussion is very interesting, but unfortunately no dimensions are shown with which to make comparisons of the copper economy to be obtained with this or another arrangement.

Mr. Mauger's points on the matter of permissible tempera-

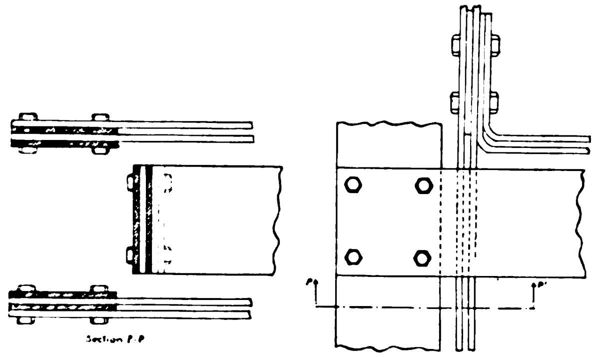

FIG. 6

ture rise are very well chosen. When a bus is to be connected to some switching device designed for a 30-deg. cent. rise, it is obvious that the bus copper must operate at the same, if not at a lower, temperature. It is impossible to make contacts for use in switching devices as good as a stationary bolted contact, and they must be protected. There are, however, a great many places where a bus is not connected to switching devices, for instance, between a transformer and rotary converter, and in such cases experience has shown that considerably higher temperatures may be maintained without any trouble from oxidation.

Fig. 6 herewith shows a sample top on a bus for high capacity. Tops in other directions can be made with equal ease.

REFRACTION OF SHORT RADIO WAVES IN THE UPPER ATMOSPHERE

(BAKER AND RICE)

NEW YORK, N. Y., FEBRUARY 9, 1926

A. E. Kennelly: The paper is very timely and interesting because so much attention has been drawn in recent months, not to say years, to the marvelous properties of very short waves. The paper makes a definite and very reasonable attempt to explain some of those properties. The direct wave dies out at a relatively short distance from the sending station and then nothing more is heard of it or received from it until it has traveled a relatively great distance. That phenomenon repeats itself at least once.

Here we are between certain rival theories of refraction and reflection from effects produced in the upper atmosphere at a distance at which we can only guess. It is very remarkable that we know so little. We are necessarily ill-informed concerning the conditions that exist in the atmosphere at a distance of, let us say, fifty-kilometers above our heads, while fifty kilometers along the ground we can cover in an automobile in an hour or less.

The wonderful thing is that we are able already to form opinions, such as are expressed in the paper, as to what does take place in that region above our heads which is so near and yet so far. The promise is very brilliant that we shall be able to learn from radio observations, in the not far-distant future, the electrical properties of the atmosphere at distances from ten to 100 or more kilometers above the earth, and it will be very surprising if the information thereby gained does not have a marked influence upon weather forecasts at least in the region up to twenty or thirty kilometers above the surface.

Personally, I think it is early yet to form hard and fast opinions or to make very definite conclusions as to just what these phenomena are. We know that there must be refraction. We know that there must be rotary polarization and we also know that there must be reflection. Probably all three of these things occur simultaneously. I think we must therefore retain an open mind for the present—until more information can be secured by observation.

W. B. Kouwenhoven: The author's conclusions are similar to those of Dr. J. Zenneck who published a paper on this subject in "Elektrotechnik und Maschinenbau", Vol. 43, p. 593 and 612, 1925. Dr. Zenneck concludes from observations that radio waves enter the upper atmosphere and that these waves may come back to earth at some distant point because of refraction.

Radio transmission takes place by means of ground waves and by means of waves that pass through the upper atmosphere. In the case of short waves the ground radiation is rapidly absorbed as pointed out by the authors, while the absorption is much less for long-wave transmission.

The electric field produced by a radio wave in the upper atmosphere sets the ionized particles in motion. In the case of long waves the mean free path of the ionized particle is short compared to the wave length, and collisions occur. The energy is therefore absorbed and very little if any of the wave is refracted back to earth. In the case of short waves the absorption is much less in the upper atmosphere, and the wave is refracted and reaches the earth again at some point distant from the transmitter.

M. I. Pupin: Mr. Einstein would probably say that you are wrong when you say that the wave can be propagated by a velocity greater than the velocity of light wave. What would you answer if he did object?

W. G. Baker: I think it is one of the cases of distinction between the velocity of a group of waves and the phase velocity.

With reference to the question of reflection versus refraction raised by Dr. Kennelly, I believe that most of the people who talk about reflection from the Kennelly-Heaviside layer use it as an approximation; they do not wish to bother with the complexity introduced by refraction. Actually the transition from the neutral to the ionized medium must be gradual, and will therefore not be sufficiently abrupt to produce appreciable reflection except on the very long wave lengths. Unless the ionization changes by a large amount in a distance comparable with the wave length of the radio wave no appreciable reflection can occur, but electron refraction may easily bend the wave back to earth.

Rotary polarization and other effects due to the action of the earth's magnetic field on the electron motion will require consideration in a complete theory of the propagation of radio waves as Dr. Kennelly has pointed out. We have evaded that phase of the question as well as we could by dealing only with the case of short waves where the earth's magnetic field cannot have much effect. There is a certain resonance frequency of the electrons produced by the earth's magnetic field which corresponds to a wave length of about 214 meters. If we are working well above that frequency the effect of the earth's magnetic field on the motion of the electrons can be neglected without serious error.

We wish to thank Dr. Kouwenhoven for calling our attention to Dr. Zenneck's paper, and we are interested to hear that his conclusions concerning the propagation of short radio waves are similar to ours.

Recently there has been a good deal of surmising, on the part of radio men, as to the height of the ionized medium. Obviously we cannot speak of the height of the actual medium since we do not know where to say it begins, where the maximum is, or where

it ends. The effective height of the layer as judged by a sharp reflection theory will, of course, vary with the wave length, distance between transmitter and receiver, etc. On short waves we require a relatively large amount of ionization to bend the ray back to earth. Therefore the ray will penetrate deep into the ionized medium before it returns to earth. Here the apparent height of the layer as judged on the reflection theory may be very great. On longer waves a smaller ionization density is sufficient to bend the same ray back to earth so that the depth of penetration will be less and the apparent height of the medium will be lower than that estimated from the short-wave experiments. A further difference is brought in by the effect of the earth's magnetic field.

CIPHER PRINTING TELEGRAPH SYSTEMS[1]

(VERNAM)

NEW YORK, N. Y., FEBRUARY 9, 1926

L. F. Morehouse: This work on the development of arrangements for secretly transmitting telegrams was done during the War under the direction of Mr. Gherardi. The problem was to see if a simple and effective means that would be entirely secret could be devised for handling telegraph business. The method used should be such that an enemy could not decipher the messages even if he could capture the mechanism used, thoroughly understand its operation, and obtain contact with the line circuits.

A large number of systems were studied. Of the many suggestions made, the most promising were set up and tested out in the laboratory. Various schemes for breaking up the dots and dashes were proposed, but in the last analysis all were found to be unsatisfactory. We found in studying this problem that many methods had been devised. Where mechanical devices were used, they involved, sooner or later, a repetition of the key. If there is such a repetition, the messages can be deciphered and the real secrecy has disappeared.

Printing telegraph methods were found to be more promising. The key in the form of a paper tape or resulting from the combination of two such tapes can be made as long as desired without repetitions with the result that the cipher becomes impossible to break. For ordinary business purposes, however, a simpler cipher using a key that might repeat at infrequent intervals would be entirely practical and sufficiently secret.

P. W. Evans: None of the present military codes or ciphers offers complete satisfaction in its security, speed or simplicity. The Signal Corps of the Army will appreciate any assistance or suggestions which may be offered on this important phase of our national defense problem.

CONCLUDING STUDY OF VENTILATION OF TURBO-ALTERNATORS MULTIPLE PATH RADIAL SYSTEM[2]

(FECHHEIMER AND PENNEY)

NEW YORK, N. Y., FEBRUARY 9, 1926

S. L. Henderson: This paper covers the results of a considerable amount of experimental work done subsequent to the papers written in 1924 by Mr. Fechheimer and Mr. Bratt. As the later tests were made on stationary models, the constants could be determined more accurately than on a moving model, and the accuracy of the equations is demonstrated in the comparison between tests and calculations as given in Figs. 13 and 14. The results of this work are being used in the design of turbine generators with considerable practical benefit. On one design, in particular, it was possible to shorten the machine considerably through the use of these equations.

The choice of the number of vents and the division of these vents into intake and outlet zones is thus made relatively simple. The number of vents is determined by the velocity of air required in the radial vents to obtain satisfactory cooling on the sides of the vent spaces. The number of vents is also determined by the width of the iron package between vents which can be allowed without having an excessive temperature drop in the package. Several trials, as in most questions of design, must be made in order to obtain the best proportions. After the number of vents has been decided upon, the division of these vents into intake and outlet zones can be carried out through the use of the equations in this paper.

1. A. I. E. E. JOURNAL, February, 1926, p. 109.
2. A. I. E. E. JOURNAL, April, 1926, p. 347.

A NEW WAVE-SHAPE FACTOR AND METER[1]

(DOGGETT, HEIM, AND WHITE)

NEW YORK, N. Y., FEBRUARY 11, 1926

J. J. Smith: When considering the effect of harmonics, it is perhaps well to divide them into different classes: (1) those which may give rise to resonant conditions or large circulating currents on the power circuit, (2) those which may give rise to telephone interference, (3) those which may give rise to radio interference, (4) those which may give rise to any other type of trouble that may be discovered. Let us consider, for instance, the case of telephone interference, as somewhat similar remarks will apply to other types of interference. In the telephone-interference-factor meter an attempt was made to weight the various harmonics in accordance with the experimental data available as to the interfering effect of each harmonic. A special type of network was designed to do this, and the impedance characteristics of such a network, which is used in the telephone-interference-factor meter, can be varied, within certain limits at least, to correspond with any new data which may show that it is desirable to weight the harmonics differently. In the method suggested by Messrs. Doggett, Heim, and White, no such adjustment is possible.

The method proposed may also be compared with a method such as the use of the telephone-interference-factor meter by noting the ratio between the maximum and minimum values obtained on machines in actual operation. The T. I. Fs. given on the machines of Table I of the 1919 Report of the A. I. E. E. Subcommittee on Wave Shape Standards vary from 11 to 550, while the ratios given by Messrs. Doggett, Heim and White vary from 2.746 to 3.724, giving a ratio of 50 to 1 with one method and 1.35 to 1 with the other.

It is well to remember that direct-current and other types of machines produce harmonics, and that it is undesirable to have a wave-shape meter which will apply to three-phase systems only. Also, in certain cases of telephone interference which have occurred on systems with the neutral grounded, it is the wave shape from line to neutral and not from line to line which is of interest.

I would like to inquire if the authors found any difficulty in making measurements on systems on which there were large variations in load. In making measurements of harmonics on such systems we have found that the magnitude of the harmonics varied with the load over short periods of time (in the order of one or two seconds). I wonder if fluctuations of this nature would not make it impossible to get a consistent curve from which to pick the maximum as in Fig. 5.

It may be well to consider the first paragraph of the paper by briefly considering what accuracy may be obtained in analyzing a wave obtained with the oscillograph. Let us assume an oscillogram has a maximum ordinate of 2 in. and that the line is of average thickness, which, in order to get a good film, may be 1/20 in. or less. Using a wave micrometer ruled in fortieths of an inch there is no reason why the values of the ordinates should not be measured to within half of one division or 1/80 of an inch. This is an error of 1 in 160 or let us say 0.7 per cent. As the probability is that all these errors will not be in the same direction, it would appear more proper to take, perhaps, half of this, or say 0.35 per cent, as the probable error in measuring

1. A. I. E. E. JOURNAL, February, 1926, p. 131.

the oscillograms. Using this figure the maximum deviation in the first case quoted by the authors from the *Revue Générale de l'Electricité* should have been between the limits 2.6 per cent and 1.9 per cent or the maximum value is in excess of the average by about 15 per cent of the average value, and correspondingly less in the other case.

The large discrepancies quoted by the authors may be due to the inherent difficulty in superposing the equivalent sine wave of equal length in such a manner as to give the least difference, as required by A. I. E. E. Standards, 1922, No. 3274. It would be impossible, however, to explain them without making a detailed study of the calculations which were made in each case. Also, a comparison of the T. I. Fs. calculated from oscillograms and those taken direct with the T. I. F. given in the 1919 Report of the Subcommittee on Wave Shape of the A. I. E. E. Standards Committee, will show that the large discrepancies quoted by the authors cannot be the general rule. Furthermore, it should be remembered that by using a filter or some such device for stopping off the fundamental, a very much higher degree of accuracy in measuring harmonics may be obtained with the oscillograph.

F. K. Brainard: It is generally recognized that sine waves in a-c. apparatus are desirable and since commercial alternators frequently have voltage waves which differ considerably from sines, it would be highly desirable to have a wave-form factor which could be easily determined and which would be a measure of the detrimental effect resulting from a distorted wave. Various factors have been suggested including the following: (a) form factor, (b) peak factor, (c) telephone-interference factor, (d) differential distortion factor, (e) integral distortion factor, (f) curve factor, and (g) harmonic factor. None of these appears to be entirely satisfactory, partly because the detrimental effect of a distorted wave depends upon the trouble under discussion and partly because some of the above factors are not readily measured. If telephone interference is being considered, the telephone-interference factor is undoubtedly the proper criterion to apply, but if the core loss of transformers is under consideration or the dielectric strength of insulating material is being measured, it is quite obvious that some other factor should be used.

While this new factor gives the greatest weight to the seventh harmonic, there is not an exceedingly great variation in weight given between any of the harmonics, and in this respect it resembles the "harmonic factor" which is defined by Bedell as the ratio of the effective value of the harmonics to the effective value of the fundamental, but is superior to it in that it is very easily measured, although it is applicable to three-phase circuits only. Possibly an Institute rule using both the telephone-interference factor and this new factor specifying limiting values of both, would be desirable. In that case, the telephone-interference factor would limit possible telephone interference and this new factor would limit other troubles due to the presence of the lower harmonics.

The authors are to be complimented for the development of a wave-shape factor which gives promise of being a valuable one. The question now seems to be the determination of the value of this factor as a criterion for the comparison of voltage waves.

C. W. Bates: The paper contains a satisfactory analysis of the proposed method which should give reasonably correct values for the harmonics present, when the conditions are ideal. The paper does not, however, contain any investigation of the errors which may arise from such sources as the use of voltmeters containing some inductance, condensers whose loss is not negligible, and unbalanced line voltages. The entire theory of the proposed method rests on the assumption that when no harmonics are present the potential of the neutral point of the circuit used is displaced to such a point that the voltmeter readings have the ratio of 3.732. This is true only when both voltmeters are absolutely non-inductive, the condensers are absolutely without loss, and the voltages of the three phases are absolutely equal.

If it is assumed that each voltmeter has an inductance L in addition to its resistance R and that the condenser has a loss represented by its equivalent series resistance r in addition to its capacity c the ratio of the voltages indicated with exactly balanced three-phase line voltages will be approximately equal to $3.732 \left[1 + \sqrt{3} \left(\frac{\omega L}{R} - r \omega c \right) \right]$ when $R = \frac{1}{\omega c}$. The fractional error is then equal to $\sqrt{3} \left(\frac{\omega L}{R} - r \omega c \right)$ or practically equal to the difference of the angles of defect (from the ideal) multiplied by $\sqrt{3}$. The approximation in this result is due only to considering that the angles of defect are equal to their respective sines and tangents and that the cosines are equal to unity. These approximations are entirely justifiable for any voltmeters or condensers whose use could be considered.

The importance of these errors may be judged by considering two examples:

Voltmeters: $R = 1000$ ohms, $L = 53$ millihenries

$$\frac{\omega L}{R} = .02 \text{ at 60 cycles,}$$

$$\text{Condenser: } \frac{1}{\omega c} \text{ 1000 ohms, } r = 50 \text{ ohms}$$

$r \omega c = 0.05$ (3 deg. approximately)

The fractional error in the ratio will be equal to $\sqrt{3}$ (0.02 − 0.05) = − 0.052 or − 5.2 per cent. (By the exact expression this is 4.9 per cent, thus justifying the approximate expression given for the error). If the voltmeter inductance is 5.3 millihenries as may occur in the best modern dynamometer voltmeters and the condenser phase angle is 17 min. as might be found in a good mica condenser, each angle of defect is one-tenth the former value and the error is 0.52 per cent. Even this error is quite appreciable in the calculation of the method shown in the paper. Fortunately the errors due to inductance and to condenser loss are opposite in sign and therefore, by a suitable adjustment, they may be made to neutralize each other.

The error due to unbalanced three-phase voltage may be much greater and moreover varies continually with line-voltage fluctuations. This error may be readily analyzed by the use of the symetrical coordinates developed by C. L. Fortescue. By this method any unbalanced system of three-phase voltages is resolved into two balanced systems of opposite phase rotation. Since the direction of shift of the potential of the neutral point is determined by the phase sequence, it may be readily appreciated that voltages of opposite phase sequence simultaneously impressed will not result in the ideal ratio of voltmeters of 3.732, even if no harmonics are present.

The analysis of this error is too complicated to be presented in a brief discussion but the results of the analysis may be illustrated numerically. Let m be the degree of unbalance expressed by the ratio of the negative-sequence voltage to the positive-sequence voltage. This is roughly equal to the greatest deviation of any one of the three voltages from the mean. The error due to unbalance will depend not only on this ratio but on the phase angle between the two oppositely rotating components noted with reference to any instant. Accordingly the limits of the error are given in the first four lines of the tabulated illustrations below. Since the authors state that any small error due to voltage unbalance may be eliminated by stepping the line terminals around the circuit terminals and averaging the results obtained by the use of each of the three connections, a comparison of the error of this average is given also, in the last four lines.

Two numerical examples are given in the table, one corresponding to a 10 per cent unbalance such as would result from

voltages of 90, 105, and 105, or to 91.3, 100, and 108.7, each of these groups being approximately respective phase voltages which would result in a 10 per cent negative-sequence voltage, the difference in line voltages resulting in a different phase angle. The other example is based on a 1 per cent unbalance due for example to voltages of 99, 100.5 and 100.5. In general the unbalance will be between these limits, as the first corresponds to very poor service voltage while the second will be difficult to maintain even under laboratory conditions. From the figures given in the table it is seen that the results of a single pair of readings are entirely untrustworthy even with very well balanced voltages, and that good balance is necessary in order to secure reliable results, even if the terminals are stepped around. It may be noted that the average ratio is always high.

Negative-sequence Voltage m	10 Per cent	1 Per cent
Maximum ratio of readings	6.04	3.882
Error of maximum, per cent	62	4.0
Minimum ratio of readings	2.68	3.593
Error of minimum, per cent	29	3.7
Maximum average ratio	4.022	3.7335
Error of maximum average ratio, per cent	7.8	0.043
Minimum average ratio	3.755	3.7333
Error of minimum average, per cent	0.6	0.033

The formula from which these results were calculated is included without derivation, for the sake of completeness.

Ratio of voltmeter readings

$$= \sqrt{\frac{A + \frac{m^2}{A} + 2\,m\cos(60° + \alpha)}{\frac{1}{A} + A\,m^2 + 2\,m\cos(60° - \alpha)}}$$

$$= A\sqrt{\frac{1 + \frac{m^2}{A^2} + \frac{2\,m}{A}\cos(60° + \alpha)}{1 + A^2 m^2 + 2\,A\,m\cos(60° - \alpha)}}$$

where

A = 3.732,

m = ratio of negative - to positive-sequence components,

α = angle between components in the reference phase which is taken to be that across which the voltmeters are connected.

L. A. Doggett: We have been very pleased to have Mr. Bates attack this problem from his own angle of approach and not only check our (2 plus $\sqrt{3}$) but also show us the method of eliminating the errors due to the inductance of the voltmeters and the resistance of the condenser.

So far as the effect of unbalance is concerned we would like to submit for comparison with Mr. Bates' figures the data for one test. With balanced voltages the wave-shape factor for a certain wave was 3.693. With the same wave and with voltages of 100, 97, and 97.5, the wave-shape factors, as the terminals of the wave-shape meter were stepped around, were 3.54, 3.95, and 3.60, averaging 3.697. Experimental study of the effect of unbalanced voltages indicated that useful results were obtainable up to 2 per cent unbalance.

Mr. Smith has brought out some of the contrasts between the telephone-interference-factor meter and the present wave-shape meter. He has also covered the question of the accuracy obtainable from oscillograms. As the wave-shape meter is not a telephone-interference-factor meter, no discussion is devoted to their comparisons. Mr. Smith has described what might be called the utmost accuracy obtainable from oscillograms. The results cited in our paper are considered fair samples of every-day accuracy obtainable. As to the effect of load pulsations, we find no difficulty in getting results while undergraduate laboratory work is in full swing.

In concluding the discussion, it should be pointed out that the instrument, made accurate in the manner described by Mr. Bates, is particularly well adapted to shop testing of three-phase alternators, which have three exactly balanced voltages. Like the telephone-interference-factor meter, this meter has its distinctive characteristic. While the T. I. F. meter penalizes the 17th and 19th harmonics for 60-cycle alternators, the present wave-shape meter penalizes harmonics of phase rotation opposite to that of the fundamental.

Lastly, we find this meter admirably suited for showing and recording changes in alternator wave shape as the character of the load changes. Functioning thus, the wave-shape meter has brought to our attention some rather remarkable facts.

THEORY OF THE AUTOVALVE ARRESTER[1]

(Slepian)

New York, N. Y., February 9, 1926

K. B. McEachron: The comparison made by Dr Slepian between the energy to be handled by the valve-type arrester and the arc-resistance type for equal protection is important. With the arc type, if the flow of system energy following the impulse is not to be excessive, it is necessary to employ considerable series resistance with the result that the arrester's ability to discharge the impulse is seriously impaired. To prevent system current from following the discharge of an impulse through an arrester, it is necessary that the voltage across the arrester, as the impulse ceases, be equal to or greater than the system crest voltage. The modern valve-type arresters are designed to operate on this principle.

In his discussion of the glow discharge Dr. Slepian states that with an electrode spacing of slightly less than 0.001 cm. a voltage of 350 volts is required to maintain the glow. The theory given states that the voltage required to start the glow is less than 400 volts and the current density in the glow is about 10 amperes per sq. cm. until the disk area is covered, after which the gap voltage increases with increasing current becoming 387½ volts with a current density of 25 amperes per sq. cm. Since the effective area inside the mica spacer is of the order of 15 sq. cm. the voltage drop across the air-gap based on Dr. Slepian's figures should be constant at 350 volts with a current of 150 amperes or less increasing to 387½ volts with a current of 375 amperes.

A series of tests covering a period of two years made on these disks have led the writer to suspect that the voltage across the air gap during a discharge was not maintained at approximately 350 volts during a discharge.

It was found, for instance, that with 280 volts (crest) applied that current would follow an impulse so timed as to strike near the crest of the 60-cycle wave. This seemed to indicate a voltage much less than 350 volts following the impulse since 280 volts was sufficient to cause current flow. With steep-wave-front impulses, applied voltages as high as 1200 volts were indicated across a single gap which showed that the breakdown might be more than three times the glow voltage.

More recently we have been able, using the cathode-ray oscillograph to determine accurately the volt-ampere characteristic of disks with spacers even when the discharge lasted but a few millionths of a second. With this oscillograph photographs have been taken showing wave fronts of less than a microsecond duration with oscillations whose frequencies were of the order of 100,000,000 cycles showing so plainly that their wave shape could be determined. With this instrument, three volt-ampere curves were taken on a stack of sixteen disks with fifteen mica spacers, each different volt-ampere curve having a different crest value of current. The disks were then coated with copper on each side and stacked up without the spacers and a volt-ampere curve taken from which the voltage drop in the disks was determined for any particular value of current. By this means it was

1. A. I. E. E. Journal, January, 1926, p. 3.

found that the average resistance of a single disk was 3 ohms at 10 amperes and 2 ohms with 150 amperes flowing. With 450 amperes the average disk resistance is 1.1 ohms.

The volt-ampere curves of the air gaps for the three different currents were obtained by subtracting the disk volt-ampere curves from the disk-plus-spacer volt-ampere curves. Using Dr. Slepian's statement that with current densities less than 10 amperes per sq. cm. that the area of discharge is proportional to current it is clear that the disk voltage is constant for currents less than 150 amperes, and is numerically equal to the voltage when 150 amperes is flowing through the disk. Using this method of calculation of disk resistance the curves shown in Fig. 1 herewith were obtained. The theoretical glow voltage according to Dr. Slepian is also given. It is to be noticed that a voltage of from 600 to 700 volts was required to start current flow through the gap with the particular wave front used. As

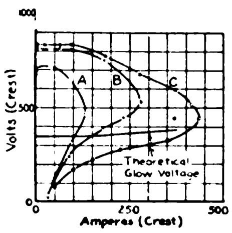

Fig. 1

the current increases to about five amperes the voltage rises to 710, 810, and 830 respectively for the three current waves. With both of the higher current curves the voltage tends to remain constant at about 800, decreasing, however, for currents in excess of about 100 amperes. When the current begins to decrease the voltage falls off until at low current values the voltage is less than 100 volts which seems to indicate the formation of an arc. It must be remembered that the shape of these curves is dependent on the amount of resistance material involved at any particular current and if the author's theory of the spreading of the discharge is incorrect then the values of resistance which have been used are not correct. The volt-ampere curve obtained across the stack of disks is a true characteristic, and the volt-ampere relations in the gap will be those given if the proper correction has been made for the resistance of the disks.

If the discharge had the characteristics attributed to it by Dr. Slepian, the voltage across the gap would be represented by 350 volts plus the additional 37½ volts as the current increased to 375 amperes. With decreasing current the relation between the voltage and the current should still be the same so that the volt-ampere curve will be represented by a single line instead of the loop which is actually found.

With all three volt-ampere curves shown, the applied voltage rose to the gap breakdown voltage in a time close to one microsecond, while the respective currents rose to their crest values in 20, 35, and 48 microseconds. From these results it would seem that the time-current relations are important in the gap discharge for with the same current, different voltages were found on each of the three different volt-ampere curves. I believe that several factors have been left out of this formula.

I have been unable to check the curves shown in Fig. 9 of this paper using this formula (corrected). I should appreciate an explanation of the formula by Dr. Slepian, and should like to know how it is plotted to get these curves.

The effect of rate of voltage application on the breakdown of the gap was not discussed by Dr. Slepian but, as with any phenomena involving ionization, time is required for the gap to reach breakdown conditions. The results of tests on sixteen disks with mica spacers are as follows:

Time-Voltage Relations of Autovalve Gap

Time to Rise to Breakdown	Gap Voltage (Crest)
1.5 microseconds	665 volts
2.5 "	530 "
30 "	390 "
60 cycles	400 " variable

These results show that in discussing the characteristics of the discharge between two electrodes as in the autovalve gap, the effect of time both before the discharge begins and after it has started cannot be neglected.

The test results given in this discussion show that discharges having quite different volt-ampere characteristics from those given by Dr. Slepian are actually to be found in the air gap between autovalve disks. These results are useful not only in connection with the theory of the glow discharge but also are of importance when applied to the actual arrester performance in service. So far as I know these results are the first to be actually obtained under impulse conditions where the time, voltage, and current relations are fully determined.

On the sixth page Dr, Slepian gives a formula for the determination of the temperature rise at the surface of a disk when a certain amount of energy is liberated at the disk surface.

J. Slepian: The paper which I have presented was written over a year ago, and in that time there have been some important additions to our knowledge of the theory of the autovalve arrester which I would like to mention briefly before taking up Mr. McEachron's welcome account of his researches.

The autovalve arrester in its functioning depends on the well established fact that a heavy current discharge between electrodes of resistivity of the order of ten ohms per cu. cm. remains in a high-voltage form for a relatively long time, whereas such a discharge between metal electrodes changes into a low-voltage form within less than a microsecond after its initiation. These two forms of discharge have long been known as glow and arc, respectively, and their properties, at least in the steady state, are fairly well known. As stated in the paper, it is generally believed that the arc discharge takes place when the cathode is hot enough for thermionic emission. Then, a difficulty arises because it appears that the density of energy input into a metal cathode surface from a glow is not great enough to heat a spot on the electrode to a high temperature in a time so short as a microsecond. It seems necessary to assume almost immediate convergence of current into some spot before that spot has become hot. The resistivity of the autovalve electrodes opposes this concentrating tendency.

Until recently, it was assumed that this concentration of current took place at inhomogeneities of the metal surface. Now, however, a new theory has been developed which seems to fit the facts quantitatively, and eliminates the need for inhomogeneities to start the current concentration. This theory is that in the heavy-current glow discharge at atmospheric pressure, the air immediately adjacent to the cathode becomes heated almost immediately to a temperature high enough for thermal ionization, and with metal electrodes this thermal ionization causes the glow to be unstable and to converge into an arc. Further particulars may be found in a paper which appeared in the *Journal* of the Franklin Institute for January, 1926.

Another advance which has been made is in our understanding of the factors which determine the rate of spreading of the discharge in the autovalve gap from its point of initial breakdown next to the mica spacer. We have known, from our tests on the protective valve of the arrester, that this spreading is very rapid, but now we have information as to the influence of electrode spacing, and also know how this factor influences the volt-ampere characteristic for impulse voltages.

The points of lowest breakdown in the autovalve gap are next to the mica spacer, the breakdown voltage there being usually less than 400 volts. If the mica spacer were not there,

the breakdown voltage would be much higher, depending on the width of the gap, and for a 5-mil gap would be about 1000 volts. Now it is clear, that with such a 5-mil autovalve gap, if 1000 volts is applied, the discharge does not need to start at the mica, but the gap will break down at all points together. For such a voltage then, the discharge may be said to spread instantly over the electrode surfaces. For a lower voltage the rate of spreading while still very fast will no longer be instantaneous. Since the rate of spreading of the discharge determines the rate at which

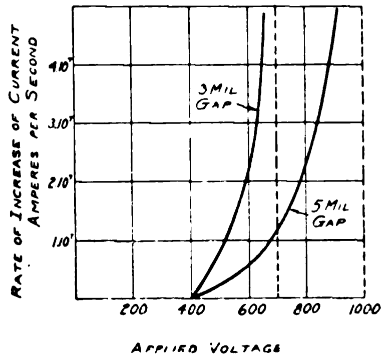

FIG. 2

the discharge current builds up in the arrester, we may expect a curve such as in Fig. 2 herewith, with an asymptote at 1000 volts for the 5-mil gap. For a 3-mil gap the asymptote will be at about 700 volts.

When an impulse current is sent through an autovalve gap, the total voltage while the current is increasing is determined by the rate at which the current is increasing. If the current is increasing slowly, the voltage will be about 400, but if the current builds up instantly the total voltage may be 1000 for

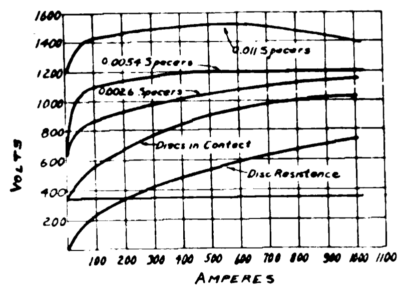

FIG. 3

the 5-mil gap and 700 for the 3-mil gap. The total voltage here includes not only the discharge voltage but also the resistance drop through the disks.

These ideas are largely the result of a study by G. F. Harrington of the impulse volt-ampere characteristics of arresters with different sizes of spacers. These were taken by determining the maximum volts and maximum amperes in a discharge by means of sphere gaps. Fig. 3 shows results obtained. It is evident that with the disks in contact, the voltage obtained corresponds to the steady-state glow, but that when the disks are separated, there is an additional rise in voltage which is necessary to cause the discharge to spread sufficiently rapidly over the disk faces.

The lowest curve in Fig. 3 is the impulse volt-ampere curve of the disk resistance, obtained by copper-plating both faces of each disk and stacking them in series. On subtracting this curve from the others in Fig. 3 we get the curves of Fig. 4. Disks in contact give a curve which lies very close to the 350-volt line, but with increasing thickness of spacer, the voltage on impulsive discharge increases rapidly.

Coming now to the results which Mr. McEachron has obtained with the cathode-ray oscillograph and which are shown in his Fig. 1, we see that as regards the magnitudes of the voltage for increasing current, there is general agreement with the results obtained by Harrington and shown in Figs. 2 and 3. It would seem from these curves that Mr. McEachron used spacers at least 0.005 in. thick, which is the upper limit for spacer thickness tolerated in the commercial autovalve arrester. With thinner spacers even better performance would be obtained. However, I believe that because of the incorrect value which he has taken for the ohmic drop through the disks, the lower parts of Mr. McEachron's curves are in error.

First of all, the current density in the discharge is only approximately 10 amperes per sq. cm., and may actually be somewhat larger. It is probably also not an absolute constant, and may vary with slight changes in disk composition. But

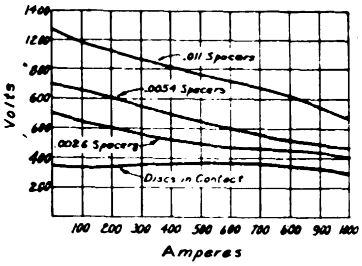

FIG. 4

taking this value, although the whole disk area is not uniformly covered for current less than 150 amperes, when the current decreases to less than this value, the discharge breaks up into a large number of very small spots which are distributed over the whole face of the disk. With this distribution of discharge the ohmic resistance is that of the whole disk and not that of only part of the disk as Mr. McEachron figured. Therefore I have redrawn Mr. McEachron's curves with the correct ohmic drop in Fig. 5.

These curves show three more or less distinct portions—first there is a higher voltage part where the current is spreading over the disk face. Then comes a drop to approximately 350

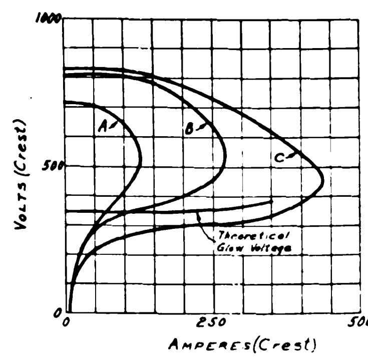

FIG. 5

volts, where the curve tends to become horizontal. The slight departure from 350 volts is readily accounted for due to uncertainty in the disk resistance, since the current distribution in plated disks is different from that with discharge, and also uncertainty in the proper value to take for the current density. Lastly there is a low-voltage part during the last 50 amperes of the discharge, which is undoubtedly due to vague contacts and lining up of particles in the gap by the intense field.

These vague contacts which follow an intense discharge explain Mr. McEachron's finding a current flow at 280 volts. By raising the resistivity of the disks this leakage current may be

reduced to as small a value as we please. In the commercial autovalve arrester this leakage is usually not detectable on an ordinary oscillograph.

Mr. McEachron's experiments on the impulse breakdown of autovalve gaps are very interesting. They show that the voltage rises to less than double for very fast discharges. When the voltage reaches the value corresponding to the gap length without distortion due to the spacer, we should expect speeds equal to that of a sphere gap.

The last point which Mr. McEachron raises is as to the correctness of Fig. 9 in the paper. The formula is incorrectly printed and should read,

$$T = \frac{W\sqrt{t}}{4.18\sqrt{\pi\, k\, c\, \delta}}$$

Taking $t = 0.001$ sec., $k = 0.016$, $\delta = 2.0$, $c = 0.185$ and $W = 3500$, gives $T = 194$ deg. which agrees with the curve of Fig. 9.

IONIZATION STUDIES IN PAPER-INSULATED CABLES—I[1]

(Dawes and Hoover)

New York, N. Y., February 8, 1926

A. E. Kennelly: Turning to the paper by Dawes and Hoover, it seems to me that the great force of that contribution lies in the fact that a bridge has been developed which employs a vibration galvanometer, with all the delicacy and precision that the vibration galvanometer affords, so that instead of having to employ a relatively great length of cable dielectric for test, it is sufficient to have only, say, a couple of meters, provided that the particular couple of meters shall represent fairly well, the whole length of a cable under consideration.

E. W. Davis: One of the most important problems which confronts the manufacturer of high-voltage cables is that of dielectric loss, its fundamental cause and its relation to the other necessary properties of a well designed cable.

The papers by Messrs. Dawes & Hoover adds one more to the numerous theories concerning the nature of dielectric loss and power factor. Unfortunately many of the papers published to date, while excellent mathematical treatises on the subject, are not founded on any scientific research work or based on data of many tests. In fact, outside of a very few isolated experiments, many of the theories cannot be checked at all.

In a recent paper presented before the British Institution of Electrical Engineers, "Dielectric Problems of High-Voltage Cable", by Percy Dunsheath, an attempt is made to connect dielectric loss with dielectric absorption, dielectric hysterisis, and dielectric conduction. Much data and many curves are given to substantiate the theory and there is included a rather unique discussion of the relation between a-c. and d-c. losses.

The paper by Dunsheath and the paper by Dawes & Hoover offer two widely divergent theories for dielectric loss, and yet both of them contain features that may be readily checked.

Fig. 1 herewith shows a few typical power factor-voltage curves that we have obtained with various impregnating compounds and at various temperatures. These tests were made in a special oil testing condenser and with a high-voltage, 60-cycle bridge. The curves are quite similar to those shown in the Dawes-Hoover paper, one in particular showing the peculiar knee found at high temperatures by these investigators.

Fig. 2 shows two curves calculated by means of the formula (17) of the Dawes & Hoover paper. By slightly varying the assumptions as to location and dimensions of the air films, both types of curves are obtained. One interpretation of such tests would indicate that compound ordinarily contains more or less air distributed through it and exhibits the same phenomena of restricted ionization as laminated insulation even though the barrier effect of the paper is not present. Another phenomenon exhibited by cable insulation, but not discussed by Dawes & Hoover, is the V curve of power factor and voltage. Numerous samples tested show a decrease of power factor with increasing voltage and then as higher stresses are reached, a rapid increase.

In built-up insulation, there are invariably minute air films. The loss through these films depends upon the conduction

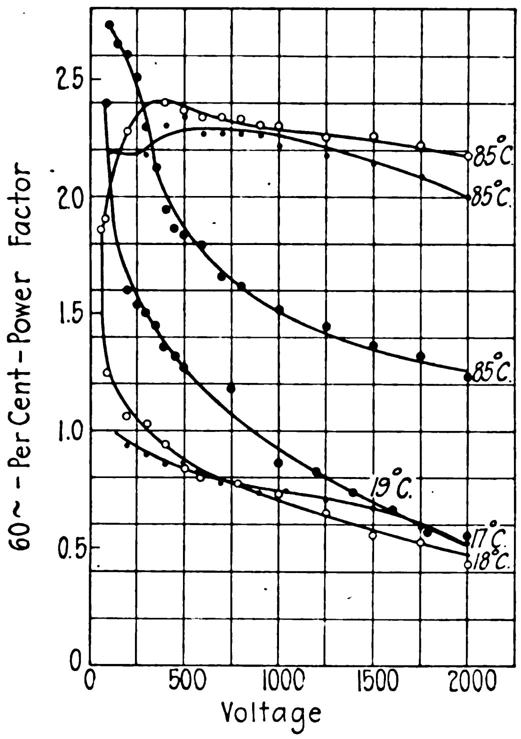

Fig. 1—Power Factor Versus Voltage Various Impregnating Compounds

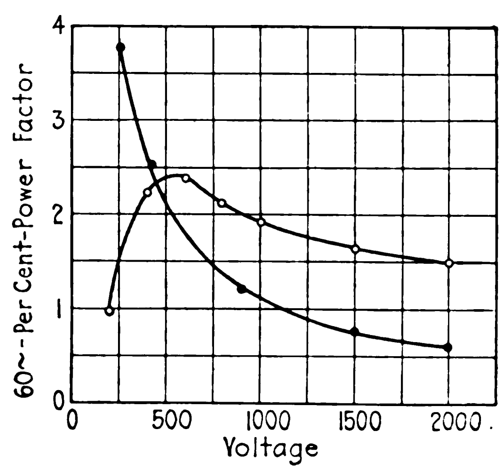

Fig. 2—Calculated Power Factor-Voltage Curves Impregnating Compounds

through and conduction around the film along the paper. The conduction loss at low stresses would follow ohm's law and at high voltages would depend upon the degree of ionic saturation or ionization. If we consider a very low-pressure air film between two paper tapes, the full ionic saturation would be reached at a very low stress and, therefore, the leakage current would not increase directly with the voltage. The dielectric loss, therefore, would not increase directly with the voltage and this would mean a decrease of power factor with increasing stress. This phenomenon holds until a point is reached where ionization

1. A. I. E. E. Journal, April, 1926, p. 337.

of the higher-pressure air in the insulation is complete. If the ionization took place at the same voltage for a large majority of the air films, we would expect a sharp increase of power factor. It is possible that the ionization point for various films may differ so much that a gradual rather than a sharp increase of power factor occurs. This effect is of course governed by the relative amount of air to insulation, the average pressure of these air films and the leakage characteristic of the paper insulation. We should not expect to find this phenomenon in a cable the paper insulation of which had quite high leakage characteristics.

Tests on Impregnated-Paper Sheets. Power-factor tests on sheets of vacuum-dried and impregnated paper were made with a high-voltage bridge in order to check the previous conclu-

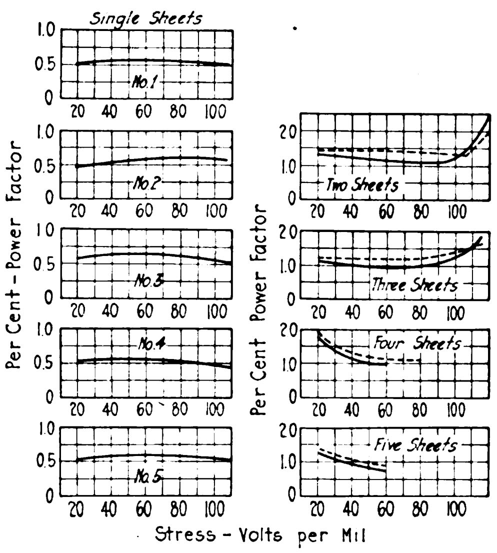

FIG. 3—SIXTY-CYCLE POWER FACTOR VERSUS VOLTAGE IMPREGNATED-PAPER SHEETS. DOTTED CURVES ARE RESULTS OF TESTS WITH PRESSURE ON UPPER ELECTRODE

sions. It was thought that tests on single sheets of paper in very close contact with the electrodes would show the characteristics of the paper insulation itself. Then, using more than one sheet, tests could be made with air films between.

The curves in Fig. 3 show the results of these tests.

In no instance was a *V* curve obtained with a single sheet of paper. Two and three sheets of paper, when placed loosely together and tested, gave decided *V* curves of both the gradual and the sharp type. With three and four sheets of paper, sufficient stress could not be obtained with the voltage available to reach the critical point in the power-factor curve but the start of the *V* curve was obtained in each instance. The application of pressure to the upper electrode when testing multiple sheets changes the character of the curves very much. In Fig. 3, when two sheets are tested under pressure, the *V* curve is partially eliminated and the voltage at which ionization takes place is increased. With three sheets under pressure, the *V* curve is eliminated completely. In the case of four and five sheets, sufficient pressure was not applied to remove the *V* curve completely but the dotted curves shown seem to indicate the tendency for this to take place.

W. A. Del Mar: The paper by Dawes and Hoover contains a wealth of experimental material which requires considerable detailed study, and it is difficult to comment upon the results without knowing more about the materials worked upon. For instance, cables impregnated with different types of compounds would probably show different characteristic curves. I think that the value of the paper would be increased very much if information were given regarding the type of compound used in the cables for which curves are given. For instance, whether the compounds are solid or liquid at the temperatures at which the experiments were made, and so on.

I notice that most of the experiments, if not all of them, were made with single-conductor cables. Some rather interesting work which Mr. Hanson has been doing and also some which has been done in England and recorded in the current Journal of the Institution of Electrical Engineers, England, indicates that in three-conductor cables, a large proportion of the loss which occurs at the higher voltages occurs in the fillers, and if the fillers are omitted or replaced by some material which has not the same characteristics as the ordinary paper crepe, those losses can practically be eliminated and the ionization curve,—that is to say, the voltage-power factor curve,—becomes virtually a horizontal line between stresses of 20 volts and 100 volts per mil, which are about the limits in Fig. 5 of the paper.

It would therefore seem that the work which the authors have done needs to be somewhat amplified by an analysis of just the parts of the cable in which the principal losses occur, at the different voltages. It is possible that by such an analysis, steps could be taken to reduce these losses at the higher voltages.

Anyone who has done any laboratory work of this kind will appreciate the immense amount of painstaking, careful work that Prof. Dawes and Mr. Hoover have done in this paper. Nevertheless, I am not entirely convinced that their curves represent insulation characteristics to the exclusion of test-apparatus idiosyncrasies. When, however, you look at the curves and compute the number of experimental points they have made, the work appears to be really prodigious, and even if some corrections should have to be made, the authors are to be congratulated upon their results.

R. W. Atkinson: I have been interested in bridge measurements ever since I became connected with the cable industry, and last year published in the *Electric Journal* a description of the method we are now using and gave a brief description of it in a discussion before the Institute. The bridge that has been shown tonight, and the one I described are about as different in general construction and circuit as two instruments both of the bridge type could well be and yet serve the same purpose. Yet I am interested to note that they both have certain fundamental characteristics and attain final results equivalent in many respects.

The sensitivity of the two types is nearly the same, so far as I can judge from the figures given in the paper, and the voltage across the measuring parts of the bridges is comparable. These are fundamental parts of the whole problem of precision measurements of dielectric losses. As Prof. Dawes has pointed out, it is very desirable indeed to have the voltage drop across the resistance in series with the measured condenser very low so that no difficulty will be experienced from the effects of the capacitance to ground of the detector and certain other parts of the circuit. His instrument and mine are closely alike in this respect and have a very much lower drop than in the case of any other dielectric-loss-measuring device of comparable sensitivity that has been described.

Some fundamental differences between the two bridges are these:—My bridge uses an a-c. galvanometer as a detector; Prof. Dawes uses a vibration galvanometer with vacuum-tube amplifiers to get the same result.

The vibration galvanometer requires accurate frequency which is not always convenient where a commercial circuit supplies the power. The a-c. galvanometer requires an auxiliary source of current to supply the field at the same frequency as that supplying the measured condenser.

An advantage of our bridge over most other devices for measuring dielectric loss is that it is so arranged that when balance is obtained, the power factor may be read directly from the dials.

There is one difference between the two instruments, which is a very important one and is in favor of the a-c. galvanometer

type. In using the vibration galvanometer, it is necessary to secure a very accurate capacity balance before the power-factor balance can be obtained. With the a-c. galvanometer type the bridge is first made sensitive almost entirely to capacity and then made sensitive almost entirely to the power factor, by changing the relation of the field so that the capacity balance does not have to be made nearly so accurately as it would otherwise have to be. This is very significant because it permits measurements to be made much more rapidly than with the other type.

E. S. Lee: With reference to the Dawes-Hoover paper, I think there are several things of great interest to those who have to work with cables and make measurements thereon. In the first place, we find that we have one more method added to the already long list and large number of different means by which we measure dielectric power loss. This is a bridge method. As Mr. Atkinson has said, about a year ago he described his bridge, and just a year ago from this same platform we were told of work which had been done with the Schering bridge, which work has been carried on for this past year with great success.

Prof. Dawes says: "On one occasion after completing a 60-cycle test, we found that the 25-cycle losses were greater than the 60-cycle losses even though sufficient time had been allowed for the cable to reach constant conditions." Such conditions are not new to those who are making these measurements continually. Also, if you will observe the curves of his Figs. 11, 13, and 16 you will observe "humps" which might be looked upon as indication of error. But Prof. Dawes has stated that they have checked those portions and they find those humps should be there in the curves. These also are found by other observers.

Thus, we are glad to find that as new investigators take up this work, their results are in agreement with what has been found in factory testing and experimentation.

I want to call attention to one point, which may not be necessary, particularly to those who are familiar with the work, but I think it is quite necessary, particularly for those who are not so familiar with the work. Some reference was made to the fact that these are characteristic curves, and I grant you that they are, except I would call to your attention that the largest portion of these curves is outside of the operating range; that is, the curves in Figs. 8 to 16 are for a cable which we would say would be normally rated at 12 kv. If you will look along the abscissas or on the curves for 12 kv., you will notice that within that value the dielectric power loss is quite small; the power factor is very low, and the change in these values is small. It is well beyond this voltage that the changes occur. In the present-day cable, the same conditions exist. We have to go beyond the operating values, considerably, in order to get these changes.

There is one other thing to which I would like to call attention: when I first looked at these curves, I thought the change in capacitance was enormous, but if you will note the scales, you will find it is not. It is only about 5 per cent. The change in the power factor is of the order of 300 to 400 per cent; the change in dielectric power loss is of the order of about 3000 per cent. So one has to observe these scales carefully in order to obtain correct conceptions. The explanation offered by the authors for the shape of these curves is good and of value, though if tests are made on cables with different treating compounds and with liquid fillers, it will be found that these same curves are not characteristic for those cables but that another set of characteristic curves will be obtained. Their shape likewise has to be explained.

I believe we are largely forgetting what power factor is. We talk about it quite a bit. I believe I am right when I say that it is the ratio between the dielectric power loss and the product of the voltage and the current. In other words, the variations in these three quantities govern the variation of the power factor; therefore, a discussion of the variation of power factor must include the variation of these factors. It is really the dielectric power loss that we are interested in. If we talk in terms of power factor, then our results become more directly comparable without regard to volume of the dielectric, but I think if we remember that the loss varies quite nearly as the square of the voltage, that the capacitance does not change greatly, hence current is proportional to voltage, we can work out the ratio of these factors and see just about how the power factor will vary. If air ionization is present, however, conditions are quite different from those when no ionization exists, particularly since the dielectric power loss varies at a faster rate than the square of the voltage.

I was interested in the agreement between calculated results and measured results, and the statement also that if we knew the constants, we could very readily calculate. I think that is true but the constants are often difficult to determine.

W. B. Kouwenhoven: The authors state that the air condenser that they employed in their bridge had a phase angle. In measurements that I have made with the Schering bridge I have never been able to detect any phase angle in the air condenser used. Slight errors, however, may creep in due to insufficient shielding of the leads and apparatus, and these will cause discrepancies which are usually assigned to a phase angle in the air condenser. Proper shielding will often eliminate these errors.

In some work that I have been doing with Dr. Whitehead

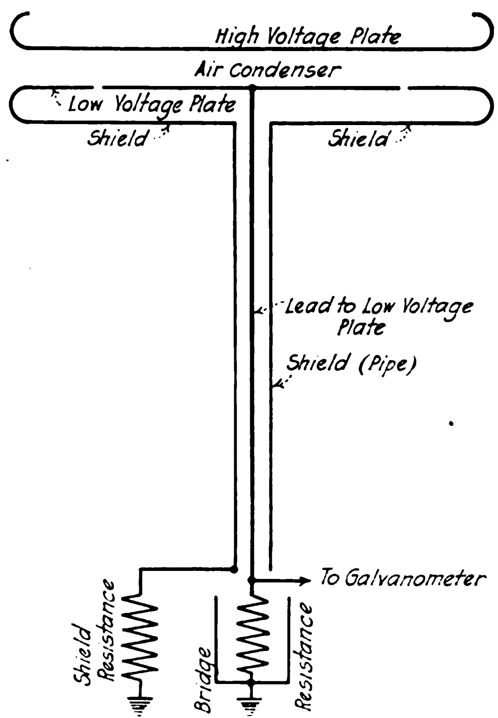

FIG. 4

we have found it necessary to shield the air condenser and its leads as shown in Fig. 4 herewith, which shows the air condenser side of a high-voltage bridge. The pipe shield on the lead to the low-voltage plate of the air condenser must be maintained at the same voltage as the lead otherwise charging currents between this lead and its shield will introduce errors in the results. Any change that is made in the bridge resistance in series with the condenser lead must be accompanied by a proportional change in the resistance in series with the shield, otherwise an error will be produced in the phase angle as determined in the bridge. The shielding of the specimens should be carried out in a similar manner.

In measuring losses at high voltages with the Schering bridge

or with the quadrant electrometer at Johns Hopkins University we have followed the practise of determining the accuracy of the apparatus. In making this check we first measure the loss in a specimen and then insert a known non-inductive resistance in series with the specimen and measure the loss again. We determine the current in the specimen circuit and calculate the loss in the added resistance. If the apparatus is functioning correctly the loss in the added resistance should equal the difference between the first and second loss measurements.

W. F. Davidson: I desire to call attention to certain limitations of the method used by Dawes and Hoover and, indeed, by most other investigators. We are dealing here with a composite insulation which is stressed to such values that ionization reaches considerable proportions. As a consequence, such "constants" as capacity and resistance cease to be true constants and not only vary with the effective value of the impressed voltage but even vary cyclically. Whitehead, Peek, and others have called attention to the distorted current wave of corona, which is merely another way of stating that the capacity and resistance are not constant.

Under these conditions the observed data, and with them the computed data, will depend upon the method of measurement—a wattmeter method will give one result and bridge methods other results.

To illustrate this, assume that the impressed voltage is not distorted in any way and that we have a reference "no-loss" circuit as well as the circuit containing the test specimen. The voltage and the two currents may be written in the form:

$e = E\,[A_1 \sin \omega t + B_1 \cos \omega t]$

$i_1 = I_1\,[a_1 \sin \omega t + b_1 \cos \omega t]$

$i_2 = I_2\,[\alpha_2 \sin \omega t + \beta_2 \cos \omega t + \ldots \alpha_n \sin n \omega t + \beta_n \cos n \omega t]$

and

$A_1^2 + B_1^2 = 1, \quad a_1^2 + b_1^2 = 1, \quad \alpha_2^2 + \beta_2^2 + \ldots \alpha_n^2 + \beta_n^2 = 1$

In the test circuit the true power will be

$$W = \frac{E\,I_2}{2}(A_1\,\alpha_2 + B_1\,\beta_2)$$

since the over-tones in the current wave have no corresponding element in the voltage wave and hence do not contribute toward the average power.

If the measurements be made with a wattmeter (dynamometer or electrostatic) with an ammeter and voltmeter, the observed and computed results will be:

Potential difference $= E/\sqrt{2}$ r. m. s. volts

Current $= I_2/\sqrt{2}$ r. m. s. amperes

Power $= \dfrac{E\,I_2}{2}(A_1\,\alpha_2 + B_1\,\beta_2)$ watts

Power factor $= A_1\,\alpha_2 + B_1\,\beta_2$

Resistance $= \dfrac{E}{I_2}(A_1\,\alpha_2 + B_1\,\beta_2)$

Capacity $= \dfrac{I_2}{E\,\omega\,\sqrt{1 - (A_1\,\alpha_2 + B_1\,\beta_2)^2}}$

If the measurements be made with a bridge using a tuned vibration galvanometer or a dynamometer with fields excited at the fundamental frequency, the results would be as follows if the measured voltage and standard capacity are used:

Potential difference $= E/\sqrt{2}$ r. m. s. volts

Current $= \dfrac{I_2}{\sqrt{2}}\sqrt{\alpha_2^2 + \beta_2^2}$

Power $= \dfrac{E\,I_2}{2}(A_1\,\alpha_2 + B_1\,\beta_2)$

Power factor $= \dfrac{A_2\,\alpha_2 + B_1\,\beta_2}{\sqrt{\alpha_2^2 + \beta_2^2}}$

Resistance $= \dfrac{E}{I_2}\,\dfrac{A_1\,\alpha_2 + B_1\,\beta_2}{\sqrt{\alpha_2^2 + \beta_2^2}}$

Capacity $= \dfrac{I_2\,(\alpha_2^2 + \beta_2^2)}{E\,\omega\,.\,\sqrt{(\alpha_2^2 + \beta_2^2) - (A_1\,\alpha_2 + B_1\,\beta_2)^2}}$

These results depend on the fact that the bridge will only balance the fundamental component of i_2 against the reference circuit. In a bridge measurement, securing balance with a hot-wire or other untuned detector, it will be impossible to secure an exact balance and the observed values will differ in many points from those above.

In closing, I should like to suggest that we have reached a point in our researches where it seems essential that we consider instantaneous value $\dfrac{\partial E}{\partial I}$ and not average values. Fortunately the means for doing this are already at our disposal in the cathode-ray oscillograph. The JOURNAL of the Institution of Electrical Engineers for November, 1925, contains three excellent papers dealing with this powerful tool of the modern investigator into dielectric phenomena.

G. B. Shanklin: Several years ago I made a special study of the subject of "ionization in cables," and as a co-author submitted some of the findings in Institute papers. Our work dealt largely with "cause and effect" from a practical standpoint. No quantitative nor qualitative analysis was attempted. The work, in conjunction with that of contemporary workers, resulted in recognition of the cause and importance of ionization in cables and established methods of eliminating or reducing it. Recent advancement in the voltage rating of cables is based on the principles demonstrated by this early work.

A more expert and systematic study by qualified physicists and research engineers familiar with the electron theory has long been needed. This excellent paper by Messrs. Dawes and Hoover represents, I hope, a beginning which will result in eventually establishing the theory of ionization in cables on a firm quantitative basis.

Their present results are not only a distinct advancement but are in good agreement with our previous work, as far as it went. By using a length of ordinary impregnated paper cable with a special loose sheath, we obtained curves very similar to those in Fig. 7 of the paper. The curves were not, as theirs are, subject to accurate analysis, for ionization of the large air space directly under the loose sheath was obscured by simultaneous ionization through the thickness of paper insulation. The use of a model cable sample enabled them to obtain much more accurate data.

Change or shifting of ionization curves, as shown in Fig. 9, is, as they state, a function of time. I agree that residual or free ions, after the voltage is reduced, are the main contributing cause of this, but do not agree that absorption or higher internal temperature plays an important part. Instead, there appears to be a factor discovered by J. J. Thomson and called "ionization pressure," which is important. When the gas spaces are first ionized, this "ionization pressure" pushes the softened compound back, resulting either temporarily or permanently in enlarged gas spaces. A particular cable might operate indefinitely at normal voltage without ionization, but if a momentary over-voltage, such as produced by a switching surge is applied, ionization might persist for some time after the voltage drops back to normal. This is, in effect, exactly the same characteristic shown in Fig. 9.

The irregular shape of the first section of the high temperature-power factor curves, as shown by Figs. 11 and 13, is, I have believed for some time, due to the liquid nature of the compound. Some form of ionic conduction through this liquid is apparently responsible, for these peculiar shapes are obtained only with liquid filling compounds. I have seen the same type of curves obtained at room temperature when a thin oil is used for impregnation.

On the fourteenth page the authors make the statement: "It has been recognized for some time past that, although the paper itself has lower dielectric strength than the impregnating compound, the dielectric strength of the cable is increased by using paper in combination with compound." This statement is misleading. They evidently mean that cellulose fiber in paper form and in combination with air has less strength than when in combination with compound. This is evident since compound has greater strength than air. Actually, cellulose in pure form is an excellent insulator, and this is why paper, acting as a barrier, improves the dielectric strength of the compound.

Their theory of the formation of tree designs seems very plausible. Certainly, it must be due to tangential stresses along and between the surfaces of the paper wrappings. The high-frequency nature of this discharge is also well established. It might be pointed out that impregnated paper insulation has something like one-tenth the dielectric strength longitudinally between surfaces of wrappings, that it has radially or perpendicular to these surfaces. The absence of fiber barriers in this direction accounts for this.

It is sincerely hoped that the authors will continue their valuable work to a final conclusion.

J. B. Whitehead: We have had some difficulties which Professor Dawes doesn't mention, and which I hope he hasn't had. There are also some that he has had which we have not. Dr. Kouwenhoven has called attention to one of our greatest difficulties, that is, the screening of the test electrode and maintaining the guard electrode at exactly the same potential. On our Schering bridge, we found we could get power-factor measurements in the same range that Professor Dawes is working, that would differ by 50 to 100 per cent simply by a variation in the resistance in the tail of the guard circuit. I presume he has solved that difficulty, or perhaps his bridge is not so sensitive to it as our own.

As to the phase difference of his air condenser, I am astonished at the value that he finds. We have found nothing to indicate such a difference in our condenser. We have split it into two halves, put one-half in each side of the bridge, and have added small resistances in the tail circuit of the side we are measuring, thus checking by successive increments of power factor, to see whether there is any initial value of phase difference. We have not detected any, and I hope that Professor Dawes, will tell us what he consideres to be the source or cause of the phase difference he finds. In this connection I have the following references to phase difference in air condensers:

Giebe and Zickner, in the Archive fur Elektrotechnik, find that in standard air condensers of the Reichsanstalt no phase difference can be detected by methods measuring the same to an accuracy of from one to two seconds of arc. These are small air condensers, and I think the maximum voltage upon them was about 300 volts, and the measurements were directed only at the possibility of a phase difference due to the normal ionization of the air. This is the only source that I can think of for a phase difference, unless, one has actual point discharges between the plates of the condenser, in which case you could get ionization losses of any description. I assume that Professor Dawes' condenser was free from error of this type.

E. Möller also finds that radium rays and copious brush discharge in the neighborhood of an air condenser have no effect on its phase difference, but he is working at frequencies up to 180,000 and above, so perhaps his figures cannot be taken.

C. H. Willis who is working in my laboratory has computed the value of the phase difference due to the normal ionization in the air. This was for a condenser of our dimensions, in which the space separation up to about 35,000 or 40,000 volts is two inches. The ratio of charging current to conduction current is based on the normal velocity of ions in the air, and the potential gradient and the frequency, and so on, a very simple calculation. The value of the phase difference in this case works out to be 4×10^{-6}. This is far below the figures which Messrs. Dawes and Hoover have given and indicates a negligible phase difference.

I do not feel that it is necessary to invoke the structure of the atom in explanation of the behavior of this type of insulation. I believe that the change in the power factor, as it rises beyond the ionization point, can be accounted for by the saturated conditions in these air layers, if it be remembered that this ionization is extinguished at every half wave, as the voltage goes down below the critical value. We have every reason to suppose that at such frequencies as we are using here, there is complete extinction, every half wave. As a consequence there arises the question of the recombination of the ions, and I think it is clearly evident from the very interesting and beautiful experiments on the artificial cable with an air layer, that there is a normal saturated condition due to a limited air area, beyond which you do not get any further ionization and therefore no further loss, as you go on up in voltage.

Another thing that we have to note here is that there are two possible sources of loss in ionization: one due to the actual process of ionization itself, the actual collision or the knocking apart of component parts, and then on top of that such conductivity as exists due to the passage of the ions across the air space. I think it is very easy to picture a saturated condition and if we have that, it is very easy to see that as the voltage curve goes up, the power factor may reach a maximum.

I also was particularly interested in the difference between the ascending and descending curves, and I would like to ask whether these curves repeat themselves accurately. Nothing has been said here about the effect of the presence of ionization on the cable structure itself. It is a most powerful destructive agent. If you have any layer in which there is active ionization going on, I wouldn't say that it would remain in the same condition for more than a few seconds. I think it probable that much of the trouble in cable insulation is due to the fact that it is rapidly destroyed as soon as we let ionization start. I venture the prediction that in a few years' time we are going to see some curves of this kind which will be flat, and when you do that, and not until you do, will you have cable that will be satisfactory. When ionization goes on, the cable is going to pieces, and it seems to me that it is only a question of thorough and complete impregnation. If we can get that, I don't see how we can fail to straighten these curves out and get rid of the principal cause of this trouble.

C. A. Adams: Referring to the destructive effect of internal corona, I have photomicrographs which show the fusing by corona of mica laminae in the insulation of a 25,000-kv-a. turbo alternator. There was in this case conclusive evidence of what might be called a "corona blast," namely the reaction of the corona currents on the magnetic field due to the load currents in the armature conductors; the corona current being perpendicular to the magnetic field.

C. L. Dawes: Mr. Del Mar requested some more data on the cable. These are in the hands of the Committee. We have the cable numbered and I believe we know the manufacturer, but we we do not know the compound. He states that he hopes we determine in which part of the cable the loss occurs. At the present time we are analyzing the cable layer by layer, finite thicknesses from the center out, those thicknesses being so small that they are practically surfaces. Our one source of error is that we must assume that the air spaces are equally distributed through the insulation. If that is not true, our work obviously will be in error.

He states that we have done a lot of work and determined so many experimental points. I merely wish to add to that and state that these are just a few representative data. There wouldn't be room in an ordinary journal to include all the curves which we could put in.

We are very glad Mr. Lee pointed out the fact that we were

carrying the operating range of the cable above the ordinary operating voltage. It is necessary to do this, however, in order to study the phenomena. We are studying ionization itself, and we are not attempting to obtain the ordinary commercial curves which have been published or which are readily obtainable in many manufacturers' laboratories.

Mr. Davidson brought out the fact that the current is distorted by the variable factors in the circuit. We have had that in mind for some time, and Mr. Hoover and I have discussed the possibility of obtaining oscillograms of the charging current through the cable. That is one of the details which we have set aside until a more opportune time comes to make an investigation in that particular direction. I will state, however, that in some of our early experiments the man who was doing the work at that time told me that he had obtained a power factor of something like 0.1 per cent. I questioned it very much, and on further investigation I found that he was using as a source the commercial lighting circuit, and he had not become familiar with the galvanometer, and inadvertently he tuned in for the third harmonic; in other words, he was balancing up the third harmonic and in his calculations he obtained a power factor which was one-third of what he should have obtained.

P. L. Hoover: I will reply first to Mr. Atkinson's statement that in balancing a bridge "it is necessary to secure a very accurate capacity balance before the power-factor balance can be obtained." It can be shown mathematically that this effect is inherent in the bridge and does not depend on the type of measuring instrument used. Furthermore, with the Wien and Schering bridges it can also be shown that the power factor, as determined by a minimum deflection of the detecting instrument, may be in error by 50 or 100 per cent if the capacity balance is out by about one per cent. This effect does not enter in the bridge used for this investigation. With this new bridge an accurate capacity balance can not be obtained if the power-factor balance is out very far. The two balances must be obtained simultaneously.

Furthermore, an amplifier is not necessary with this bridge although it helps considerably at the lower voltages if the sample is small. At higher voltages, above 25 kv., the amplifier is not used.

The question raised by Professors Kouwenhoven and Whitehead concerning the grounding of the condenser shield through a resistance is interesting in that it points out another advantage of this new bridge over the Wien and Schering bridges. Since, with the latter bridges, it is necessary to make the capacity balance to extraordinary precision in order to get a fair precision in the power-factor balance, it is essential to maintain the guard ring or shield at exactly the same potential as the low-voltage electrode of the condenser. Otherwise the effective capacity of the condenser will change due to the change in the potential distribution within the condenser. This effect is largely eliminated in this new bridge since the power-factor balance does not depend upon such a critical balance of the capacitances.

It should also be noted that the resistance in the shield circuit is not a constant, neither is it equal to the resistance in the other arms of the bridge. If C_1 and C_2 represent the capacitances of the low-voltage electrode and the shield respectively, and R_1 and R_2 the resistances in series with these capacitances, then, for the shield to be at the same potential as the low-voltage electrode the shield resistance must be $R_1 = R_2 (C_1 \; C_2)$. Consequently the resistance in the shield must be changed every time the bridge is changed. With the Wien and Schering bridges this effect is very important and accounts for Prof. Whitehead's observation that a small change in the shield resistance may change the power factor by 50 to 100 per cent.

Check measurements made since the writing of this paper have shown that the angle of our air condenser was due to insufficient shielding of the lead from the low-voltage electrode of our air condenser as Prof. Kouwenhoven has pointed out. In our particular case there was magnetic coupling as well as electrostatic. Shielding corrected the difficulty and our air condenser now has no measurable loss.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

THE LIGHT-COLOR PLAYER*

If, by a person seated at an instrument, illumination could be as flexibly and delicately controlled as sound can be by one seated at a piano, is it not conceivable that we should have a new method of emotional expression which might ultimately become a rival to music, or at least a valuable and glorious accompaniment to it?

While the main problem involved in designing such an instrument has always been the flexible and continuous grading of the intensity of illumination from darkness to its highest pitch, and vice versa, of course the problem of color-play at once assumed its interactive importance. Color is so wonderful a phenomenon in the act of seeing that it could not be ignored in the attempt to express emotion through the sense of vision; such a source of highly pleasurable sensations must be taken advantage of. And yet the injection of color-play has tended, in the popular mind, to obscure the full appreciation of what light-play is.

Through long association with lighting effects on the stage, or by watching moving picture screens, one naturally thinks of color-play on screen or stage, as being something at which an audience would sit and look. It is true that colors may be most beautifully presented when thrown on a monochromatically reflecting screen—preferably a white silvered curtain, hanging in loose folds. And it may be that while color-play on such a curtain, or on other objects or surfaces of a stage, will constitute an important feature of this new art, yet, after all, this is but a fraction of its main object. To produce its maximum emotional effect, or, conversely, to express most fully the emotions of the performer, the illumination of the whole interior must be played upon. This is because of the very wide seeing angle of the eye—both horizontally and vertically—and because illumination, like the atmosphere, is all pervading, surrounding the whole person and the whole assemblage of persons. If the highest expression of this new art is to be conveyed a play on that all enveloping illumination must be secured.

This light play in the illumination of the interior should not be thought of as a mere grading up and down of intensity—with or without color changes. It is not confined to that, but may constitute an extension of the space to be illuminated. Starting, for instance, with a brilliantly lighted curtain and the auditorium in darkness, the glow may be made to grow in area, with the smoothness of a dawn, from a spot on the curtain to gradually reach the rear and covers the whole

*From a paper presented before a meeting of the Philadelphia Section of the Illuminating Engineering Society, Jan. 26, 1926, by Mary Hallock Greenewalt.

interior. In other words, a climax may be reached either by gradually increasing the intensity throughout or the area illuminated. And, of course, either of these processes may be reversed, or, to a certain extent, they may be combined.

This play on the whole interior illumination may be illustrated by phenomena of nature. Everyone is familiar with the change of mood which accompanies the passing of a heavy cloud across the face of the sun, or the gradual transformation of a brilliant morning into a cloudy day. Also, how ominous is an unusually heavy cloud, producing near-darkness at midday! Conversely, how may one's mood change when an overcast gloomy day clears at sunset and fills the world with glorious radiance and, be it observed, with glorious color. A day of doubt and skepticism closes with the conviction that "all's right with the world." Again, who has not been seated on terrace or lawn of a summer evening and become conscious of a soft radiance suffusing the landscape, slowly growing in clearness, until the full moon, having risen behind the foliage and at last surmounting the tree tops, spreads its glorious illumination through all space? The magic effect is not that of something viewed, but of being bathed in universal radiance. Depending on the arrangement of lamps, effects of similar type may be produced in any interior by one seated at the console of this light-color player. And color-play is not necessarily confined to screen or curtain on the stage, but may be suffused throughout the interior.

A play of light and color on a curtain or stage, watched by an audience seated in uniform darkness, or near-darkness, may be compared to a performance of music in the presence of a uniform buzzing or hissing sought throughout the auditorium. For its perfect enjoyment, music must be the only sound reaching the ear; it must be unconfused in the whole interior and dominate the consciousness of the listener. So it is with the play of light; it must be capable of filling the whole eye of the watcher and of dominating his emotions.

It probably goes without saying that this art of mobile light admits of projecting changing patterns or shapes (coloring them as desired) by providing mechanism for gradually changing the shapes of the beams thrown by the projecting lamps. The earliest experiments, many years ago, were concerned with this type of light and color-play, but it was soon realized that it is but one small phase of the main problem in developing this art of mobile light and color. However, it is an inclusive phase.

The console contains three rheostats, each about 30 30 in. high by 36 in. long, so designed and arranged that the illumination intensity given by the lamps connected to them can be changed by steps so small as to seem continuous. Mercury switches absolutely noiseless of operation are used, so arranged that the same body of mercury makes contact between a choice of various pairs of conducting leads. The console is relatively light in weight and is about 30 in. wide by 42 in. long. The seated player controls the play of light and color by using keys and pedals.

The auditorium accessory consists of an arrangement of switches in a separate compact box not over 20 in. long, connected to the console and to the wiring of the auditorium lighting system in such a manner that the illumination in large auditoriums, even those consuming a wattage as high as 250,000, may be varied up or down at will by minute steps, so as to seem continuous. The regular lighting system of an auditorium may be so connected and utilized, but, of course, if special effects are desired, or color effects, special lamps would need to be properly placed.

The lamp head is designed for getting different colors from exactly the same point and to save wattage. The lamp is mounted in a special reflector, and fitted with a color wheel equipped with variable timing control, and a color signalling attachment. For color-play on curtain or stage, the lamps would naturally be placed as the character of the distribution is helped. Separate lamps, each with its fixed color screen, may be used in place of the color wheel. Of course, for certain limited or temporary purposes, where it is desired to use the instrument for color-play as a stereopticon, the lamp head, or several of them, may be mounted directly on the console, thus providing a self-contained portable color-player.

A musical composition to secure permanence and permit of indefinite performance by others needs a written record. So with a light composition. A system of scoring has been designed for light compositions which anyone familiar with musical scores can easily master, and a basis of permanence for this new art is thus laid.

The development of an instrument to play with light and color, to be operated by one person, must have awaited the advent of the incandescent electric lamp; it could not have been done with the light from the candle, kerosene lamp or gas lamp. It has been helped by the development of high wattage, high candle power lamps, and of various technical devices, such as the mercury switch. It must have awaited facts developed by physiological research, including the seeing increments of the eye under varying intensities. A new means of emotional expression and of esthetic enjoyment is thus given to the world—who can predict the extent of its ultimate development? Perhaps a time will come when it will be a factor in heightening the enjoyment of music, deepening the devotion of religious worship, augmenting the effect of oratory, enhancing the brilliancy of dances, banquets and social functions, beautifying and refining whatever may be done on the stage, platform, or motion picture screen, and, when played on the silver curtain, becoming in itself a source of joy to the following generations.

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Annual Convention at White Sulphur June 21-25

A wide variety of technical subjects, the choice of a charming location, and enjoyable recreational features mark the program for the Annual Convention of the A. I. E. E. which will be held at The Greenbrier, White Sulphur Springs, W. Va., June 21-25, 1926.

Technical Sessions

The technical papers cover a broad range of subjects and the reports of the Technical Committees will describe the important developments which have occurred in the various fields of electrical theory and application. The papers will include the subjects of the theory of synchronous machines, non-harmonic alternating currents, a-c. circuits, dielectric breakdown, rectifiers, magnetization, heat transfer in machines, auto-transformers, electrical measurement of mechanical vibrations, remotely controlled substations, high-speed circuit breakers, regenerative braking and windings for d-c. machines. The accompanying tentative program gives more detailed information on the technical features.

The Attractive Location

No finer place than the Greenbrier at White Sulphur Springs could have been selected for the convention. This magnificent, modern hotel is located in the Greenbrier Mountains 2000 feet above sea level in most attractive surroundings. Small cottages, close to the main hotel, are available for those who desire them. There is every opportunity for outdoor sports and recreation. Close to the hotel there are two 18-hole golf courses which are among the finest in the country and also a splendid nine-hole course. Excellent tennis courts will be available and both golf and tennis tournaments are planned.

A swimming pool, 40 by 103 ft. in size and fed from one of the large springs, is another attraction at this hotel.

A fine stable of thoroughbred horses is maintained there and those interested may enjoy horseback riding on well kept trails over the mountain ridges through very beautiful scenery. Also automobile driving is very enjoyable in this country and many people motor to the Greenbrier from New York, Philadelphia and Washington.

Special Addresses

An interesting feature of the meeting will be the addresses on three organizations which play an important part in the electrical industry, namely, the International Electrotechnical Commission, the American Engineering Council and the American Engineering Standards Committee. The speakers will be C. H. Sharp, President of the U. S. National Committee of the I. E. C., L. W. Wallace, Executive Secretary, A. E. C., and C. E. Skinner, Chairman A. E. S. C. Many members will be glad to hear these talks on the objects, organization and activities of these bodies.

Recreation

The recreational side of the convention is receiving special attention and every afternoon will be free for sports and pleasure. There will be a reception and dance on Tuesday evening of the convention week and dancing will be enjoyed on other evenings.

The ladies will be especially welcome and many plans are being made for their enjoyment.

Section Delegates' Conference

During the morning and afternoon of Monday, June 21, a conference of the delegates of Institute Sections will be held under the suspices of the Sections Committee, but all interested are welcome to attend.

Registration and Hotel Accommodations

It will be appreciated if those who plan to attend the convention will notify Institute headquarters, 33 W. 39th Street, New York, as soon as possible.

Hotel accommodations should be reserved by communicating directly with The Greenbrier, White Sulphur Springs, W. Va. A list of rates is given below.

Rates per Person at The Greenbrier

Cost of Meals is Included

Single room without bath	$9.00
Single cottage room with use of bath (average five rooms per cottage with two or three baths)	$10.00
Double room (twin beds) and single room with bath between	$10.00
Two double rooms (twin beds) with bath between	$10.00
Two single rooms with bath between	$11.00
Double room (twin beds) with bath	$11.00
Single room with private bath	$12.00

Reduced Railroad Rates

Special railroad rates have been granted for those who attend the convention. These rates are available under the "certificate plan" which requires that each member or guest request a certificate when purchasing his railroad ticket to White Sulphur Springs. If 250 certificates are deposited with the Transportation Committee at The Greenbrier, each certificate holder is entitled to half-fare on his return trip over the same route. There are certain restrictions as to some limited trains, date of travel, etc., on which information should be obtained from local ticket agents.

Every member and guest should get a certificate whether or not he will use it. This will insure that those who want to take advantage of the reduced fare will not be deprived of the opportunity.

The following table shows the schedules on trains arriving in the morning in White Sulphur Springs from several cities. While this schedule will probably be in effect until after the convention, members should consult their local ticket agents relative to trains. It is advised that parlor-car and sleeping-car accommodations be reserved at the earliest possible date.

The general committee in charge of arrangements for the convention is as follows: Farley Osgood, Chairman, W. R. Collier, W. S. Lee, E. B. Meyer, W. E. Mitchell, A. M. Schoen and H. B. Smith.

SCHEDULE OF TRAINS ARRIVING AT WHITE SULPHUR SPRINGS IN THE MORNING

From the East

Lv. New York, Penn. Sta.	Penn. R. R.	5:45 p. m. (E.S.T.)
Lv. West Philadelphia	Penn. R. R.	7:53 p. m. (E.S.T.)
Lv. Wilmington	Penn. R. R.	8:34 p. m. (E.S.T.)
Lv. Baltimore	Penn. R. R.	10:00 p. m. (E.S.T.)
Lv. Pittsburgh	B. & O. Ry.	12:55 p. m. (E.S.T.)
Lv. Washington	C. & O. Ry.	11:20 p. m. (E.S.T.)
Ar. White Sulphur Springs	C. & O. Ry.	7:25 a. m. (E.S.T.)

This train carries through Pullman sleepers from New York.

From the West

Lv. Chicago	Big Four Ry.	1:00 p. m. (C.S.T.)
Lv. Indianapolis	Big Four Ry.	6:15 p. m. (C.S.T.)
Lv. St Louis	Big Four Ry.	12:00 Noon (C.S.T.)
Lv. Detroit	Mich. Cent. Ry.	12:20 Noon (E.S.T.)
Lv. Toledo	Big Four Ry.	2:00 .p m. (E.S.T.)
Lv. Louisville	C. & O. Ry.	6:00 p. m. (C.S.T.)
Lv. Cincinnati	C. & O. Ry.	9:10 p. m. (C.S.T.)
Ar. White Sulphur Springs	C. & O. Ry.	8:40 a. m. (E.S.T.)

This train carries through Pullman sleepers from Chicago, St. Louis, Cincinnati and Louisville to White Sulphur Springs.

E.S.T = Eastern Standard time C.S.T = Central Standard time.

TENTATIVE TECHNICAL PROGRAM

Tuesday Morning, June 22

President's Address, Dr. M. I. Pupin

Presentation of A. I. E. E. Prizes for Papers

Developments in Electrical Engineering as described in the reports of the Technical Committees and of the Standards Committee as indicated below.

Research, J. B. Whitehead, Chairman.
Electrophysics, J. H. Morecroft, Chairman.
Education, Harold Pender, Chairman.
Standards, H. S. Osborn, Chairman.
Instruments and Measurements, A. E. Knowlton, Chairman.
Communication, H. P. Charlesworth, Chairman.
Production and Application of Light, P. S. Millar, Chairman.
Electrical Machinery, H. M. Hobart, Chairman.

Wednesday Morning, June 23

Session A

Synchronous Machines (Extension and Interpretation of Blondel's Treatment), R. E. Doherty and C. A. Nickle, both of General Electric Co.

Non-Harmonic Alternating Currents, Frederick Bedell, Cornell University.

Graphical Solution of A-C. Circuits, F. W. Lee, Johns Hopkins University.

Session B

Remote Controlled Substations, W. C. Blackwood, N. Y. & Queens Elec. Lt. & Pr. Co.

The High-Speed Circuit Breaker in Railway Feeder Networks, J. W. McNairy, General Electric Co.

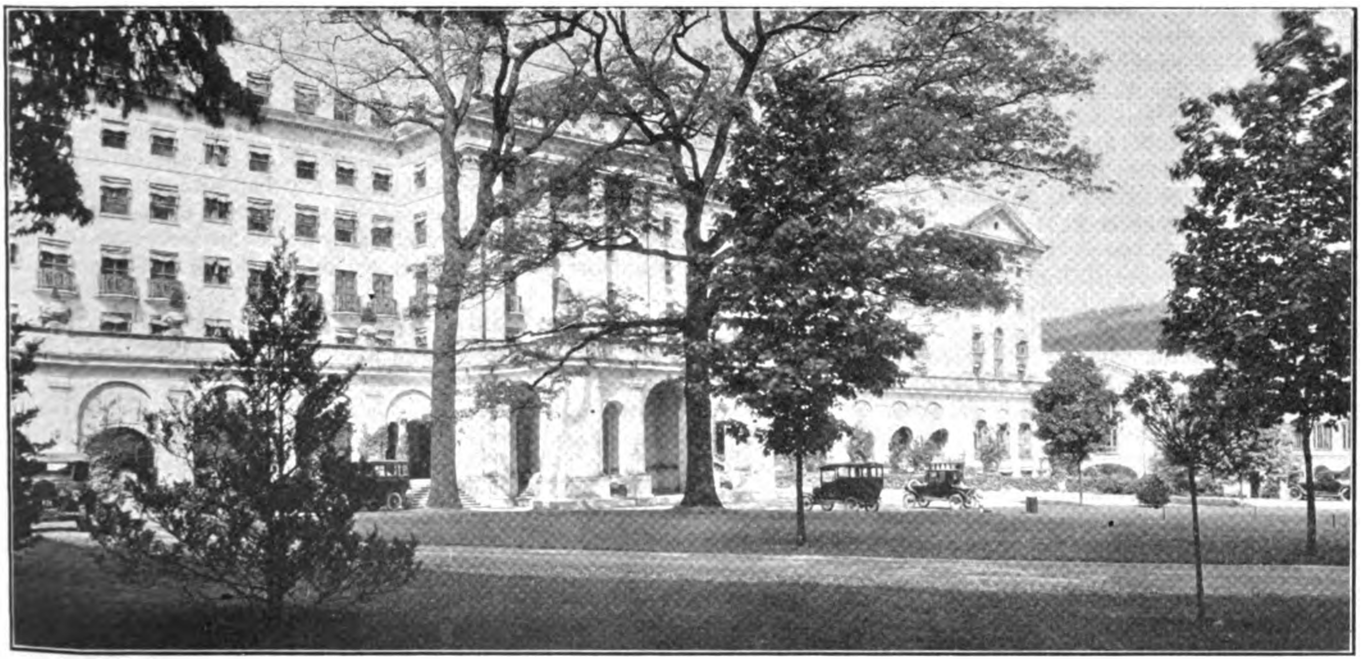
Regenerative Braking for D-C. Locomotives, Alfred Bredenberg, Jr., General Electric Co.

Multiplex Windings for D-C. Machines, C. C. Nelson, Massachusetts Inst. of Technology.

Thursday Morning, June 24

Developments in Electrical Engineering as described in the reports of the Technical Committees indicated below.

Power Generation, V. E. Alden, Chairman.
Power Transmission and Distribution, P. H. Thomas, Chairman.
Protective Devices, E. C. Stone, Chairman.
General Power Applications, A. M. MacCutcheon, Chairman.
Applications to Iron and Steel Production, F. B. Crosby, Chairman.
Applications to Mining Work, F. L. Stone, Chairman.
Applications to Marine Work, L. C. Brooks, Chairman.
Transportation, C. T. Hutchinson, Chairman.
Electrochemistry and Electrometallurgy, G. W. Vinal, Chairman.



A. I. E. E. Convention Headquarters—Greenbrier Hotel, White Sulphur Springs

FRIDAY MORNING, JUNE 25
SESSION A

The Mechanism of Breakdown of Dielectrics, P. L. Hoover, Harvard University.

Mercury-Arc Rectifiers, D. C. Prince, General Electric Co.

Electrical Recording of Vibrations, A. V. Mershon, General Electric Co.

SESSION B

Law of Magnetization, S. L. Gokhale, General Electric Co.

Surface Heat Transfer in Electric Machines with Forced Air Flow, O. E. Luke, Westinghouse Elec. & Mfg. Co.

General Theory of the Auto-Transformer, W. L. Upson, Washington University.

The Niagara Falls Regional Meeting

As we go to press with this issue of the JOURNAL, the Regional Meeting of the A. I. E. E. at Niagara Falls, N. Y., is convening for its first session. The number of early arrivals registered indicates an unusually good attendance, and the diversified program and excellent weather conditions which prevail presage a most interesting and enjoyable time for both the indoor and outdoor features of the meeting. The program was published in full in the May JOURNAL and preliminary copies have been mailed to all the membership in the eastern part of the United States. A complete account of this meeting will appear in the July JOURNAL.

Regional Meeting Held at Madison

The first regional meeting of the Great Lakes District of the Institute was held in Madison, Wis., May 6 and 7, with headquarters in the Hotel Loraine. It was most enjoyable and instructive to the one hundred eighty who attended. There were three well attended technical sessions, a regional dinner, and a number of interesting trips.

At the first session on Thursday, May 6, two papers were presented, namely, *Rural Electrification*, by G. C. Neff, and *Important Features of a Successful Plan for Rural Electrification*, by G. G. Post. Quite a number discussed these papers. Included were E. A. Stuart, A. H. Ford, E. H. Lehman, K. A. Pauly, Eugene Holcomb, C. B. Hayden and F. W. Duffee.

Three papers on high-voltage cable were presented Friday morning. These were as follows: *The Quality Rating of High-Tension Cable with Impregnated Paper Insulation*, by D. W. Roper and Herman Halperin; *Tests of Paper-Insulated, High-Tension Cable*, by F. M. Farmer; and *The Effect of Internal Vacua in High-Voltage Cables*, by W. A. Del Mar. These papers were received with great interest and extended discussion followed. Those taking part were: R. W. Atkinson, W. S. Clark, E. S. Lee, D. M. Simons, R. J. Wiseman, H. G. Burd, S. J. Rosch, Percy Dunsheath, E. C. Willman, F. A. Brownell, and E. M. Tingley.

Following these papers F. G. Boyce presented a paper on *Some Interconnected-System Operating Problems.* This was discussed by D. W. Roper, H. J. Burton, Carl Lee, and R. L. Dodd.

A session on *Cooperation between the Colleges and the Industries in Research* occupied Friday afternoon. Papers on this topic were read by the following: W. E. Wickenden (read by J. T. Rood), A. A. Potter (read by C. F. Harding), B. F. Bailey whose paper was entitled *Can the University Aid Industry?*, and Edward Bennett whose paper was entitled *Seminars for Practising Engineers.* Those contributing discussions were E. B. Paine, John Mills, S. H. Mortensen, J. S. Coldwell, F. E. Tourneur, and C. F. Harding.

L. J. Peters then presented a paper on *Behavior of Radio Receiving Systems to Signal and to Interference* which was discussed by Prof. Edward Bennett.

An enjoyable feature of the meeting was the regional dinner held on Thursday evening. A very inspiring address was made by Dr. Glenn Frank, President of the University of Wisconsin. Dr. Frank drew attention to the present sociological and economic problems of this country and suggested as possible remedies two courses of action. The first he called a "new scientific renaissance" which could be accomplished by making the knowledge of researchers in all lines of science available for general understanding and practical utilization. The second remedy he called a "new industrial revolution." The main lines of action in such a revolution would be four, namely, (1) to decentralize industry, (2) to regularize production and distribution, eliminating excessive seasonal activities, (3) to reduce unemployment, and (4) to allay the insecurity of the labor class. In elaborating on these propositions Dr. Frank suggested as one means of accomplishing them, the small factory making standardized parts and situated in farm territory where laborers might alternate between farm work and factory work.

Meetings of the Branch Counselors of the District were held on Thursday and Friday at which were present the counselors of ten Branches and several other professors who were interested.

Many of the visitors took the trips which were arranged in and around Madison and a number also found time to play golf.

Student Convention Held at M. I. T.

A convention of enrolled students of the Northeastern District of the A. I. E. E. was held at Massachusetts Institute of Technology, Cambridge, Mass., on May 7. The meeting, which was arranged by a student committee assisted by the Boston Section, had an attendance of one hundred sixty. There were three technical papers presented and a number of inspection trips were made. A banquet was also given.

At the technical session in the morning, at which S. A. Tucker, Chairman of the Yale Branch, presided, the following papers were presented: *D-C. Transmission Considerations*, by S. W. Marshall, M. I. T. graduate; *A Phase of Distribution Engineering*, by O. W. Briden, Brown 1926; and *Electrical Characteristics of Richmond Station of the Philadelphia Electric Company*, by Constantine Barry, M. I. T. 1927.

At the banquet in the evening, Prof. H. B. Smith, Vice-President in the Northeastern District, was toastmaster. Dr. S. W. Stratton, President of Massachusetts Institute of Technology, welcomed those present in a short talk, after which three addresses were made. Dr. M. I. Pupin, President of the A. I. E. E., chose as his subject *Science and Engineering.* He was followed by Prof. C. F. Scott, Yale University, who spoke on *How Student Branches Came into Being*, and R. E. Doherty, Consulting Engineer, General Electric Company, who spoke on *Employment with a Large Manufacturing Company.*

In the afternoon many took the trips which were made to the following places: Edgar Station of the Edison Electric Illuminating Company; the plant of the Simplex Wire and Cable Company; a machine-switching exchange of the New England Telephone Company; and the M. I. T. Laboratories.

A meeting and luncheon of the Branch Counselors of the District was held at which every Counselor was present besides a number of others interested in Branch and Section activities.

Establishing of Louisville Section

A meeting was held on May 13 in Louisville, Kentucky to consider the advantages of establishing a local Section of the Institute in that city. Some sixteen A. I. E. E. members were present and listened to an interesting talk on the value of local Sections given by W. E. Mitchell of the Alabama Power Company, Vice-President of the A. I. E. E. from the Southern District. It was decided that the establishing of a local Section in Louisville would be a distinct advantage to every one concerned and a committee was appointed to complete the formalities and present a report at a meeting to be held in September. Those named on the committee were, E. D. Wood, Operating Electrical Engineer, Louisville Gas & Electric Co. and D. C. Jackson, Jr., Professor of Mechanical and Electrical Engineering at the University of Louisville.

Cummings C. Chesney

PRESIDENT-ELECT OF THE A. I. E. E.

Cummings C. Chesney, Manager and Chief Engineer, General Electric Company, Pittsfield, Mass., has been elected President of the American Institute of Electrical Engineers for the year beginning August 1, 1926, as announced in the report of the Committee of Tellers published elsewhere in this issue.

President-elect Chesney was born in Selingsgrove, Pa., October 28, 1863. He was graduated from Pennsylvania State College in 1885, and for three years taught mathematics and chemistry. In 1888 he joined Mr. William Stanley's laboratory force at Great Barrington, Mass., and the following year entered the services of the United States Electric Lighting Company in Newark, N. J., a subsidiary of the Westinghouse Electric and Manufacturing Company. In 1890 he moved to Pittsfield, Mass., where he was one of the original incorporations of the Stanley Electric Manufacturing Company, started with a capital of $25,000. The company was organized to develop the alternating-current inventions of William Stanley, John Kelley and C. C. Chesney. The work was primarily of a pioneer character with little precedent to guide it.

C. C. Chesney

This company developed the well-known S. K. C. system (Stanley, Kelly, Chesney). The first polyphase transmission plant equipped with the S. K. C. system to be put into successful operation and the first in America was installed in 1893 and is supplying power and light today for use in the towns of Housatonic and Great Barrington, Massachusetts. In 1895 a 12,000-volt plant was installed for service from Lowell to Grand Rapids, Michigan. The operating success of these alternators was due to special design in which the high-tension currents were generated in the stator element by the revolving rotor, these being the first alternators to produce a true sine wave. As early as 1896 alternating-current generators of 6000 volts with control equipment were put into successful operation on the transmission line of the Montmorency Electric Power Company, Quebec. In 1898 generators up to 12,000 volts were placed in service. During the early period two-phase alternating-current induction motors were developed, electrostatic condensers at 500 volts and electric transformers of 100-light capacity. In developing the transformer all spaces in the coils were filled with Gilsenite to provide better heat dissipation and insulation. This occurred as early as 1892, as did the development of cloth treated with oxidized linseed oil. The most effective general insulation in use today was developed by the Stanley Company, in 1891-1892, superseding the old insulating methods using shellac and P. & B. paint. In 1893 belt-driven alternators were put into successful operation and in 1899 alternators of this design direct-connected to steam engines went into successful operation in the power house of the Staten Island Electric Company. These were the first alternators to be operated in parallel and in regular commercial service. Switchboard instruments, high-tension arc breaking devices, frequency indicators, indicating wattmeters, lightning protection for high and low-tension currents, condensers, etc., were among other apparatus manufactured by the Stanley Company. The company built the first revolving field types of alternators used in America. These were extensively used in hydraulic stations, notably the Bay Counties and Standard companies' lines in California, at that time the longest high-voltage lines in the world, using 40,000 to 60,000 volts.

Mr. Chesney was vice-president and chief engineer of the Stanley Company from 1904 to 1906. On the latter date he took up the duties of chief engineer and manager of the Pittsfield works of the General Electric Company, which company had acquired the Stanley Manufacturing Company. Under Mr. Chesney's supervision the Pittsfield works in recent years have made particular progress in the development of apparatus for commercial service up to 220,000 volts, and lately have completed successful tests of 1,000,000 volts for transmission purposes.

Mr. Chesney is a Fellow of the Institute, and has taken an active interest in its affairs. He served as manager from 1905 to 1908 and as vice-president from 1908 to 1910. He is also a member of the Society of Arts, London, of the American Society for the Advancement of Science and of the Engineers Club of New York. During the year 1920 he was president of the Engineering Society of Western Massachusetts. He has always had a strong civic interest, taking an active part in the life of his community. He is chairman of the industrial committee of the crippled

children's home in Pittsfield, one of the best equipped industrial rehabilitation schools for children in New England; and is director of the Agricultural Bank and president of the Morris Plan Bank of Pittsfield.

The Edison Medal was awarded to Mr. Chesney in 1921, "for early developments in alternating-current transmission."

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, May 21, 1926.

There were present: President M. I. Pupin, New York; Vice-Presidents Harold B. Smith, Worcester, Mass.; Arthur G. Pierce, Cleveland, Ohio; Managers H. M. Hobart, Schenectady, N. Y.; G. L. Knight, Brooklyn, N. Y.; National Secretary F. L. Hutchinson, New York.

A minute was adopted in memory of the late Carl Hering, Past President of the Institute.

Reports were presented of meetings of the Board of Examiners held April 26 and May 17, 1926, and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 93 Students were ordered enrolled; 164 applicants were elected to the grade of Associate; 18 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 3 applicants were transferred to the grade of Fellow; 18 applicants were transferred to the grade of Member.

The Board ratified the approval by the Finance Committee, for payment, of monthly bills amounting to $21,343.99.

The National Secretary reported 1330 members delinquent in the payment of dues for the fiscal year ending April 30, 1926; and the Board directed that the usual efforts be continued to collect these dues, through the Secretary's office and by bringing the list to the attention of the Section officers concerned.

The annual report of the Board of Directors for the fiscal year ending April 30, 1926, as prepared in the National Secretary's office was presented and accepted for presentation at the annual business meeting of the Institute to be held during the evening of the same day. The annual report of the National Treasurer was presented, accepted, and ordered filed.

The annual reports of various standing committees (exclusive of the technical committees, whose reports will be presented at the Annual Convention in June), abstracts of which were incorporated in the Board of Directors' report, were received and ordered filed for reference by the committees of the next administration.

The following new by-law was adopted, in order to incorporate in the Institute by-laws the action taken by the Board of Directors on April 9, 1926, in adopting the policy of providing for the affiliation with the Institute of engineering student organizations in colleges in which it is not feasible to establish Student Branches of the Institute because of the limited number of students:

"SEC. 59A. An established student engineering society in a university or technical school of recognized standing may, upon application of its officers and a member of the Institute connected with the school, and the approval of the Board of Directors, become associated with the Institute. Members of such associated student engineering society may have the same privileges as enrolled Students of the Institute and will be governed by the same requirements."

Upon the recommendation of the Committee on Student Branches, the Board approved for printing and distribution in pamphlet form, "Suggested By-laws for Student Branches."

The Standards Committee submitted for the Board's approval, a revision of Section 7 of the A. I. E. E. Standards (Alternators, Synchronous Motors and Synchronous Machines in General), and the Board voted to approve the recommended revision.

An invitation to nominate a candidate for the 1926 Kelvin Medal was accepted and referred to the President with power. President Pupin stated that he would confer with the presidents of the other Founder Societies before acting in the matter.

In accordance with Section 37 of the constitution, the Board considered the appointment of a National Secretary for the administrative year beginning August 1, 1926, and National Secretary F. L. Hutchinson was reappointed.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Board of Directors' Report for the Year Ending April 30, 1926

The annual report of the Board of Directors of the American Institute of Electrical Engineers was presented at the annual business meeting of the Institute held in New York Friday evening, May 21.

This report consists of a brief summary of the principal activities of the Institute during the year, including abstracts of various reports submitted by officers and committees, covering their respective branches of work. The more important matters referred to in the report have been, or will be, covered in much more detailed form in the JOURNAL, and therefore the report will not be published in full herein; but any member of the Institute may obtain a pamphlet copy upon application to the National Secretary.

The growth in Institute membership during the year is indicated in the following tabulation:

	Honorary	Fellow	Member	Associate	Total
Membership on April 30, 1925	4	597	2,436	14,282	17,319
Additions:					
Transferred		33	178		
New Members Qualified		5	97	1,976	
Reinstated			8	45	
Total	4	635	2,719	16,303	
Deductions:					
Died		7	16	71	
Resigned		2	36	333	
Transferred			18	193	
Dropped		1	26	800	
Membership, April 30, 1926	4	625	2,623	14,906	18,158
Net increase in Membership during the year					839

The activity of the Sections and Branches during the year and the growth in the number of these organizations, also in the number of meetings held by them and in the aggregate attendance, are shown in the following statement:

	For Fiscal Year Ending			
	May 1 1919	May 1 1921	May 1 1923	May 1 1926
SECTION				
Number of Sections	34	42	46	51
Number of Section meetings held	217	303	344	405
Total Attendance	25,837	37,823	46,672	58,959
BRANCHES				
Number of Branches	61	65	68	86
Number of Branch meetings held	156	443	503	714
Attendance	6,441	21,629	26,893	35,270

The Finance Committee's report, together with the general balance sheet and detailed financial statements of the public accountants who audited the Institute's books, is included in the report.

Report of Committee of Tellers on Election of Officers

To the President,
American Institute of Electrical Engineers

DEAR SIR:

This committee has carefully canvassed the ballots cast for officers for the year 1926-1927. The result is as follows:

Total number of ballot envelopes received		4811
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 34 of the Constitution	43	
Rejected on account of voter being in arrears for dues for year ending May 1, 1926, as provided in the Constitution and By-Laws	99	
Rejected on account of ballot not being enclosed in inner envelope, or being improperly marked, or on account of inner envelope or ballot bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution	111	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution	14	267
Leaving as valid ballots		4544

These valid ballots were counted, and the result is shown as follows:

For President	
C. C. Chesney	4399
Blank	145
For Vice-Presidents	
District	
No. 1 *North Eastern*	
H. M. Hobart	4397
Blank	147
No. 3 *New York*	
G. L. Knight	4385
Blank	159
No. 5 *Great Lakes*	
B. G. Jamieson	4402
Blank	142
No. 7 *South West*	
A. E. Bettis	4362
Blank	182
No. 9 *North West*	
H. H. Schoolfield	4371
Blank	173
For Managers	
F. J. Chesterman	4441
Blank	103
H. C. Don Carlos	4433
Blank	111
I. E. Moultrop	4439
Blank	105
For Treasurer	
George A. Hamilton	4407
Blank	137

Respectfully submitted,

SERGIUS P. GRACE, *Chairman*
E. S. HOLCOMBE
W. E. COOVER
E. F. THRALL
E. F. WATSON
J. T. WELLS
Committee of Tellers.

Date May 10, 1926.

Annual Meeting of A. S. T. M.

The Twenty-Ninth Annual Meeting of the American Society for Testing Materials will be held at Chalfonte-Haddon Hall, Atlantic City, N. J., June 21-25 inclusive. The program will be diversified including the following sessions: Tuesday morning Committee Meetings; afternoon, First Session, Wrought Iron, Cast Iron and Magnetic Testing. Wednesday, June 23, (a. m.) Third Session, Steel; Fourth Session, Brick, Tile, Refractories and Fire Tests; Fifth Session, (p. m.), Edgar Marburg Lecture. Thursday, June 24, (a. m.), Sixth Session, Corrosion and Fatigue of Metals; Seventh Session, Road Materials, Waterproofing, Petroleum Products and Thermometers. Evening Sessions, Non-Ferrous Metals and Metallography; Textiles, Rubber, Coal, Timber, Insulating Materials and Slate. Tenth Session, Symposium on Resin. Friday, June 25th, (a. m.), Eleventh Session, Preservative Coatings and Naval Stores; Twelfth Session, Cement, Lime, Gypsum and Nomenclature.

Special, reduced rates have been prearranged for those who wish to attend if 250 certificates are filed, and as he registers, each member will receive a complete set of reports and papers prepared for this meeting. Golf and tennis tournaments, an informal dance and smoker will supply entertainment of a more recreative nature.

1926 Convention of the Illuminating Engineering Society

The Twentieth Annual Convention of the Illuminating Engineering Society will be held at Spring Lake, N. J., from September 7-10, inclusive, with headquarters at the Essex and Sussex Hotel. The Essex and Sussex is ideally located directly on the ocean front, a short trip from New York and Philadelphia. It is beautifully appointed and enjoys a most enviable reputation for its service and cuisine.

A well-rounded papers program is being prepared with special features showing the developments in specific fields which have taken place during the twenty years of existence of the Society. Special and unique features are also being planned for the entertainment program and it is confidently expected that the 1926 Convention will prove to be a most successful one.

Annual Meeting and New York Section Meeting, May 21, 1926

The annual business meeting of the Institute was held at the Engineering Societies Building, New York, on Friday evening, May 21, 1926. President Pupin presided, and called upon National Secretary Hutchinson, who presented in abstract the annual report of the Board of Directors, printed copies of which had been distributed to members in attendance. (This report is referred to elsewhere in this issue).

The report of the Committee of Tellers on the election of officers of the Institute was then presented by Mr. Hutchinson, and, in accordance therewith, President Pupin declared the election of the following officers, whose terms will begin on August 1, 1926:

PRESIDENT:	Cummings C. Chesney, Pittsfield, Mass.
VICE-PRESIDENTS:	
District No. 1	H. M. Hobart, Schenectady, N. Y.
District No. 3	George L. Knight, Brooklyn, N. Y.
District No. 5	B. G. Jamieson, Chicago, Ill.
District No. 7	A. E. Bettis, Kansas City, Mo.
District No. 9	H. H. Schoolfield, Portland, Ore.
MANAGERS:	F. J. Chesterman, Pittsburgh, Pa.
	H. C. Don Carlos, Toronto, Ont.
	I. E. Moultrop, Boston, Mass.

NATIONAL TREASURER: George A. Hamilton, Elizabeth, N. J.

These officers, together with the following hold-over officers, will constitute the Board of Directors for the next administrative year, beginning August 1: M. I. Pupin, New York; Farley Osgood, New York; P. M. Downing, San Francisco, Calif.; Herbert S. Sands, Denver, Colo.; W. E. Mitchell, Birmingham, Ala.; Arthur G. Pierce, Cleveland, Ohio; W. P. Dobson, Toronto, Ont.; W. M. McConahey, Sharon, Pa.; W. K. Vanderpoel, New York; H. P. Charlesworth, New York; John B. Whitehead, Baltimore, Md.; J. M. Bryant, Austin, Tex.; E. B. Merriam,

Schenectady, N. Y.; M. M. Fowler, Chicago, Ill.; H. A. Kidder, New York; E. C. Stone, Pittsburgh, Pa.

Dr. Pupin then called upon Mr. H. A. Kidder to preside during the remainder of the meeting which was under the auspices of the New York Section.

Chairman Kidder, after a few preliminary remarks on the value of modern methods of obtaining data on circuit breaker performance as compared with the early days when the certainty of performance of a breaker was an almost unknown quantity, introduced the speaker of the evening, W. R. Woodward, General Engineer, Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa. In the presentation of his paper, "A High-Power Laboratory for Testing Oil Circuit Breakers and Other Apparatus," Mr. Woodward outlined the advantages and disadvantages of factory testing as compared to field tests, described the ever increasing demand for larger and larger test sets, and the effort which has been made to make the laboratory complete, flexible, and safe. The paper was profusely illustrated with lantern slides. Discussion of the paper was given by R. M. Spurck, G. E. Co., and E. K. Read of the Westinghouse Co.

The Montefiore Triennial Prize

April 30, 1927 has been set as the latest date upon which papers may be submitted to the jury of award for the George Montefiore Foundation Medal.

This prize is awarded every three years upon the basis of international competition for the best original work in scientific progress and progress in technical application of electricity in any of its branches. Popular works and simple compilations are precluded. Papers submitted are subject to the following general stipulations:

Only such papers as have been prepared during the three years preceding the meeting of the acting jury will be acceptable; all must be either printed or typewritten, in both French and English, and twelve copies sent free of postage to M. le secretaire-archiviste de la Foundation George Montefiore, rue Saint-Gilles, 31 Liege, Belgium, by whom they will be acknowledged to the author. A majority vote of four-fifths by the board of award allows of one-third of the amount available being bestowed for the presentation of a valuable discovery in the scientific field or the statement of a new idea which may lead to important development in electrical progression. Should the prize for any year not be awarded or any portion of it remain undistributed this amount will be added to the award for the next triennial period. Any paper upon which the jury decides will be published in the Bulletin de l'Association des Ingenieurs électriciens of l'Institut électro-technique Montefiore, 25 reprints to be sent to the author free of charge but no further profit to be derived by him from its reprinting. The award carries with it a gratuity of 20,500 francs (about $600) to be distributed at the discrimination of the jury of award, which is comprised of ten electrical engineers, all holding diplomas of the Institute Electrotechnique Montefiore, five Belgians and five others, presided over by the director of the Institute Electro-Technique Montefiore, who automatically becomes one of the Belgian delegates.

At the head of all papers submitted, or in some other conspicuous place should be plainly written: "Travail soumis au concours de la Foundation George Montefiore, session de 1923-1926" (Paper submitted for the competition of the George Montefiore Foundation).

American Engineering Standards Committee

WELCOME SUGGESTIONS ON SYMBOLS AND ABBREVIATIONS

Under the auspices of the American Engineering Standards Committee, an undertaking which will lead eventually to the standardization of scientific and engineering symbols and abbreviations has now been fairly launched. The sectional committee, which in its representation includes thirty-one trade, technical and scientific bodies, held its organization meeting January 21, 1926, societies taking the leading part in the work as sponsors being, the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education. The secretary of the sectional committee, (Preston S. Millar, Electrical Testing Laboratories, 80th Street and East End Avenue, New York City) will be very glad to receive in cooperation any suggestions which interested organizations may care to make with regard to symbols and abbreviations to be adopted in the various fields of engineering and industry. Completion of the entire work will require the participation of many interests, it is the committee's present plan to concentrate upon the fields in which there is the greatest need of unification of standards, taking up further work as opportunity affords.

Carnegie Institute Summer Course

Excepting a few guest instructors and special lecturers, none but members of the regular college teaching staff has been appointed to the faculty for the summer courses this year at the Carnegie Institute of Technology, according to an announcement from the Pittsburgh institution. The guest members of the faculty, it is further announced, will be on duty at various periods during the six weeks' courses for teachers from June 28 to August 6 in the College of Fine Arts. For the eight weeks' courses from June 4 to August 6 for undergraduates in the industrial and engineering courses, only members of the regular college faculty have been engaged.

As a result of the increasing interest shown in the type of technical instruction featured at this institution. Carnegie officials report plans to receive another large enrolment of summer students for this year.

ENGINEERING FOUNDATION

EDWARD DEAN ADAMS GIVES GENEROUSLY TO RESEARCH

A gift of $100,000 has been made to the Engineering Foundation and the Engineering Societies Library by Edward Dean Adams, as announced by W. L. Saunders President of the United Engineering Society and Chairman of its endowment committee at a meeting of the Foundation the evening of May 19th when a dinner was held at the Union League, with Mr. Adams as guest of honor.

This generous gift of Mr. Adams' brings research endowment fund up to a total of $650,000, with Mr. Ambrose Swasey's initial endowment of $500,000 and the $50,000 received under the will of the late Henry R. Towne.

The sum of $12,000 was contributed toward the support and promulgation of a fundamental research in blast furnace slags, now in progress at the University of Wisconsin under the direction of Richard S. McCaffery, member of the Institute of Mining Engineers and Professor of Metallurgy at the University. The investigation is being conducted with the understanding that information established by the work done will be contributed to the research data of the Engineering Foundation before the 20th of each January, covering progress of the preceding calendar year; any unused portion of the funds appropriated to revert to the Foundation.

The Foundation also voted $5000 a year for two years, to promote electrical insulation research on the specific subject of dielectric absorption, through investigation to be conducted at the Johns Hopkins University under the direction of John B. Whitehead, Fellow of the American Institute of Electrical Engineers and Professor of Electrical Engineering at Johns

Hopkins University. Results on these investigations are to be returned to the Foundation before January 20th of each year covering the previous calendar year with full accounting of the funds expended and return of any residue which may exist.

The personnel of the Endowment Committee is as follows:

Ex officiis:

W. L. Saunders, President, United Engineering Society, *Chairman.*

L. B. Stillwell, Chairman, Engineering Foundation.

Sydney H. Ball, Chairman, Library Board.

Nominees of American Society of Civil Engineers:

Charles F. Loweth, Chicago; Chief Engineer, Chicago, Milwaukee & St. Paul Railway.

H. deB. Parsons, New York; Consulting Engineer.

Ralph J. Reed, Los Angeles; Chief Engr., Union Oil Company.

Nominees of American Inst. of Mining and Metallurgical Engineers:

D. W. Brunton, Denver; Chairman, Board of Consulting Engineers, Moffatt Tunnel.

J. V. N. Dorr, President, The Dorr Company (metallurgical, chemical and sanitary process equipment). New York.

Thomas Robins, New York; President, Robins Conveying Belt Co., member, Naval Consulting Board.

Nominees of American Society of Mechanical Engineers:

J. W. Lieb, New York; Vice-President & General Manager, The New York Edison Company.

Wynne Meredith, San Francisco; member of firm, Sanderson & Porter.

E. A. Simmons, New York; President, Simmons-Boardman Publishing Company.

Nominees of American Institute of Electrical Engineers:

Calvert Townley, New York; Assistant to President, Westinghouse Electric & Manufacturing Company.

H. A. Lardner, Vice-President, J. G. White Engineering Corporation, New York.

E. Wilbur Rice, Jr., Schenectady; Honorary Chairman, General Electric Company.

Members-at-large:

Charles F. Rand, New York; Past-President, American Inst. of Mining and Metallurgical Engineers.

James H. Perkins, New York; President, The Farmers' Loan and Trust Company, financial adviser and custodian of securities for United Engineering Society.

H. Hobart Porter, New York, of Sanderson & Porter, and President, American Water Works & Electric Company.

Robinson Fellowship—Ohio State University

At a recent meeting of the Robinson Fellowship Committee it was voted to recommend Mr. Herbert L. Rawlins of Fredericktown, Ohio, Senior in Electrical Engineering, for the award of the Stillman W. Robinson Fellowship for the year 1926-27.

This fellowship has a value of $750 and provides that the successful applicant shall devote his entire time to graduate study and research, leading to the degree of Master of Electrical Engineering.

This fellowship was endowed by Stillman W. Robinson, formerly Professor of Mechanical Engineering and a famous inventor of shoe and other automatic machinery. Professor Robinson also gave the University the large experimental boiler in the Mechanical Engineering Department.

Dr. E. J. Berg Gives Steinmetz Lecture Before Schenectady Section

The second Steinmetz Lecture, entitled *The Solution of Transient Phenomena by Elementary Mathematics* was delivered by Dr. Ernst J. Berg, Professor of Electrical Engineering, Union University, at the meeting of the Schenectady Section on April 23. The Steinmetz Lectures are a series of annual addresses which was instituted last year by the Schenectady Section in honor of the late Dr. C. P. Steinmetz. The first address was given by Dr. M. I. Pupin in 1925. For the second lecture Dr. Berg selected a subject in which Dr. Steinmetz was deeply interested throughout his lifetime. The lecture was much appreciated by the 450 who were present. Copies of the address may be obtained from Institute headquarters, New York.

National Capital Park and Planning Commission

Since the development of plans for this Commission, engineers generally have been interested because of a proposal to make prominent engineers from the District of Columbia and elsewhere, members. Under the provision of the Act at least one man would be appointed from the District of Columbia and as announced on May 19th at the White House engineers are pleased to find a prominent member of their profession, F. A. Delano, on the list of appointees. Other men prominent in the engineering architectural development of city planning appointed to the and Commission by the President, were:

M. B. Medary, Philadelphia, Pa., President of the American Institute of Architects,

F. L. Ohmstead, of Boston, Mass.,

J. C. Nichols, of Kansas City, Mo.

Bureau of Standards Visiting Committee Meets

The Visiting Committee of the Bureau of Standards met with Director Burgess at the Bureau on April 29th. This body is composed of five scientists appointed by the Secretary of Commerce and entrusted with the work of going over the policy of the Bureau from time to time to look into the status of scientific experimentations and outline new phases of investigation.

It is understood that the Committee, during its recent meeting, went over the requirements of the Bureau of Standards and worked with the Director in developing some plans for the future. The nature of the Committee's report has not been disclosed. It was stated by Dr. George K. Burgess, Director of the Bureau, that the complete report will be submitted at a later date. The members of the Committee are: Wilder D. Bancroft, of Cornell University; Gano Dunn, New York; William F. Durand, New York; Samuel W. Stratton, Massachusetts Institute of Technology, and Ambrose Swasey, of Cleveland, Ohio. Prior to their meeting at the Bureau, the committee paid a complimentary call on Secretary Hoover.

Three members of the committee are also members of the American Institute of Electrical Engineers.

Stamp Memorial to John Ericsson

Postmaster General New has authorized a special five cent postage as a memorial to John Ericsson, engineer, builder of the *Monitor*, according to an announcement at the Post Office Department under date of May 5th. It is understood that an issue of 15,000,000 of these stamps will be placed on sale first at New York City, Chicago, Minneapolis and Washington, on May 29th. The stamp is being released simultaneously with the unveiling of the John Ericsson Memorial Statue in Potomac Park, Washington, D. C., on May 29th.

According to a statement issued by the State Department the Crown Prince of Sweden will unveil the statue. Representatives of the leading engineering and allied technical organizations of America have been invited to attend this ceremony. The subject of the stamp will be a replica of the John Ericsson Memorial, designed by the sculptor, James Earle Fraser.

Levy Medal to F. W. Peek, Jr.

Frank W. Peek, Jr., consulting engineer of the General Electric Company in charge of the company's high voltage experimental laboratory at Pittsfield, Mass., was awarded the Levy gold medal by the Franklin Institute of Philadelphia. This award, founded by Louis Edward Levy, was given Mr. Peek in recognition of his paper presented a year ago before the institute on "High-Voltage Phenomena."

Mr. Peek is one of the world's best known figures today in the investigation of artificial lightning and high voltages. He has produced, in the General Electric's laboratory, voltages greater than two million. Outstanding in his research work has been his formation and establishment of laws regarding corona, the investigation of lightning and its effect on high voltage transmission, the study of dielectric phenomena, line insulations and the problems connected with the transmission of high voltage currents.

Obituary

Carl Hering, pioneer electrical engineer and an outstanding figure in today's electrical engineering circles, died suddenly on Monday, May 10th, at the Hahnemann Hospital, Philadelphia, where he had gone to recuperate from what he considered a slight affection of the heart.

Born in Philadelphia in 1860, Doctor Hering's early education was through the schools of that city and in Germany. He quickly became a leader in the technical world, especially in the electrical field in its modern form, which had just sprung into being as he arrived at the age of manhood. In 1880, he graduated from the University of Pennsylvania with a degree of Bachelor of Science and high honors; seven years later, he had conferred upon him the post-graduate degree of M. E. and again, in later years, he received from this same university the honorary degree of Doctor of Science. In 1882, while teaching at the university, he began the study of electrical engineering and in 1883 he published his first technical article, the precursor of a long series of contributions to the profession, including innumerable papers read before the various societies, press articles and no less than eight books. In this same year he was appointed a member of the jury for the international electrical exhibition in Vienna and in the years following he was called upon at least eleven times for similar service both in Europe and at home. There was scarcely an international or otherwise important exhibition associated with the electrical art in which he did not participate. In 1885 he became chief electrical engineer for a German company manufacturing and installing motors and dynamos, but early in 1886 he returned to his native country to practise consulting electrical engineering in the city of Philadelphia. In 1889 he was appointed officer of Public Instruction by the French Government, which, in 1891, made him Knight of the Legion of Honor. Among his many other attainments, Doctor Hering was an enthusiast on the subject of scientific explanation of exceptions to generally accepted physical laws, and through his own personal research, contributed much to the classification of electrical nomenclature. In 1892 he was technical editor of the *Electrical World* and a year later established the "Digest of Current Electrical Literature." For ten years he conducted a department, abstracting notable articles on electrical science in all technical papers of the world. Doctor Hering's work in the electrochemical world began prior to 1890 with extended researches into storage batteries. From these results he obtained numerous patents. He also investigated the regeneration of battery solutions and, in 1900 made electric furnace tests for the reduction of arsenic ore. Some six years later, while designing and operating electric furnaces, he began a series of experiments which resulted in the discovery of a new electromagnetic force to contract a conductor through which current is flowing even to the extent of rupture, when it is fluid. This was known as the "pinch" effect. He also discovered other effects showing that the electromagnetic forces act upon the material of the conductor. In 1909 he applied these forces to impart rapid motion to molten masses and based upon this principle, he invented an electric furnace now in wide commercial use. As early in his career as 1883 he was computing conversion factors for electrical and mechanical energy, publishing a comprehensive treatise on this subject in 1904. A few years later, however, he recalculated all electrochemical equivalents. In 1908 he made exhaustive analyses of the interrelations of various units entering into the calculation of light phenomena and in that same year he described an experiment purporting to demonstrate a hitherto unrecognized factor in electromagnetic induction to show that the well-known Maxwell law of induction should be modified in order to become universal. Doctor Hering was one of the three men to plan and organize the American Electrochemical Society and was also instrumental in founding the *Electrochemical Industry* now *Chemical and Metallurgical Engineering,* published by the McGraw-Hill Publishing Company.

In 1900-1901 he served the Institute as its President; in 1904 he was elected president of the Engineers' Club and in 1906, president of the American Electrochemical Society. Other scientific groups of which he was a valued member are American Association for the Advancement of Science, the Franklin Institute and Illuminating Engineering Society.

At its May 21 meeting, the Board of Directors of the A. I. E. E. passed the following Resolution:

In the death of Dr. Carl Hering on May 10th a distinguished member has been removed from the ranks of the A. I. E. E. pioneers. From eighteen eighty-eight, when he affiliated with the Institute, down through his years of faithful and able service as a committeeman and as President in 1900 and 1901, Dr. Hering stood firmly for the maintenance of Institute ideals. It is with a sense of the great loss sustained that the Board of Directors hereby extends to his family and associates its sincere sympathy, and orders this minute spread upon the records.

Robert Sanford Riley died Friday, May 7, 1926. His death closes a career of much more than usual success not only in his home community but also throughout the entire engineering world. Coupled with high ability, he had high humanity. He led but also served.

Mr. Riley was born in Canada in 1874. His boyhood was spent in Winnipeg. Both his father and mother are descended from a line of old Yorkshire, England. He was graduated with honors in 1896 from Worcester Polytechnic Institute.

He began his business career as an apprentice in a locomotive works. Between 1898 and 1903 Mr. Riley worked his way around the world as a marine engineer starting from Cramp's shipyard in a ship which as draftsman he had helped to design. Sailing the Pacific in the Empress Line, he joined the United States Navy in Hong Kong. He went through the boxer uprising and came home via the Indian Ocean and Suez Canal as chief engineer of the *Arethusa*, a naval auxiliary used as a base ship for torpedo boats. He left the sea to enter the employ of the New York Ship Building Company.

In 1906 Mr. Riley became manager of the American Ship Windlass Co. of Providence, R. I., and here he had an opportunity to put his naval engineering experience to further use in the design of windlasses and steering engines. He soon specialized on the "Taylor" stoker, then being manufactured by the American Ship Windlass Co. in the crude form in which it was left by the death of the inventor. Mr. Riley redesigned and improved the "Taylor" stoker and built up a large business, and became known as a pioneer in the commercial development of high capacity under-feed stokers.

In 1911 Mr. Riley sold out his interests in the American Ship Windlass Co. and later organized the Danford Riley Stoker

Company of Worcester, Mass., to develop and market the Riley Self-Dumping Underfeed stoker.

In July 1918, Mr. Riley's services were called for by the Emergency Fleet Corporation under Chas. L. Schwab. He organized a department for the conducting of trial trips and observing performance in service of boats of the Emergency Fleet Corporation which in January 1919 he turned over to the permanent organization of the Emergency Fleet Corporation.

In 1918 Mr. Riley was elected President of the Worcester Chamber of Commerce and was re-elected in 1919. He was vice-president of the Worcester Y. M. C. A., a member of the A. S. M. E. and served on various of its committees, contributing many valuable papers, he was a member of the Naval Architects and Marine Engineers, the Alpine Club of America, the Appalachian Club, Engineers Clubs of Boston and New York, the Worcester Club, the Tatnuck Country Club, the Detroit Athletic Club. He took an active interest in the movement for the betterment of the city, and was a large contributor to its worthy causes. He gave not only of his money but of his time and energies.

Henry Fleetwood Albright, Fellow of the Institute and since 1917 vice-president of the Western Electric Company, Chicago, died Tuesday, May 11th, after an illness of several months.

Mr. Albright was born in Lancaster, Pennsylvania, October 5th, 1868. Immediately upon his graduation from the Philadelphia High School, he started his technical education under private tutelage and in 1886 entered the employ of the Fuel Gas and Electric Company of Pittsburgh which, at that time, was installing all Westinghouse plants. In 1892 he joined the Western Electric Company as a salesman of electric light and power apparatus in Chicago, and two years later was transferred to its Construction Department in New York, in 1897 becoming plant engineer of the New York factory. His brilliant success and natural aptitude led, in 1899, to his advancement to the position of general manager, and eight years later he received his appointment as general superintendent of the company's manufacturing plants. Shortly thereafter, he again removed to Chicago, where he was largely responsible for the building of the Hawthorne Works of the Western Electric Company, starting its development on a prairie site on the outskirts of Chicago in 1904 and developing it into the largest telephone factory in the world. Almost forty thousand men and women were employed and Mr. Albright's outstanding contribution to it was scientific factory planning and management. At the time of his death he was head of all the company's manufacturing and plant engineering activities.

Closely coupled with his managerial and scientific ability was his aptitude for making friends, and to this qualification, allied with his natural application and zest to any undertaking, may be attributed Mr. Albright's achieved brilliant success.

Mr. Albright joined the Institute in 1892 in the grade of Associate, but advanced to full Member March 20, 1894 and became a Fellow in 1912, typifying in this, as in all of his activities, his constant progression.

William H. Forde, Associate of the Institute and Electrical Engineer for the Stone & Webster Company, Boston, was killed in an automobile accident at Conowingo, Maryland, May 11th.

Mr. Forde was born in Natick, Mass., February 14, 1893. In 1913 he graduated from the Electrical Engineering course at Sheffield Scientific School, and his first position was light and power solicitor for the El Paso Electric Railway Co. He then became solicitor of light and power for the Electric Company, Milford, Mass., and later spent two years as salesman for the Electric Storage Battery Company, Boston. In July 1912, Mr. Forde was chosen electrical inspector for the Stone & Webster Company, with whom he was still affiliated at the time of his death.

PERSONAL MENTION

W. R. Marshall, formerly branch manager for the Westinghouse Company at Buffalo has been selected for new duties as District Manager, Pittsburgh, Pa.

Henry Eggelhof, Dallas, Texas, was recently appointed exclusive representative for the Eastern half of Texas by the Uehling Instrument Co. of Paterson, N. J.

Erwin G. Fleming has been transferred from the Central Station Engineering Dept. of the General Electric Company, Schenectady to the Jacksonville, Fla. office. Mr. Fleming will stay at Miami.

C. W. Stokes has joined the organization of the American Brown Boveri Electric Corporation and will be connected with their Chicago office. He was formerly Canadian manager for the English Electric Co., Ltd., and also for a number of years manager for the Sterling Engineering Co., Montreal, Canada.

L. C. Brooks, who has been identified with the Electrical Marine Industry since the first electric ships (The U. S. S. *Kearsage* and *Kentucky* built at Newport News in 1900) and whose resignation as Electrical Engineer of the Bethlehem Shipbuilding Corporation was recently announced, may now be addressed at Groton, Mass. He is taking a much needed rest before forming other business connections, but in the meantime will continue his interests along marine lines. Mr. Brooks has served as chairman of the Institute Committee on Application to Marine Work.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—William E. Ames, Detroit Edison Co., Detroit, Mich.
2.—H. R. Bailey, Electric Bldg., Portland, Ore.
3.—J. Roy Barclay, 3424 Harrison St., Kansas City, Mo.
4.—Hubert L. Clary, 782 West 24th St., Milwaukee, Wis.
5.—J. F. Clinton, 3682 Broadway, New York, N. Y.
6.—J. E. Contesti, 350 W. 58th St., New York, N. Y.
7.—Hugh Denehy, The Inst. of Elect. Engrs., Savoy Pl., Victoria Embankment, London W. C. 2. Eng.
8.—Ralph Elsman, 120 Broadway, New York, N. Y.
9.—Charles A. Foust, 10505 93rd St., Woodhaven, N. Y.
10.—George Frasher, 1209 So., 4th Ave., Louisville, Ky.
11.—S. Alden Griffin, 19 Elliott St., Springfield, Mass.
12.—Harold G. Haines, 7416 Sylvester, Detroit, Mich.
13.—William A. Hincy, Colonial Apts., Media, Pa.
14.—Elmer D. Johnson, 1481 Harvard St., Washington, D. C.
15.—John E. Lewis, 376 Meyran Ave., Pittsburgh, Pa.
16.—F. A. Lindlof, 610 So. Spring St., Los Angeles, Calif.
17.—Charles W. Lueek, 1454 First Ave., New York, N. Y.
18.—Charles W. Magee, c/o Pelser, 210 West 102nd St., New York, N. Y.
19.—Shu-Sing Man, 541 West 124th St., New York, N. Y.
20.—J. A. McDermott, Y. M. C. A., Lima, Ohio.
21.—Irving Menschik, c/o Dublier Cond. & Radio Corp., 48 W. 4th St., New York, N. Y.

22.—Erwin H. Mitchell, c/o Schmeltz, 481 6th St., Brooklyn, N. Y.
23.—Robert H. Russell, 1128 Warren West, Detroit, Mich.
24.—Lieut. A. G. Scott, 68 West 107th St., New York, N. Y.
25.—Kermit G. Seaman, P. O. Box No. 68, Boulder, Colo.
26.—A. B. Smedley, c/o Cooper Hewitt Elec. Co., 1406 First Nat'l. Bank Bldg., Cincinnati, Ohio.
27.—C. D. Smith, 857 St. Charles St., New Orleans, La.
28.—Will M. Strickler, 301 Detroit Life Bldg., Detroit, Mich.
29.—O. G. Utt, 4738 Oak St., Kansas City, Mo.
30.—Leo A. Van Etsen, 1100 Park Ave., New York, N. Y.
31.—John D. Walker, 2686 Woodstock Ave., Swissvale, Pa.
32.—A. R. Williamson, 561 Delaware Ave., Norwood, Pa.
33.—C. A. Winder, Southern Equipment Co., San Antonio, Texas.

Book Review

NEW HANDBOOKS OF THE BUREAU OF STANDARDS

Handbooks No. 6 and No. 7, giving Safety Rules for the Installation and Maintenance of Electrical Supply Stations and Electric Utilization Equipment, respectively, are now on distribution through the Bureau of Standards, Washington. Price 10 cents each. These are published in small 5-in. by 7-in. paper covered pamphlets No. 6 comprising Part I the Grounding Rules of the fourth edition of the National Electrical Safety Code, while No. 7 consists of Part III and the Grounding Rules of the fourth edition of the National Electrical Safety Code. Publication dates, February 5 and March 12, 1926, respectively. Address Superintendent of Documents, Government Printing Office, Washington, D. C.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (MAY 1-30, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

CRYSTALLINE FORM AND CHEMICAL CONSTITUTION.

By A. E. H. Tutton. Lond. & N. Y., Macmillan & Co., 926. 252 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.60.

An account of the present position of chemical crystallography, based upon a course of lectures delivered at Cambridge University. The book is intended primarily for students of chemistry, physics or mineralogy, but an introductory chapter which summarizes the essential facts of pure crystallography renders it available to readers unfamiliar with the subject.

AUSGEWAHLTE METHODEN FUR SCHIEDSANALYSEN UND KONTRADIKTRISCHES ARBEITEN BEI DER UNTERSUCHUNG VON ERZEN, METALLEN UND SONSTIGEN HUTTENPRODUKTEN....

By Gesellschaft Deutscher Metallhutten-und Bergleute. Berlin, The Society, 1926. (Mitteilungen, t. 2). 146 pp., 9 x 6 in., boards. $2.50.

A collection of methods for the chemical analysis of metals and ores, recommended by the Chemical Section of the Society of German Metallurgists and Miners for umpire analyses. The methods cover the examination of zinc, zinc ash and zinc ores; cadmium; nickel, nickel ores and alloys; cobalt and bismuth, and their ores and alloys; lead compounds; magnesium and its alloys; corundum and carborundum; and the secondary ingredients in antimony and its ores. A chapter on proper methods of sampling is included.

APPAREILLAGE ELECTRIQUE.

By P. Maurer. Paris, Gauthier-Villars et Cie., 1926. 317 pp., illus., diagrs., tables, 10 x 6 in., paper. 55 fr.

A text-book on apparatus for interrupting, protecting, regulating and distributing electricity. The treatment is largely descriptive and treats of the design and use of switches, circuit-breakers, rheostats and switch-boards of the commercial types in use in France.

DICTIONARY OF APPLIED CHEMISTRY, v. 6.

By Sir Edward Thorpe. Revised & enlarged edition. Lond. & N. Y., Longmans, Green & Co., 1926. 791 pp., illus., diagrs., 9 x 6 in., cloth. $20.00.

The death of Sir Edward Thorpe, in February, 1925, interrupted the completion of the Dictionary, but publication is now resumed under the editorship of Dr. H. Forster Morley, and it is hoped to complete the work during 1926.

The present volume includes a number of lengthy articles on substances of great industrial importance, prepared by competent authorities. Saponification, silver, soap, sodium and its salts, starch, sugar, sulfur, sulfuric acid, synthetic drugs, tannins and tantalum are thus treated, together with many others. The new edition easily maintains the work in its rank as the leading English encyclopedia of industrial chemistry.

FUNDAMENTAL CONCEPTS OF PHYSICS IN THE LIGHT OF MODERN DISCOVERY.

By Paul R. Heyl. Balt., Md., Williams & Wilkins Co., 1926. 112 pp., 7 x 5 in., cloth. $2.00.

An account of the evolution of our present concepts through the eighteenth, nineteenth and twentieth centuries. Dr. Heyl studies the antecedents of present views, tracing correlations, analogies and similarities wherever they are found, and regarding the concepts in their philosophical aspects. The book is an interesting, non-mathematical description, accompanied by a list of references to more detailed works.

GUTERUMSCHLAG.

Die Guterumschlag-Verkehrswoche des V. D. I. in Düsseldorf und Köln, 1925. Sonderausgabe der Zeitschrift des V. D. I. Berlin, V. D. I. Verlag, 1926. 256 pp., illus., diagrs., 11 x 8 in., paper. 30.-rm.

In September, 1925, a week-long conference on the problems of freight traffic was held in Düsseldorf and Cologne under the auspices of the Verein Deutsche Ingenieure. The papers presented appeared in the V. D. I. Zeitschrift and are now collected in the present volume.

While questions of railroad freight handling are most extensively treated, there are papers on boat traffic, harbor machinery, street and light railroads, motor-truck and airship freight handling. Special attention is given to loading and unloading machinery and to the efficient utilization of equipment.

HERTHA AYRTON; a Memoir.

By Evelyn Sharp. London., Edward Arnold & Co., 1926. 304 pp., illus., port., 9 x 6 in., cloth. $5.50. (Gift of Longmans, Green & Co., N. Y.)

Mrs. Ayrton's chief interest to engineers arises from her investigations of the electric arc, which were published in book form in 1902. In 1899 she was elected a member of the Institution of Electrical Engineers, being the first woman to attain that distinction. She also engaged in an investigation of the formation of sand ripples, which led her, during the War, to the invention of the Ayrton fan, a device for driving back poison gas.

Her biographer traces her career from early childhood to her death in 1923.

INTRODUCTION TO INDUSTRIAL CHEMISTRY

By S. I. Levy. N. Y., McGraw-Hill Book Co., 1926. 288 pp., illus., diagrs., 8 x 6 in., cloth. $4.00.

Dr. Levy's book departs from the usual textbook on industrial chemistry, which deals with the specialized technique of particular branches of chemical industry. Instead, he offers a general introduction to the whole subject, in which are discussed such matters as costing, methods of heating, cooling, pulverizing, filtering, extracting, distilling, drying, etc., on a large scale, and the transporting and handling of gases and liquids. The presentation of these foundation processes is supplemented by brief accounts of certain selected industries; fuel, sulfuric acid, alkali, intermediates and explosives. The book is intended to bridge the gap between the methods of the laboratory and those used industrially.

LOKOMOTIVVERSUCHE IN RUSSLAND.

By G. Lomonossoff. Berlin, V. D. I. Verlag, 1926. 330 pp., illus., diagrs., tables, 12 x 9 in., cloth. 42.-mk.

In the years 1898 to 1900, Professor Lomonossoff devised a method for testing locomotives, by which the engine was subjected to the working conditions customary for laboratory tests, on the actual roadway instead of in the laboratory. Wind resistance and the jolting from passage over the rails here introduce factors absent from laboratory tests.

Since 1908 the method has been used in Russia to investigate each new type of locomotive. The present work presents some of the results of tests made from 1908 to 1923.

The purpose and method of testing is first explained. The eight types of locomotives tested are then fully described, after which the results of tests on a locomotive of the newest Russian type are given in detail. The most important results of the tests of the remaining types of locomotives are then given. The final chapter illustrates the use of the experimental results for the solution of problems of locomotive operation.

METHODS OF MEASURING TEMPERATURE.

By Ezer Griffiths. 2nd edition. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1926. 203 pp., illus., tables, 9 x 6 in., cloth. 10s 6d.

Written for those concerned with the measurement of temperature in scientific investigations or in industrial operations. Attention is given chiefly to the experimental basis of the methods in general use, the calibration of the instruments and the precautions to be observed in practice.

A connected account of the classical researches with the gas thermometer is given. Subsequent chapters deal with the mercury thermometer, the resistance thermometer, the thermocouple, the radiation pyrometer and the optical pyrometer. References are appended to each chapter.

The changes in this edition are, in addition to the correction of errata, chiefly in the portion on optical pyrometry.

POWER-FACTOR WASTES.

By Charles R. Underhill. N. Y., McGraw-Hill Book Co., 1926. 326 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.50.

This discussion of power-factor wastes is intended to present the subject from many points of view and thus to direct more attention to their importance. It aims to acquaint those responsible for these wastes with their causes, their cost and their cures. Many chapters are contributed by specialists on their subjects.

PYROMETERS.

By Ezer Griffiths. Lond. & N. Y., Isaac Pitman & Sons, 1926. 126 pp., illus., diagrs., tables, 7 x 5 in., cloth. $2.25.

Intended as a connecting link between textbooks on heat and advanced treatises on pyrometry, this little book describes recent pyrometric apparatus, including expansion thermometers, thermoelectric pyrometers, resistance thermometers, optical and total radiation pyrometers. Only a few types of each class are described, but these have been selected from outfits designed to meet unusual requirements.

RAILROAD ELECTRIFICATION AND THE ELECTRIC LOCOMOTIVE.

By Arthur J. Manson. 2nd edition. N. Y., Simmons-Boardman Publishing Co., 1925. 332 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

Intended to provide information of value to those concerned with the operation and maintenance of electric locomotives, or interested in the general subject of railroad electrification. Technical detail is reduced to small dimensions, but the fundamental units and principles of electricity are explained, the design and construction of electric locomotives are described and illustrated, and the solutions of a number of practical problems incident to electrification are given. An appendix gives a brief history of electrification in the United States.

TOPOGRAPHICAL DRAWING NOTES.

By G. P. Schubert. 2nd edition. Houghton, Mich., Michigan College of Mines, 1926. 82 pp., 11 drawings & diagrs., 6 x 9 in., cloth. $1.65.

This textbook supplements the lectures and laboratory work in a course on topographical drawing and traverse computations given at the Michigan College of Mines. It treats various methods of calculating and plotting traverses and of drawing suitable topographic maps. The course is planned to enable surveyors and mining engineers to do as much of this class of work as they may be called upon to do in their regular practice.

Past Section and Branch Meetings

SECTION MEETINGS

Boston

Modern Methods of Combustion Control, by E. G. Bailey, Bailey Meter Co. Joint meeting with A. S. M. E. April 15. Attendance 150.

The Art of Making Good Concrete, by W. C. Voss, Portland Cement Association; E. S. Larned, Civil Engineer, and J. G. Ahlers, Barney-Ahlers Construction Corp. Joint meeting. April 21. Attendance 228.

Chicago

Automatic Stations and Their Remote Supervision, by Chester Lichtenberg, General Electric Co. Joint meeting with Western Society of Engineers. May 3. Attendance 200.

Cincinnati

Modernizing Industrial Control Apparatus, by G. O. Wilms, Allen-Bradley Company. April 8. Attendance 84.

Cleveland

Industrial Motor Bearings from a Maintenance Point of View, by H. G. Veit, National Malleable Castings Co.;

Large Synchronous Motors for Industrial Drives, by P. C. Jones, Goodyear Tire and Rubber Co., and

Some Design Features of Industrial Motors, by E. E. Dreese, Lincoln Electric Co. April 22. Attendance 93.

Connecticut

Relativity and the Einstein Theory, by W. B. Hall, Yale University. April 29. Attendance 65.

Denver

Operation of D-C. Motors on Direct and Alternating Current Simultaneously, by Edwin Heath, University of Colorado;

Some New Developments in High-Voltage Insulators, by P. M. Brown, University of Colorado; and

The Application of Vacuum Tubes to Magnetic-Flux Measurements, by K. A. Browne, University of Colorado. April 16. Attendance 70.

Engineering in Russia, by S. M. Marshall, Perine and Marshall. April 22. Attendance 28.

Detroit-Ann Arbor

Power from Mercury Vapor, by W. L. R. Emmet, General Electric Co. Illustrated by slides and motion picture. March 16. Attendance 200.

Inspection trip to River Rouge Plant of the Ford Motor Company. April 3. Attendance 50.

Power Factor, What Is It and What Can We Do About It, by E. L. Bailey, Sales Engineer. Joint meeting with Detroit Engineering Society. April 23. Attendance 175.

Erie

Oil-Electric Locomotives, by Herman Lemp, Consulting Engineer. Illustrated with slides. Joint meeting with A. S. M. E. and A. C. S. April 20. Attendance 200.

Fort Wayne

The Consolidation of the Traction Company with the Insull Properties, by R. M. Fuestel, Indiana Service Corporation. Illustrated with motion pictures. April 28. Attendance 54.

Indianapolis-Lafayette

The Development of Steam Generators and Radiant Heat, by G. A. Orrok. Joint meeting with A. S. M. E. April 20. Attendance 119.

Ithaca

Finding and Filling Your Place in Industry, by C. R. Dooley, Standard Oil Company of New Jersey. March 15. Attendance 200.

Lightning and High-Voltage Phenomena, by F. W. Peek, Jr., General Electric Co. April 14. Attendance 70.

The Social and Economical Aspect of Niagara Falls Power, by W. K. Bradbury. May 7. Attendance 130.

Kansas City

Light Radiations as Shown by the Spectroscope, by F. E. Johnson, Kansas University Engineering School;

Loop Feeders of the Kansas City Power and Light Company, by W. O. Edmonds, Kansas City Power and Light Co., and

Super Power Systems, by B. J. Denman, United Light and Power Co. March 31. Attendance 48.

Lightning Protective Devices, by A. L. Atherton, Westinghouse Electric and Mfg. Co. The following officers were elected: Chairman, R. L. Baldwin; Secretary, S. M. DeCamp. April 30. Attendance 51.

Los Angeles

Modern Developments in Astronomical Research, by Ferdinand Ellerman, Mount Wilson Observatory. Illustrated. May 4. Attendance 150.

Lynn

The Industrial Conditions of the Nation, by D. S. Kimball, Cornell University, and

The Activities of Lynn, by Hon. Ralph S. Bauer, Mayor. March 20. Attendance 184.

Mexico

Maximum-Demand Meters, by Solis Payan. May 6. Attendance 18.

Milwaukee

The Mechanical Engineer in the Large Industries Today, by O. A. Anderson, Armour and Company. March 17. Attendance 70.

The Tremendous Responsibilities Which Confront the Engineer, by Roy Wright, Vice-President, A. S. M. E. April 21. Attendance 60.

Minnesota

Transmission of Pictures over Wire, by R. D. Parker, American Telephone and Telegraph Co. April 26. Attendance 150.

Nebraska

Tasks Ahead in Engineering Education, by O. J. Ferguson, University of Nebraska. April 9. Attendance 35.

Niagara Frontier

Automatic Train Control, by W. H. Reichard, General Railway Signal Company. The following officers were elected: Chairman, H. B. Alverson; Secretary-Treasurer, A. W. Underhill, Jr. April 30. Attendance 42.

Philadelphia

Progress, by L. F. Deming, General Electric Co. Illustrated with slides. April 12. Attendance 105.

Pittsburgh

Lightning, by F. W. Peek, Jr. Illustrated with slides and motion picture. The election of the following officers was announced: Chairman, W. C. Goodwin; Secretary, D. M. Simons. May 11. Attendance 385.

Pittsfield

Annual Dinner, held at the Hotel Wendell. The speakers were: C. C. Chesney, President-Elect of the A. I. E. E.; H. M. Hobart, Vice-President-Elect in District No. 1; Harold B. Smith, Vice-President in District No. 1; E. D. Eby, Chairman of the Pittsfield Section, and Dr. J. J. Walsh of Brooklyn, N. Y. Entertainment was furnished by the Radio Four Quartet, the Kilowatt Orchestra—an orchestra composed of electrical engineers, and Harold B. May's dance orchestra. The program was broadcast through WGY. March 30. Attendance 309.

Inspection trip to the Schenectady Works of the General Electric Company. April 19. Attendance 350.

Portland

The Influence of Line Voltage upon Induction-Motor Characteristics, by C. H. Bjorquist and H. E. Rhoads;

The Effect of Three-Phase Transformer Connections on Induced Harmonics, by D. O. Bergey, E. E. Kearns and C. W. Leihy, and

The Characteristics of Distribution Transformers at High Overloads, by F. C. Mueler, C. R. McLean, B. E. Plowman, O. W. Hurd and W. W. Bonar. These papers were presented by senior students of the Oregon Agricultural College. A demonstration of first-aid methods was also given by members of the Pacific Telephone and Telegraph Co. April 9. Attendance 135.

Providence

Fundamental Considerations of Power Limits of Transmission Systems, by R. E. Doherty, General Electric Co. Joint meeting with A. S. M. E. and Providence Engineering Society. April 8. Attendance 35.

Most Recent Radio Developments, by E. L. Bowles, Massachusetts Institute of Technology. The following officers were elected: Chairman, E. E. Nelson; Vice-Chairman, F. N. Tompkins, and Secretary-Treasurer, F. W. Smith. April 20. Attendance 60.

San Francisco

Manufacture, Treatment and Testing of Special Alloy Steels, by G. A. Richardson. Joint meeting with A. S. M. E., A. S. C. E. and Chemical Society. April 14. Attendance 250.

Engineering Education—Its History and Prospects, by H. H. Henline, Stanford University. April 23. Attendance 80.

St. Louis

The Position of Capital in the Electrical Industry, by W. A. Layman, Wagner Electric Corp. September 16. Attendance 122.

Lightning, by E. E. F. Creighton, General Electric Co. October 23. Attendance 275.

The Klydonograph and Its Application, by J. H. Cox, Westinghouse Electric and Mfg. Co. November 18. Attendance 102.

Engineering Research, by B. L. Newkirk, General Electric Co. December 16. Attendance 200.

Long-Distance Cable Communication, by H. H. Nance, American Telephone and Telegraph Co. January 20. Attendance 162.

Dance. Joint with A. S. M. E. February 17. Attendance 205.

Development of Electric Power Generation and Distribution, by Col. Peter Junkersfeld, McClellan and Junkersfeld. March 17. Attendance 180.

Automatic Stations, by C. A. Butcher, Westinghouse Elec. & Mfg. Co. April 21. Attendance 60.

Schenectady

The Relation between Technical and Business Training, by J. G. Callan, Harvard College of Business Administration. April 16. Attendance 350.

Seattle

Cost Analysis of Engineering Problems, by E. G. Champreux, The Pacific Telephone and Telegraph Co. The following officers were elected: Chairman, C. E. Mong; Secretary-Treasurer, C. R. Wallace. April 21. Attendance 81.

Sharon

Steel-Mill Electrification, by G. E. Stoltz, Westinghouse Electric & Mfg. Co. May 4. Attendance 101.

Spokane

Automatic Train-Control Equipment, by R. C. Charlton, Oregon-Washington Railroad and Navigation Co. April 23. Attendance 40.

Saskatchewan

Annual Meeting. The following officers were elected: Chairman, S. R. Parker; Secretary-Treasurer, W. P. Brattle. April 15.

Springfield

Automatic and Supervisory Controlled Substation, by R. J. Wensley, Westinghouse Elec. & Mfg. Co. April 20. Attendance 100.

Toronto

High-Power Laboratory of the Westinghouse Electric and Manufacturing Company, by W. R. Woodward. April 23. Attendance 300.

Toronto—Past and Present, by T. A. Reed. The following officers were elected: Chairman, M. B. Hastings, Secretary, F. F. Ambuhl. May 7. Attendance 63.

Utah

Loud-Speaker Horns, by J. V. Laird;

Electro-Chemical Reduction of Metals, by S. M. Young;

A Proposed Railway Electrification, by C. E. Hoffman;

Characteristics of Vacuum Tubes, by I. S. Pierson; and

Automatic Control of Substations, by A. LaMont Nelson. These papers were furnished by students of the University of Utah. April 28. Attendance 22.

Vancouver

Some Recent Developments in Urban Transportation, by H. M. Lloyd, British Columbia Electric Railway Co., Ltd. April 6. Attendance 26.

Washington

Developments in Motor-Vehicle Headlighting, by Lieut-Col. R. E. Carlson, Bureau of Standards. The following officers were elected: Chairman, C. A. Robinson; Vice-Chairman, M. G. Lloyd; Secretary-Treasurer, D. S. Wegg. May 11. Attendance 38.

Worcester

Electrical Reproduction of Music, by H. H. Newell, Worcester Polytechnic Institute. May 5. Attendance 80.

BRANCH MEETINGS

Alabama Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, J. D. Stewart; Vice-Chairman, W. L. Garlington; Secretary-Treasurer, I. L. Knox. April 21. Attendance 22.

The Application of the X-Ray to Industry, by Dr. Fred Allison. May 5. Attendance 52.

University of Arizona

Power-Distribution Practise, by B. L. Jones;

Mine Lighting, by S. A. Sinclair, and

Underground Power Installation, by W. T. Wishart. April 10. Attendance 18.

University of Arkansas

Engineering English, by Dr. Jones. November 3. Attendance 32.

Natural-Period Vibration of Machinery, by Prof. Theorle, and

Equipment of a Modern Power Plant, by E. Reynolds. November 17. Attendance 28.

Power Distribution, by A. S. O'Bar;

Benefits of Engineering Organization, by B. A. Avery, and

Production of Casing-Head Gas, by E. T. Martin. December 1. Attendance 28.

Carrier Waves in Telephony, by R. A. Austin, and

Economy in Modern Steam Locomotives, by F. H. Smith. January 19. Attendance 20.

Gas-Engine Electric Railways as Used in England, by Frank Lane, and

Engineering Exhibit at Arkansas State Fair, by J. F. Toohey. February 2. Attendance 25.

Improved Methods of Combustion, by Prof. Strate. April 7. Attendance 11.

Development and Use of Searchlights, by Russell McFarland, and

Automobile Lights, by Elmer Nichols. April 20. Attendance 14.

High-Frequency Apparatus, by E. F. Nichols. The following officers were elected: President, Carroll Walsh; Vice-President, C. W. Collier; Secretary-Treasurer, W. H. Mann. May 4. Attendance 15.

Armour Institute of Technology

Smoker. April 14. Attendance 71.

Business Meeting. The following officers were elected: Chairman, M. T. Goetz; Secretary, C. W. Schramm; Treasurer, C. W. Burcky. May 6.

Brooklyn Polytechnic Institute

Motion pictures, entitled respectively "Revelations by X-Ray," "Endurance Tests of Induction Motors," and "Manufacture of Okonite Cables," were shown. April 14. Attendance 45.

California Institute of Technology

Business Meeting. April 27. Attendance 23.

Inspection trip to the Shrine Temple in Los Angeles. April 30. Attendance 12.

University of California

Inspection trip to P. T. & T. Co. January 29. Attendance 30.

Inspection trip to G. & E. Co. Broadcasting Station KGO. February 9. Attendance 45.

Inspection trip to P. T. & T. Co. March 17. Attendance 25.

Business Meeting. April 14. Attendance 31.

Case School of Applied Science

The Application of Carbon Products to Industry, by P. D. Manbeck, National Carbon Co., Inc. April 27. Attendance 38.

Catholic University of America

Radio, by B. J. Kroeger. Illustrated with slides. April 22. Attendance 21.

University of Colorado

Operation of a Series Motor with A-C. and D-C. Simultaneously, by Edwin Heath;

High-Voltage Insulators, by P. M. Brown. Illustrated with slides.

The Measurement of Magnetic Flux by the Use of the Vacuum Tube, by Kenneth Brown. April 16. Attendance 50.

University of Florida

Construction and Operation of Gas-Electric Busses, by F. P. Dean, and

Early Development of Steam Engine, by G. C. Robertson. April 26. Attendance 15.

Georgia School of Technology

Business Meeting. The following officers were elected: President, W. M. McGraw; Secretary-Treasurer, F. L. Kaestle. April 20. Attendance 45.

State University of Iowa

The Selenium Cell and Its Uses, by A. J. Plath. and

The Cathode-Ray Oscillograph, by R. B. Prunty. April 14. Attendance 34.

Wind Power, by Theo. Van Law;

Atomic-Hydrogen Arc Welding, by R. C. Van Ness, and

Insulating Materials Used in Transformers, by R. H. Perry. April 21. Attendance 33.

A motion picture, entitled "Coal is King," was shown. April 28. Attendance 35.

Patent Laws, by G. Gunderson, and

110-Volt Filamentless Vacuum Tube, by N. Jensen. May 5. Attendance 36.

Kansas State College

The Theory of Electrostatic and Electromagnetic Fields, by E. R. Lyons. January 12. Attendance 83.

Synchronous Machinery and Equipment, by E. S. Henningsen, General Electric Co. March 4. Attendance 98.

Growth of Utilities, by Arthur Groesbeck, United Light and Power Corp. April 12. Attendance 72.

Public-Utility Publicity, by H. W. Davis. April 27. Attendance 55.

Lafayette College

Talks were given by C. L. Craven and P. O. Farnham. March 31. Attendance 21.

Inspection trip to Lehigh Telephone Company's Central Station in Easton, Pa. April 7. Attendance 20.

The Use of Compressed Air in Industry, by A. H. Taylor, Ingersoll-Rand Co. April 28. Attendance 21.

Lehigh University

Some Problems of the Electrical Industry, by L. W. W. Morrow, Managing Editor, *Electrical World*, and

Organization and Operation of a Public Utility, by Chas. Zug, Jr., student. March 11. Attendance 49.

Recent Developments in Electric Traction, by J. D. Alrich, General Electric Co. A motion picture, entitled "Electrification of the Mexican Railroad," was shown. April 15. Attendance 66.

Lewis Institute

The Use of Mercury-Arc Rectifiers in Substations, by R. B. Freston. April 30. Attendance 18.

Massachusetts Institute of Technology

The Outlook for the Electrical Engineer Now in College, by Dr. E. W. Wickenden, Society for the Promotion of Engineering Education. April 23. Attendance 22.

University of Michigan

A film, showing the Okonite method of manufacturing insulated wires and cables, was shown. April 26. Attendance 30.

School of Engineering of Milwaukee

Standing Waves at Ultra-Radio Frequencies, by Ben Chromy. A motion picture, entitled "White Coal," was shown. April 20. Attendance 41.

Inspection trip to the Nash Motors Corporation. April 28. Attendance 40.

Motion pictures, entitled "The Audion" and "The Go-Getter," were shown. May 11. Attendance 25.

University of Minnesota

The Application of Synchronous Machines, by C. W. Place General Electric Co. March 9. Attendance 75.

Montana State College

Diesel-Electric Drive for Dredges, by B. W. Crowell, and

Lighting-Generator Research, by R. K. Frazier. April 8. Attendance 159.

The Graduate Engineer and His Relation to the Industries, by Mr. Caples, The Anaconda Copper Mining Co. April 12. Attendance 172.

Modernized Dipping and Baking, by S. Thompson, and

Electric Refrigeration, by H. F. Dehler. May 6. Attendance 147.

University of Nevada

Business Meeting. The following officers were elected: President, George Fairbrother; Secretary-Treasurer, Cornelius Fort. April 26. Attendance 20.

College of the City of New York

Inspection trip to Interborough Power Plant. March 30. Attendance 23.

Electric Wave Filters, by A. Granich, Bell Telephone Laboratory. Illustrated with slides. April 22. Attendance 41.

Business Meeting. May 6. Attendance 13.

New York University

Business Meeting. October 15. Attendance 21.

Opportunities for the Electrical Engineering Graduate, by Dr. L. L. Arnold. October 29. Attendance 28.

Business Meeting. November 13. Attendance 32.

Distortion in Radio Receiving Sets and Loud Speakers, by A. Senauke. December 11. Attendance 19.

Turbo-Alternators, by J. Hemingson, General Electric Co. January 15. Attendance 42.

Business Meeting. April 20. Attendance 21.

Distortion Causes in Audio-Frequency Amplifiers, by Alexander Senauke, Popular Science Radio Laboratory. April 22. Attendance 27.

University of North Carolina

The Automatic Telephone, by J. C. Fred, student. February 25. Attendance 31.

A-C. Measurements with the Electron Tube, by J. D. Finklea. March 8. Attendance 26.

The Power Possibilities of Muscle Shoals, by H. C. Klingenschmitt. April 1. Attendance 28.

Interesting Phases of the Electrical Engineering Profession, by T. J. McManis, General Electric Co. Illustrated with slides. April 26. Attendance 54.

University of North Dakota

Electrification of the Virginia Railroad, by Leonard Dagen;

The Electrical Stethophone, by Thore Hawk, and

The Life of Michael Faraday, by H. W. Augustadt. April 19. Attendance 17.

Northeastern University

Inspection trip to the Simplex Wire and Cable Company. April 2. Attendance 40.

Dangers of Electrical Shocks, by A. E. Kennelly, Harvard University. April 29. Attendance 64.

Ohio Northern University

Business Meeting. October 14. Attendance 47.

Protective Apparatus, by Mr. Roth. November 19. Attendance 22.

Business Meeting. January 20. Attendance 23.

The Application of Electric Power to Auxiliary Drives in Central Stations, by Prof. I. S. Campbell. April 14. Attendance 20.

The Application of the Compound-Interest Formula to the Various Sciences, by Prof. Whitted. April 28. Attendance 21.

Ohio State University

A motion picture, entitled "Wizardy of Wireless," was shown. April 30. Attendance 112.

Opportunities for Engineers in Public-Utility Work, by E. C. Stone, Duquesne Power and Light Co. Joint meeting with A. S. M. E. May 7. Attendance 52.

Oklahoma Agricultural and Mechanical College

Business Meeting. October 21. Attendance 66.

The Telephone Business, by Mr. Boone. Four reels of motion pictures were shown. April 21. Attendance 68.

University of Oklahoma

How To Lose Your First Job, by F. G. Tappan. April 15. Attendance 23.

Oregon State Agricultural College

The Influence of Line Voltage upon Induction-Motor Characteristics, by C. H. Bjorquist and H. E. Rhoads;

The Effect of Three-Phase Transformer Connections on Induced Harmonics, by D. O. Bergey, E. E. Kearns and C. W. Leihy, and

The Characteristics of Distribution Transformers at High Overloads, by F. C. Mueller, C. R. McLean, B. E. Plowman, O. W. Hurd and W. W. Bonar. Illustrated with slides. April 9. Attendance 56.

Pennsylvania State College

Electric Locomotives, by O. K. Harlan. Illustrated with slides. Joint meeting with A. S. M. E. March 3. Attendance 60.

Smoker. The following officers were elected: President, F. F. Wilkins; Vice-President, E. H. Basehore; Secretary, E. Huggler; Treasurer, M. I. Allen. April 28. Attendance 45.

University of Pennsylvania

After College, What?, by C. K. West, General Electric Co., and C. H. Wellerjean, Westinghouse Electric and Mfg. Co. February 25. Attendance 62.

Business Meeting. April 14. Attendance 45.

University of Pittsburgh

Crystal Control of Radio Frequencies, by F. C. Hartman, student, and

Experiences at National Tube Co., by G. M. Jarrett, student. March 5. Attendance 24.

The Liberty Bridge, by V. R. Covell, Bureau of Bridges of Alleghany County. March 12. Attendance 24.

George Westinghouse, by D. G. Nesbit, student, and

Railroad-Signal Control, by Chas. Caveny, student. March 19. Attendance 28.

Opportunities with The Duquesne Light Co., by W. F. Young. March 26. Attendance 28.

Homestead Steel Company, by A. S. Brown. April 9. Attendance 25.

Industrial Engineering, by L. P. Alford. April 16. Attendance 26.

Talks by H. J. A. Cramer and E. E. Muerer, students. April 23. Attendance 26.

Talks by E. H. Powell and J. J. Pfeiffer, students. April 30. Attendance 26.

Purdue University

The World of Paper, by P. Y. Tumey, General Electric Co. Illustrated with slides and motion pictures.

Switchboards, by C. C. Adams, General Electric Co. April 13. Attendance 100.

Westinghouse—The Institution, by Prof. L. D. Rowell. April 27. Attendance 35.

Rensselaer Polytechnic Institute

Modern Induction Furnaces, by J. A. Seede, General Electric Co., and

The Design and Operation of Electric Furnaces, by F. W. Brooke, William Swindell and Bros. April 20. Attendance 65.

Rhode Island State College

Stresses in High-Speed Turbines, by Professor Brown. March 29. Attendance 21.

Rutgers University

Finances of the Light and Power Industry, by Mr. Siddons, student, and

The Treating of Telephone and Telegraph Poles, by Mr. Miller, student. April 19. Attendance 19.

South Dakota State School of Mines

Business Meeting. April 1. Attendance 11.

University of Southern California

The Duties of a Power Salesman, by Mr. King, Los Angeles Bureau of Power and Light, and

The Application of Electricity to the Oil Industry, by Mr. Wade. April 15. Attendance 37.

Stanford University

The Pit River Development of the Pacific Gas and Electric Co., by E. A. Crellin. Illustrated with slides. April 20. Attendance 26.

Business Meeting. May 4. Attendance 21.

Stevens Institute of Technology

A motion picture, entitled "Speeding Up Deep-Sea Cables," was shown. A short talk was also given by Lincoln Walsh, student. April 15. Attendance 74.

A film, illustrating the applications of the gyroscope, was shown. a demonstration of the properties of the gyroscope by means of a small model was also given by L. G. Walsh, student. The following officers were elected: Chairman, D. B. Wesstrom; Secretary, Gene Witham. May 4. Attendance 110.

Swarthmore College

Business Meeting. April 15. Attendance 30.

Syracuse University

A motion picture, entitled "Power," was shown. April 12. Attendance 19.

Automatic Railway Substations, by W. H. H. Wilkinson. April 19. Attendance 19.

Agricultural and Mechanical College of Texas

Electrical Show, produced by the students. In connection with the show the Southwestern Bell Telephone and Telegraph Company held a pageant showing the development of the telephone for the last 50 years. April 10. Attendance 1000.

Problems of Independent Telephone Companies of Today, by R. B. Still, Association of Independent Telephone Companies of Texas. May 7. Attendance 84.

University of Texas

A motion picture on Automatic Substation Control was shown. April 8. Attendance 23.

Business Meeting. April 22. Attendance 8.

Virginia Military Institute

The Socket Power Supply for Radio Receivers, by W. R. Noble. Motion picture, entitled "The Queen of the Waves," was shown. December 22. Attendance 19.

A motion picture, entitled "The King of the Rails," was shown. February 15. Attendance 47.

University of Virginia

Motion pictures, entitled "The King of the Rails," and "The Panama Canal," were shown. April 19. Attendance 16.

Communication from Moving Trains, by Jean Roberts. Motion pictures, entitled "The Go-Getter," and "The Queen of the Waves," were shown. May 3. Attendance 20.

University of Washington

The Design of Telephone Pole Lines, by Mr. Freed, Pacific Telephone and Telegraph Co. April 7. Attendance 22.

Worcester Polytechnic Institute

The Telephone, by Captain J. C. Fair, New England Telephone and Telegraph Co. April 21. Attendance 28.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL SWITCH DESIGNER, for automatic control of direct- and alternating-current motors. Opportunity. Apply by letter stating technical training, experience, age and required salary. Location, New York City. R-9039.

ELECTRICAL ENGINEER GRADUATES, two, with several years' experience, for distribution department of large public utility. Opportunity to enter commercial sales department. Experience in overhead distribution layout and estimating desirable. Opportunity. Apply by letter with complete details of age, education, training, experience and salary desired with recent photograph. Location, Middle Atlantic. R-9727-C.

INSTRUCTOR, electrical engineering graduate, under 30, to instruct in lecture room and laboratory educational department of large eastern public utility. Some experience in pedagogy and the electrical industry essential. Apply by letter, stating education, experience, age, salary expected, and other details. Location, New York City. R-9068.

MEN AVAILABLE

1925 GRADUATE ELECTRICAL ENGINEER, Georgia Tech., age 24, sales and business experience. Desires position with possibilities for advancement with public utility or electrical contracting company. Location, preferably Florida or Georgia. C-2004.

PLANT ENGINEER, MECHANICAL SUPERINTENDENT OR MASTER MECHANIC, mechanical engineer, age 40, with fifteen years' experience in the above, desires an opening with a progressive concern. Prefers location in Eastern or Central states. C-1182.

ELECTRICAL ENGINEER with wide and thorough experience in America and Europe, desires position as executive or chief electrical engineer. Competent in electrical and mechanical design of electrical machinery; made special study of gasoline electric automotive vehicles. Familiar with research work in electrical, mechanical and physical problems. East preferred. Minimum salary $6600. C-693.

ENGINEER, age 36, married, graduate M. E. and E. E., wide range of engineering experience, and especially well qualified in public utility electrical engineering, power plants, sub-station lines. Highly trained technically, but prefers position requiring combination of technical and executive ability. Available in two to four weeks. Location, United States. B-5842.

ELECTRICAL ENGINEER, age 32, married, technical graduate, ten years' experience in construction, maintenance and hydroelectric work with prominent companies here and in Venezuela, South America. Desires permanent position in Spanish speaking country. Available on short notice. C-917.

ELECTRICAL ENGINEER, four years' design and development experience with large manufacturing company. Would like similar work with a well established company in the Middlewest. College graduate, 28, married. C-1132.

EXPERIENCED ENGINEER, age 40, single, desires investigational work, preferably of electrical and mechanical laboratory research or development type. Ability tested in many ways. Reports on problems requiring originality and resourcefulness, and the supervision of others, most satisfactory. Available after May 15, 1926. Location preferred, Middlewest. B-6273.

ELECTRICAL ENGINEER, technical graduate, ten years' experience with large Eastern manufacturing concern, desires position as instructor in department of electrical engineering. Qualified to teach direct and alternating current machinery, and electrical laboratory. Especially interested in laboratory work. Position must offer possibilities of advancement. Location, West. C-50.

ASSISTANT EXECUTIVE, well balanced experience of thirteen years on cost analysis, industrial processing, commercial statistics, advertising administrative control. Seven years with large company servicing subsidiaries and clients. Public utility experience. Prefers administrative or commercial to strictly technical. Technical graduate, married, 34. Location, New York, New England. Available reasonable notice. B-9122.

ELECTRICAL ENGINEER, age 24, will graduate in June 1926. Interested in sales or distribution of some technical product. C-1306.

CONSTRUCTION ENGINEER, age 38, married, electrical graduate, recent study M. I. T. Allis Chalmers test. Thirteen years' experience electrical manufacture, installation power plant machinery, maintenance, general construction. Desires position steam plant construction. Salary $3600. Available June 1st. A-4018.

TECHNICAL GRADUATE OF BRITISH UNIVERSITY, electrical engineering, age 35, single, over ten years' experience in general electrical and mechanical engineering, including lighting installations, one year illumination tests, about three years mechanical drafting, inspection of finished parts, also two years' experience in patent disclosures and patent drafting. Besides English, speaks and writes two Balkan languages and French. Inventive abilities. Best references. Willing to go anywhere. B-7214.

RADIO COMPASS ENGINEER, technical graduate, desires position with reliable concern in this capacity. Present employed by U. S. Navy Department on position and direction finding by radio. C-723.

ELECTRICAL ENGINEER, B. S. in railway electrical engineering in 1924, 23, single. Two years in general engineering course; two years in central station and substation work in large Midwestern utility engineering department. Location desired, Illinois or foreign. C-1331.

INSTRUCTOR, age 28, single, B. S. and M. S. in E. E., ('23 and '24). Now taking graduate courses in mathematics. Experience; nine months time study and job analysis with an electrical manufacturer, ten months training course in generating and distributing departments of a public utility. Ready to begin about September 6th. C-1034.

ASSISTANT PROFESSORSHIP desired by an electrical engineer seeking promotion above present position. Age 30, married, three years' practical and five years' teaching experience. B. S. and M. S. degrees in electrical engineering. Man of initiative and ability. Desires position in recognized Eastern or Midwestern university. B-3376.

ELECTRICAL ENGINEER, expert switchboard designer, power station layout, relay protection, selection of oil circuit breakers and automatic switching. South West preferred. C-1333.

ELECTRICAL ENGINEER, age 27, experience in research and developing of electrical appliances, desires similar employment. Available on two weeks' notice. Salary $250 a month. B-7270.

ELECTRICAL ENGINEERING GRADUATE, age 31, married, eight years' experience in engineering research, development and teaching electrical theory and laboratory. Graduate study carried on while teaching. Available at once for continuing in similar work. C-3.

SALES ENGINEER, age 34, married, well acquainted with New England markets, desires to represent electrical manufacturer in this territory. Experienced in selling to dealers, jobbers and manufacturers. Technical education. Ten years' Engineering and selling experience. Present connection with internationally known manufacturer. Salary and expenses. Available one month. A-1330.

LICENSED PROFESSIONAL ELECTRICAL ENGINEER, versed also in mechanical, structural steel, concrete and hydraulic work. Power stations, power transmission, industrial plants, etc. Design, construction, operation; practical as well as theoretical (research). Reliable, responsible. B-7337.

RADIO ENGINEER, thoroughly educated, experienced, wants position technical correspondent or development engineer large radio company. Past four years employed as operating engineer, second in charge, in two of New York's broadcasting stations. Designed, constructed, installed third large broadcasting station Second Radio District. Two years magazine, special feature writing experience. Not interested position broadcasting station. Available two weeks' notice. Minimum salary $3000. C-1108.

ELECTRICAL ENGINEER, age 29, married, university graduate, five year course, one year in Commerce and Journalism College. Desires connection with progressive company in commercial capacity or industrial engineering firm. Work has covered estimating, contracting and manufacturing work. Available on reasonable notice. Location, Ohio. B-9865.

MECHANICAL ENGINEER, technical graduate, married, wide experience in design and construction of power plants, fire prevention and protection, and preparation of special reports, extensive acquaintance among city officials. Desires position with contractor or consulting engineer. B-7189.

ELECTRICAL ENGINEER, age 30, married, graduate E. E. M. E. Seven years' varied experience on central and substation estimating, design, construction and installation also safety and research work. Five years in responsible positions with private corporation and public utilities. Good record and references. Desires responsible position requiring ingenuity and good judgment with industrial, engineering or small power company, preferably New York or neighboring state. Available on reasonable notice. B-5505.

ASSISTANT ENGINEER, age 25, single, electrical and mechanical. Eight year course engineering theory and electrical station design. Apprenticed motor and generator building. Installed and repaired gas and crude oil engines, automatic lighting and pumping systems, machinery, etc. Available on seven days' notice. C-1301.

GRADUATE ELECTRICAL ENGINEER, will go anywhere; over twelve years' experience in construction, operation, maintenance of steam generating stations; efficient production of power; meter and installation work. Desires post leading to executive responsibility. Knowledge Spanish. Age 38. Married. $4200 minimum. Available August. C-1372.

ELECTRICAL ENGINEER, COLLEGE GRADUATE. Seventeen years' experience on power station, sub-station, transmission and industrial work as designer, chief draftsman, assistant engineer. Experience with manufacturing companies, Public Utilities and Consulting Engineers. B-7183.

ELECTRICAL construction, maintenance or appraisal engineer, wide experience in construction work including steam turbine installations, largely with electric manufacturing and public utility companies. Competent to make up prices for public utility appraisals. C-1163.

ELECTRICAL ENGINEERING GRADUATE, 29, single, wishes position with engineering or construction firm where the following experience can be used to advantage. Two years' experience on bridges, conveyer equipment, one year test and assembly electrical motors, one one year test and assembly storage batteries. Great adaptability. Hard worker, available immediately. Location, Northern Ohio preferred. B-7908.

GRADUATE ELECTRICAL ENGINEER. Special studies Business Administration—four years varied experience with large manufacturing company and as technical assistant to electrical superintendant large steel company in charge of maintenance and construction. Familiar with all details of the department including estimates, power distribution, tests, and personnel. Excellent references from former employers. C-1297.

ELECTRICAL ENGINEER, age 26, married, technical graduate, four years' experience test supervision with public utility, one year's experience teaching, executive, statistician, organizer. Desires position with progressive organization offering reasonable advancement for conscientious, energetic worker. C-1346.

ELECTRICAL ENGINEER, M. I. T. graduate, two years' active experience in telephone engineering. Desires position with a future with manufacturing company on production, technical, or sales staff. Location, vicinity of New York. Available two weeks. C-1305.

ELECTRICAL and mechanical engineer, university graduate, age 39, married, desires executive or sales position. Twelve years' executive experience, electric railway, light and power. Wide acquaintance among operating officials of all utilities, and manufacturers. Best references. Available May 1st. New York vicinity preferred. C-1235.

ENGINEER, B. S. and E. E. degrees, fifteen years' experience testing, construction, design and supervision of substation and distribution work. Desires connection with manufacturer, public utility, engineer or investment banker employing engineers. Available on one month's notice. B-9551.

ELECTRICAL GRADUATE, age 24, single, desires permanent position engineering work. One year test, one year Caines current field engineering with General Electric Company. Familiar with Utilities of the South. C-1391.

ELECTRICAL ENGINEER, college and technical graduate, age 25 years' broad experience in power plant and substation design, H. T. bus construction, power and light distribution, underground and line transmission, quantity surveys, specification writing, executive correspondence, and office charge desires position with reliable utility company, Atlantic coast preferred. B-3231.

ELECTRICAL ENGINEER, age 26, married, desires position that has good chance for advancement. Fifteen months with General Electric Company as student engineer, two years teaching electrical engineering, three months operating large hydro-electric plant. Available at once. C-54-100.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MAY 21, 1926

ALBISTON, WILLIAM AARON, Radio & Electrical Engineer, Christmas Island Phosphate Co., Christmas Island, Indian Ocean.

ALLEN, THOMAS DANIEL NORRIS, Elec. Engg. Draftsman, U. S. Veterans' Bureau, Arlington Bldg., Washington, D. C.

*ANDREWS, SIDNEY WARREN, Engineer, Foundation Co., Pittston, Pa.

BALLEW, RICHARD E., System Dispatcher, Great Western Power Co., 3729 Park Blvd., Oakland, Calif.

BANTON, FOWLER BOYNTON, Electrical Engineer, New Orleans Public Service Co., 201 Baronne St., New Orleans, La.

BECKER, FRED A., Sale Engineer, Canadian General Electric Co., 212 King St., West, Toronto, Ont., Can.

BERTING, GERALD A., Asst. Sales Manager, The North Electric Mfg. Co., Galion, Ohio.

BLENKARN, WILLIAM O., Electric Plant Operator, Salt Creek Electric Plant, Midwest, Wyoming.

BODELSSON, ALFRED, Pratt Institute, 210 Grand Ave., Brooklyn, N. Y.

BOLLINGER, NEWTON H., Distribution Engineer, Florida Power and Light Company, Miami, Fla.

BOYD, J. W. G., Jr., Engg. Dept., Canadian National Carbon Co., Toronto, Ont., Can.

BRAUN, ALFRED WILLIAM, Secretary & Treasurer, William Braun & Co., 30 Church St., New York; res., Glendale, N. Y.

BRESSNER, JOSEPH, Student, Pratt Institute, Brooklyn, N. Y.

BROWN, HAROLD HASLEY, Electrical Engineer, Wisconsin Traction, Light, Heat & Power Co., 112 E. College Ave., Appleton, Wis.

BROWN, RALPH EUGENE, Instructor, Mechanical Engg. Dept., Rhode Island State College, Kingston, R. I.

BUCHANAN, THOMAS, Engineer, The British Thomson-Houston Co., Ltd., Neasden Lane, Willesden, res.; Harlesden, London, N. W. 10, England.

BURDIN, ALBERT JOHN, Equipment Engineer, Western Electric Co., Hawthorne Sta., Chicago, Ill.

BURKHARDT, CHRISTIAN ERWIN, Supt., Municipal Power & Ice Plant, Sebastian, Fla.

CADY, WILLIAM MALCOLM, Development Work, 108 Clinton Ave., Newark, N. J.

CAROLAN, WILLIAM ALFRED, 712 Putnam Ave., Brooklyn, N. Y.

CARPENTER, HAROLD WAIT, Salesman, Sangamo Electric Co., 19 Pearl St., Boston, Mass.; res., Norwich, Conn.

CATES, ROBERT VERNOR, Transmission Man, American Tel. & Tel. Co., Charlotte, N. C.

CHANT, ARTHUR E., Chief Accountant, Dept. of Telephones, Telephone Bldg., Regina, Sask., Can.

CLARK, OLPHA SIMPSON, Engineer, Transmission Dept., Union Gas & Electric Co., 2016 Dana Ave., Cincinnati, Ohio.

CLARKE, PHILIP CORLISS, Draftsman, General Electric Co., 6801 Elmwood Ave., West Philadelphia; res., Philadelphia, Pa.

COLVIN, A. L., Dist. Supt., Niagara Lockport & Ontario Power Co., Angola, N. Y.

CRAWFORD, WILLARD K., Tester, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

CSEPELY, JOHN ANTHONY, Electrical Engineer, The Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.; res., Guttenberg, N. J.

DAVIS, ALBERT EDWARD HARRY, Electrical Engineer, Frank J. Yorke Co., 159 Elizabeth Ave., E., Detroit, Mich.

DAVIS, HARRY FRANKLIN, Electrician, Monongahela West Penn Public Service Co., Bethlehem Bldg., Fairmont, West Va.

DeDONA, ANTHONY JOSEPH, Plant Supervisor, Postal Telegraph Co., 253 Broadway, New York, N. Y.

de POLAC, LEON C., Sales Correspondent, Westinghouse Elec. & Mfg. Co., 150 Broadway, New York, N. Y.

de ZAMACONA, LUIS, Testing Engineer, Mexican Light & Power Co., 20 Gante St., Mexico City, Mex.

DOWNIE, CHRISTOPHER GORDON, Metropolitan-Vickers Electrical Co., Ltd., Manchester; res., Sale Cheshire, Eng.

DUNCANSON, PETER, Electrician, Western Electric Co., Kearny; res., Jersey City, N. J.

DUNSTAN, RUSSELL ALFRED, Student Engineer, General Electric Co., Schenectady, N. Y.

EIGHMY, GEORGE WELLS, Electrical Engineer, General Electric Co., 1100 Electric Bldg., Buffalo, N. Y.

ELLIS, CHARLES RUSSELL, Electrical Field Engineer, Louis T. Klauder, 1300 Bankers Trust Bldg., Walnut & Juniper Sts., Philadelphia; res., Bristol, Pa.

*ENGELKEN, RICHARD C., Field Surveyor, Brooklyn Edison Co., 360 Pearl St., Brooklyn; for mail, New York, N. Y.

ENGH, JAMES STONEHAM, Field Operating Engineer, Automatic Electric, Inc., 1033 W. Van Buren St., Chicago, Ill.

FARRELL, JAMES J., Caribou Power House, Great Western Power Co., Caribou, Plumas Co., Calif.

FELDMAN, JOSEPH JAY, Sales Engineer, Westinghouse Elec. & Mfg. Co., 160 7th St., Brooklyn, N. Y.

FERREIRA, AULIO CLEMENTE, Asst. Supt., Elec. Studies & Investigations, The Sao Paulo Tramway Light & Power Co., Ltd., R. Bento, Freitas 51, Sao Paulo, Brazil, S. A.

*FOLTZ, JOSEPH P., Student, Westinghouse Elec. & Mfg. Co., 1308 Center St., Wilkinsburg, Pa.

FORKEL, WALTER HEINRICH, Draftsman, Metropolitan Electr. Manufacturing Co., Boulevard & 14th St., Long Island City; res., Brooklyn, N. Y.

*FOSTER, HARRY BLISS, Tester, Wireless Specialty Apparatus Co., 76 Atherton St., Boston; res., Medford, Mass.

FOWLER, JAMES RICHMOND, Electrical Inspector, Westchester Lighting Co., Mt. Vernon; res., Brooklyn, N. Y.

GALER, FRANK CHARLES, Electrican, Lancashire Dynamo & Motor Co., 45 Niagara St., Toronto, Ont., Can.

*GERMAN, CORNELIUS, Instructor, Elec. Engg. Dept., College of Engineering, University of Philippines, Manila, P. I.

GLOVER, GEORGE C., Switchboard Operator, Chile Exploration Co., Chuquicamata, Chile, S. A.

*GRUENBERG, ANATOLE R., Junior Partner, W. T. Swoyer & Co., Taylor Bldg., Johnson City, Tenn; for mail, De Land, Fla.

HADDOCK, CHARLES COLVOCORESSES, Asst. Engineer, Brooklyn Edison Co., 55 Johnson St., Brooklyn, N. Y.

HAIG, CLINTON M., Engineer, New England Tel & Tel. Co., 50 Oliver St., Boston, res.; Arlington, Mass.

HANKEY, WILLIAM JOSEPH, Electrical Engineer, Cleveland Railway Co., 13404 Chapelside Ave., Cleveland, Ohio.

HARRINGTON, GEORGE W., Student, Industrial Elec. Engg., Pratt Institute, Ryerson St., Brooklyn, N. Y.

*HARRISON, ARTHUR TEMPLETON, Operator, Hat Creek No. 1, Pacific Gas & Electric Co., Cassel, Calif.

HARRISON, JOHN KEARSLEY MITCHELL, Engineer, Harrison & Co., 1824 Land Title Bldg., Philadelphia, Pa.

*HARTE, JOSEPH A., Mechanical & Electrical Draftsman, Dept. of Plant & Structures, Municipal Bldg., New York, N. Y.

HEINSTALL, WILLIAM GODFREY, Plant Supt., Lignite Utilization Board, Bienfait, Saskatchewan, Can.

HERBERS, HERMAN HEINRICH WILHELM, Asst. Engineer, New York Edison Co., 302 Ditmas Ave., Astoria, N. Y.

HINDMAN, EDWARD RUSSELL, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HOLLEMAN, ELWOOD MONROE, Radio Salesman, Germains, 6th & Main Sts., Los Angeles, Calif.

HOLTON, THEODORE R., American Steel & Wire Co., Cable Works, Worcester, Mass.

HUDSON, ALFRED, Student Engineer, General Electric Co., Schenectady, N. Y.

HUDSON, FLOYD EDWARD, Electrical Tester, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

HUGHES, GRIFFITH OSBORNE, Chief Operator, Power Plant No. 2, Bureau of Power & Light, City of Los Angeles, Saugus, Calif.

ISHII, TADASHI, Electrical Engineer, Japanese Government Railways, 1 Madison Ave., New York, N. Y.

JONES, FRANK AUGUSTUS M., Chief Draftsman, The Pacific Tel. & Tel. Co., 140 New Montgomery Bldg., San Francisco, Calif.

JONES, JOHN PAUL, Consulting Engineer, 1740 E. 12th St., Cleveland, Ohio.

*JONES, RALPH WILLIAM, Distribution Engineer, Consumers Power Co., Flint; res., Clio, Mich.

JUND, DANIEL, Foreman, W. C. Lagerway, 181 West End Ave., Instructor, New York Electrical School, New York, N. Y.

KELHOFER, LEON MARTIN, Electrical Engineer, Commonwealth Power Corp., Jackson, Mich.

*KHALIFAH, ABD-EL-RAHMAN AMER, Mechanical Engg., Baldwin Locomotive Works, Broad & Spring Garden Sts., Philadelphia, Pa.

KIRKPATRIC, KENNETH JOHN, Supt., Telephone Cable Factory, Metal Manufactures Proprietary Ltd., Port Kembla, N. S. W., Aus.

KLEIN, FERNAND A., Engineer, Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.
KOTHARE, MAHADES BAPUJI, Chief Engineer, Broach Electric Supply & Development Corp., Ltd., Broach, India.
KOVALSKY, JOSEPH FRANK, Electrical Engineer, Control Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Swissvale, Pa.
KOVEDIAEFF, BORIS E., 1018 W. 73rd St., Los Angeles, Calif.
KUPFERLE, ARTHUR TROMMER, Instrument Repair Man, Meter Laboratory, Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.
LAMANTIA, JOACHIM C., Student, Brooklyn Polytechnic Institute, Brooklyn; res., New York, N. Y.
LAPPIN, JOHN L., Electrical Draftsman, General Electric Co., 5 Lawrence St., Bloomfield, N. J.
LAUTH, EDWIN HARRY, Electrical Engineer, Street Lighting Section, City of St. Louis, City Hall, St. Louis, Mo.
LEWIS, FRANK M., Plant & Engg. Dept., Northwestern Electric Co., Portland, Ore.
LONGY, VINCENT, Resident Electrical Engineer, British Engine, Boiler & Electrical Insurance Co., Ltd., Barcelona, Spain.
MANNING, EDWARD RALPH, Sales Engineer, Weston Electrical Instrument Corp., 50 Church St., New York, N. Y.; res., Bayonne, N. J.
MARKOVITS, JOSEPH ARPAD, Draftsman, Westinghouse Elec. & Mfg. Co., 432 Meek St., Sharon, Pa.
MARSHALL, ARMOND EDWIN, Electrical Draftsman, The Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.
MARTIROSIAN, MICHAEL M., Student, State College of Washington, Pullman, Wash; res., New York, N. Y.
McCULLOCH, HAROLD, Asst. Electrical Engineer, Hydro-Electric Dept., Hobart, Tasmania.
McGINNIS, NEIL W., Chief Electrician, Parafine Co.'s, Inc., Vernon & Santa Fe Aves., Los Angeles, Calif.
McGRATH, MARTIN HAGER, Research Laboratory Standard Underground Cable Co., 17th & Pike Sts., Pittsburgh, Pa.
McINTYRE, ROBERT JOSEPH, Asst. Service Manager, Gray Electro Chemical Laboratory, 9-11 W. 20th St., Bayonne; res., Jersey City, N. J.
*McKEON, JOHN BRICHER, Cadet Engineer, Elec. Dept., Rochester Gas & Electric Corp., Rochester, N. Y.
MILNE, KENNETH HARVEY, Commonwealth Power Corp., Jackson, Mich.
MIMMACK, ARTHUR, City Electrician, Engg. Dept., City Hall, Beverly Hills; res., West Hollywood, Calif.
MORORO, DORGIVAL GONCALVES, 3100 North Grand Blvd., St. Louis, Mo.
MOSS, JOHN E., Electrician, West Penn Power Co., Washington, Pa.
MURPHY, JOHN ANSON, Asst. to Elec. Supt., McClellan & Junkersfeld, Inc., St. Louis, Mo.
*NEMETZ, VICTOR W., Electrical Engineer, Commonwealth Power Corp., Jackson, Mich.
NERGES, FRANK ANTHONY, Electrician, U. S. N., U. S. S. Owl No. 2, N. O. B., Hampton Roads, Va.
NIXON, JOHN HUMPHREY RUSSELL, Electrical Machine Designer, Messrs, Brush Elec. Engg. Co., Ltd., Falcon Works, Loughborough, Leicestershire, Eng.
NOGUCHI, KOJU, Member of Research Staff, Mitcubishi Research Laboratory, 29 Kamifujimaecho, Komagome, Hongo, Tokyo, Japan.
O'SHEA, M. VINCENT, Jr., 529 N. Pinckney St., Madison, Wis.
OVERFIELD, G. BRYAN, Sales Engineer, Burke Electric Co., 12th & Cranberry Sts., Erie, Pa.
*PANTON, HARRY A., Engineer, Buffalo General Electric Co., Electric Bldg., Buffalo, N. Y.
PASAYIOTIS, GEORGE N., Proprietor, Book-News & Novelty Co., 852 Penn St., Reading, Pa.
PATEL, DAHYABHAI BAKORBHAI, Research Work, Indian Electrical Problems, c/o Brown Boveri & Co., Baden, Switzerland.
PETERSEN, HENRY N., Load Dispatcher, Great Western Power Co. of California, 3729 Park Blvd., Oakland, Calif.
PETERSON, JOHN REYNOLD, Radio Interference Inspector, Western Union Telegraph Co., 49 Geary St., San Francisco, Calif.
PETTIT, ZACHARY T., Underground Electrical Engineer, Los Angeles Gas & Electrical Corp., 810 S. Flower St., Los Angeles; res., San Gabriel, Calif.
PHELPS, MERRICK W., Dist. Manager, Pittsburgh Transformer Co., 601 Electric Bldg., Buffalo, N. Y.
PHILIPSON, RALPH E., Designer, Electric Bond & Share Co., 65 Broadway, New York, N. Y.
*PYLE, ALBERT JOCELYN, Instructor, Elec. Engg., Moore School of E. E., Univ. of Penna., Philadelphia, Pa.
RAGG, FRED C., Electrical Engineer, Textile Dyeing Co. of America, Paterson, N. J.
RANSFORD, HERBERT EARL, Sales Engineer, Henry N. Muller Co., 812 Westinghouse Bldg., Pittsburgh, Pa.
REIFSNYDER, SIDNEY EARLE, Supt. of Construction, Chas. Cory & Son, Inc., 15th & Venango Sts., Philadelphia, Pa.
REILLY, FRANCIS JOSEPH, Sales Engineer, Tork Co., 8 West 40th St., New York, N. Y.
ROBINSON, JOHN WILLIAM, Instrument Maker, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.
RODGERS, KARL F., Member, Technical Staff, Bell Tel. Laboratories, Inc., 463 West St., New York, N. Y.
ROSS, RAYMOND W., Drafting & Designing Dept., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.
ROYERE, JEAN EUGENE, Plant Operator, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.
*SAMSON, DAVID FORSYTH, Electrical Contracting, 71 Chestnut St., Branford, Conn.
SCANLON, DALE LESTER, Electrical Foreman, Chile Exploration Co., Chilex, Chuquicamata, Chile, S. A.
SCHMELTZER, CAESAR FRÈDERICK, Specification Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago; res., Cicero, Ill.
SCHOLZ, CHARLES BRADFORD, Plant Engineer, Interstate Utilities Co., 424 Hutton Bldg., Spokane, Wash.
SCHROEDER, EDWARD H., Division Supt., Installation Dept., Western Electric Co., Inc., 1505 Race St., Philadelphia, Pa.
SCOTT, THOMAS WEBB, Signal Supervisor, Baltimore & Ohio Railroad, Connellsville, Pa.
SISKIND, ROBERT PEER, Research Assistant, Elec. Engg. Dept., Harvard Engineering School, 204A Pierce Hall, Cambridge; res., Brookline, Mass.
SMITH, HAROLD L., Student Engineer, Southern Ontario Gas Co., Merlin, Ont., Can.
SNOW, HOWARD BARTLEY, Asst. Engineer, Public Service Production Co., 80 Park Place, Newark, N. J.
SNYDER, FRANKLIN L., Engineer, Transformer Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon; res., Sharpsville, Pa.
SPECTOR, BARUCH, Transformer Draftsman, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
SPENCER, RIPLEY M., Electrical Inspector Los Angeles Gas & Elec. Co., 725 Channing St., Los Angeles, Calif.
STEEB, GEORGE, Asst. to Supt., Niagara Lockport & Ontario Power Co., Gardenville, N. Y.
STEINKAMP, WALTER, Distributor, X-Ray & Electro Medical Equipment, 253 Alexander St., Rochester, N. Y.
STEVENS, EDWARD JAMES, Jr., Inspector, Gurney Elevator Co., Inc., 300 8th Ave., New York, N. Y.; res., Belleville, N. J.
STINSON, MALCOLM JOSEPH, Relief Operator & Power Director, Montville Power Station, Uncasville, res., Norwich, Conn.
STUBBS, WALTER W., Electrical Repairman, Champion Coated Paper Co., Hamilton, Ohio.
SZAPPANYOS, ALEXANDER, Draftsman, Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
THOMAS, RALPH EDWIN, Commercial Engineer, Westinghouse Elec. & Mfg. Co., 1535 6th St., Detroit, Mich.
THOMPSON, WILLIAM SCOTT, Field Engineer, Michigan Bell Telephone Co., 1365 Cass Ave., Detroit, Mich.
TRACEY, FRANK S., Manager & Treasurer, Lockport & Newfane Pr. & Water Supply Co., 16 State St., Middleport, N. Y.
TRACY, GORDON FREDERICK, Instructor, Elec. Engg. Dept., University of Wisconsin, Madison, Wis.
TRAINOR, JOHN FRANCIS, Electrical Inspector, Underwriters Laboratories, 40 Central St., Boston; res., Fall River, Mass.
TURNER, WILLIAM FISHER, Employment Interviewer, Brooklyn Edison Co., Inc., 360 Pearl St., Brooklyn, N. Y.
WAGNER, VIRGIL CESAIRE, Electrical Estimator, Fischbach & Moore, Inc., 222 E. 42nd St., New York; for mail, Astoria, N. Y.
WASHBURN, JOHN C. B., Right-of-Way Dept., Narragansett Electric Lighting Co., Providence; res., East Greenwich, R. I.
WATLING, ROBERT GROVER, Engineer, Plant Dept., Southern California Telephone Co., 433 S. Olive St., Los Angeles; res., Glendale, Calif.
WATSON, H. KENNETH, Draftsman, Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
*WEINER, LOUIS, Anaconda Sales Co., 25 Broadway, New York, N. Y.
WEITZMAN, HARRY A., Penn Public Service Corp., Johnstown, Pa.
WESTBROOK, JOSEPH A. ALBERT, Engineer, Street Cable Div., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
WILLIAMS, GEORGE SETH, Vice-President & General Manager, Central Maine Power Co., 317 Water St., Augusta, Me.
WILLIARD, JOHN ANDREW, Electrical Designer, Philadelphia Electric Co., 1035 Chestnut St., Philadelphia, Pa.
*WISSMANN, JOSEPH THEODORE, Receiving Engineer, Radio Corp. of America, Riverhead, N. Y.
WOMER, CLAUDE EMORY, Supt. of Equipment, Shamokin-Mt. Carmel Transit Co., Mt. Carmel, Pa.
WOODS, OSBORNE BAKER, Senior Operator, Newfoundland Power & Paper Co., Deer Lake, Newfoundland.
YOUNT, L. E., Asst. Manager, Western Radio, Inc., 1224 Wall St., Los Angeles, Calif.
ZEPLAIEV, PAUL PETER, Teacher, Elec. Engg. Dept., Polytechnic Institute of Leningrad, Leningrad, Russia.
ZIELINSKI, HEINZ, Draftsman-designer, Kny-Scheerer Corp. of America, 119 7th Ave., New York, N. Y.; res., Sharon, Pa.
ZIMMERMAN, EUGENE FREDERICK, Student Engineer, Southwestern Bell Tel. Co., 512 Planter's Bldg., St. Louis, Mo.

Total 161

*Formerly Enrolled Students.

ASSOCIATES REELECTED MAY 21, 1926

CRANSTON, ROBERT W., Supt. Substations, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

FLESHIEM, ROBERT STEPHENSON, Asst. Manager, Elec. Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

MAHOOD, EDWIN TERRELL, Valuation Engineer, Southwestern Bell Telephone Co., 569 Boatman's Bank Bldg., St. Louis, Mo.

MEMBER REELECTED MAY 21, 1926

SIMPSON, FRANK, Treasurer, The Collier-Simpson Co., 500 East 102nd St., Cleveland, Ohio.

MEMBERS ELECTED MAY 21, 1926

ALLEN, THOMAS SIMMONS, Engineer, Allis-Chalmers Mfg. Co., 3421 Sycamore St., Milwaukee, Wis.

BARNARD, GLENN HARRISON, Manager, Marine Sales & Philadelphia Dist. Office, Electro-Dynamic Co., Bayonne, N. J.

BECKETT, WILLIAM, Asst. Engineer, Dept. of Development, Georgia Railway & Power Co., Atlanta, Ga.

BURRI, JOSEPH JOHN, Supt. of Distribution, Staten Island Edison Corp., Staten Island, N. Y.

CASTER, JOHN HERBERT, Dist. Engineer, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

FLORY, A. C., Manager, Steam Turbine Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

HARVEY, ARTHUR FREDERIC, Asst. Engineer of Electrification, Central Argentine Railway, Victoria, F. C. C. A., Argentina, S. A.

HOADLEY, HERBERT EUGENE, Distribution Supt., The Ohio Public Service Co., Warren, Ohio.

LEWIS, HAROLD G., Springfield Service Manager, Westinghouse Elec. & Mfg. Co. 395 Liberty St., Springfield, Mass.

McLEAN, JAMES SINCLAIR, Construction Supt., The J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

SCHOLZ, CARL E., Chief Engineer, Federal Telegraph Co., Palo Alto, Calif.

SPELLMIRE, WALTER B., Manager, General Electric Co., 1307 Oliver Bldg., Pittsburgh., Pa.

THOMAS, WILLIAM ANDREW, 3rd Radio Engineer, Sonora Phonograph Co., Inc., 279 Broadway, New York; res., Brooklyn, N. Y.

THOMSON, OSCAR ROLAND, Asst. Supt., C. O. S., Hydro-Electric Power Commission of Ontario, Belleville, Ont., Can.

TRETJAK, GREGORY TIMOTHY, Teacher, Elec. Engg. Dept., Electrotechnical Institute, Pessotchnaya 5, log. 6, Leningrad, Russia.

UPP, JOHN W., Jr., Electrical Engineer, Ohio Brass Co., Mansfield, Ohio.

WILLISON, JOHN WRIGHT, Supt., Yorkshire Electric Pr. Co., 36 Park Place, Leeds, Yorkshire, Eng.

FELLOW ELECTED MAY 21, 1926

KLOSS, MAX, Prof. of Elec. Engg., Technische Hochschule, Charlottenburg; for mail, Berlin-Nikolassee, Germany.

TRANSFERRED TO GRADE OF FELLOW MAY 21, 1926

DWIGHT, HERBERT BRISTOL, Professor, Massachusetts Institute of Technology, Cambridge, Mass.

HEINZE, CARL A., Electrical Engineer in charge of Distribution, Department ofWater & Power, City of Los Angeles, Los Angeles, Calif.

OEHLER, ALFRED G., Editor — *Railway Electrical Engineer*, Electrical Editor — *Railway Age*, New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER MAY 21, 1926

ANDERSON, EDWARD T., Electrical Engineer, Board of Water & Electric Light Commissioners, Lansing, Mich.

BACKUS, CYRUS D., Principal Examiner, U. S. Patent Office, Washington, D. C.

BOHNERT, ARTHUR M., District Engineer, Ohio Brass Co., San Francisco, Calif.

BOLLINGER, HOWARD M., Supervisor of Plant Methods, Chesapeake & Potomac Telephone Co., Washington, D. C.

BROCKWAY, R. M., Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

CARPE, ALLEN, Engineer, Dept. of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

CLAPP, ROBERT H., Telegraph Engineer, American Telephone & Telegraph Co., New York, N. Y.

COLBURN, WELLEN H., Electrical Engineer, Station Engineering Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.

FINCH, WILLIAM G. H., Radio Editor and Engineer, International News Service, New York, N. Y.

GIBSON, E. S., Telephone Engineer, Bell Telephone Laboratories, New York, N. Y.

JACKSON, DUGALD C., Jr., Asst. Professor of Electrical Engineering, Trinity College, Durham, N. C.

RAMIREZ, JAVIER P., Consulting Engineer, Professor Escuela de Ingenieros Mecanicos Electricistas, Mexico City, Mex.

RORTY, M. C., President, International Telephone Securities Corp. — Vice-President, International Tel. & Tel. Corp., New York, N. Y.

SAATHOFF, GEORGE W., Chief Construction Engineer, Henry L. Doherty & Co., New York, N. Y.

SPORN, PHILIP, Assistant to Electrical Engineer, American Gas & Electric Co., New York, N. Y.

SPRACKLEN, EMERY E., Electrical Engineer in charge of Design, Ohio Public Service Co., Massillon, Ohio.

TAYLOR, NEWTON S., Manager, Switchboard Section Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

WHIPPLE, CLYDE C., Asst. Professor of Electrical Engineering, Polytechnic Iustitute, Brooklyn, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, has recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

FONDILLER, WILLIAM, in charge, General Development Laboratory, Bell Telephone Laboratories, New York, N. Y.

HUBLEY, GEORGE W., Consulting and Advisory Engineer, Louisville, Ky.

STRENG, LEWIS S., Vice-President in charge of Operation, Louisville Gas & Electric Co., Louisville, Ky.

To Grade of Member

AMES, NORMAN B., Assistant Professor of Electrical Engineering, George Washington University, Washington, D. C.

BAILEY, RAYMOND, Chief Electrical Designer, Philadelphia Electric Co., Philadelphia, Pa.

CELIS, ATILIO, Manager-Engineer, San Juan Office of International General Electric Co., Inc., San Juan, P. R.

CHADWICK, RALPH H., Section Head, Transformer Engineering Dept., General Electric Co., Fort Wayne, Ind.

CLEARY, LEO H., Electrical Engineer, Standard Engineering Co., Washington, D. C.

EDISON, OSKAR E., Associate Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.

FEDER, JOSEPH B., Electrical Engineer, Chas. Cory & Son, Inc., New York, N. Y.

GARRISON, DWIGHT, Supt., Telephone Dept., Atlantic Refining Co., Philadelphia, Pa.

GAYLORD, JOHN C., Electrical Engineer' Southern California Edison Co., Los Angeles, Calif.

GORDON, LESLIE B., Chief Electrical and Power Engineer, Kelly-Springfield Tire Co., Cumberland, Md.

HALPENNY, R. H., Electrical Engineer, Southern Sierras Power Co., Riverside, Calif.

HAMILTON, JAMES T., Supt. of Equipment, New York, Westchester & Boston R. R., New York & Stamford Ry. Co., Westchester Street Ry. Co., New York, N. Y.

HECHT, J. BERNARD, Outside Plant Engineer, Tri-State Tel. & Tel. Co., St. Paul, Minn.

HESTER, EDGAR A., Transmission Planning Engineer, Duquesne Light Co., Pittsburgh, Pa.

HOWK, CLARENCE L., Telephone Engineer, International Standards Electric Corp., New York, N. Y.

KARCHER, E. KENNETH, Chief Electrical Engineer, Utica Gas & Electric Co., Utica, N. Y.

KENNEDY, S. M., Vice President, Southern California Edison Company, Los Angeles, Cal.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1926.

Alberti, J. N., General Electric Co., Schenectady, N. Y.

Allen, J. G., Duquesne Light Co., Pittsburgh, Pa.

Ames, A. W., Lighting Dept., City of Seattle, Seattle, Wash.

Auten, L. D., Cleveland Railway Co., Cleveland, Ohio

Ballantine, R. A., Penn Electrical Engineering Co., Scranton, Pa.

Ballard, W. C., Jr., Cornell University, Ithaca, N. Y.

Banan, H. F., Westinghouse Elec. & Mfg. Co., Boston, Mass. (Applicant for re-election.)

Barse, J. H., McKinney Steel Co., Cleveland, Ohio

Bartholomew, F. J., Bartholomew, Montgomery & Co., Ltd., Vancouver, B. C.

Barton, S., Federal Telegraph Co., Clearwater, Calif.

Bayles, C. G., Black & Veatch, Kansas City, Mo.

Becker, H., Jr., Interborough Rapid Transit Co., New York, N. Y.

Beckett, R. V., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Bennett, J. W., Eastern N. J. Power Co., Allenhurst, N. J.

Bergholtz, H., General Electric Co., Schenectady, N. Y.

Binder, G. A., Ohio Brass Co., Chicago, Ill.

Blake, F. J., Public Service Co. of Colorado, Denver, Colo.

Bodge, H. H., (Member), Fall River Electric Light Co., Fall River, Mass.

Borgeson, S. E., Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.

Bornholz, F. J., (Member), Shanghai Municipal Council, Shanghai, China. (For mail, San Francisco, Calif.)

Bothwell, F. A., General Electric Co., Schenectady, N. Y.

Boyere, E. E., (Member), Electrical Specialist, Erie, Pa.

Brackett, N. W., Puget Sound Power & Light Co., Seattle, Wash.

Braithwaite, W. S., Edison Elec. Illuminating Co., Boston, Mass. (Applicant for re-election.)

Brennon, L. A., General Electric Co., Erie, Pa.

Bristow, T. N., H. B. Squires Co., Seattle, Wash.

Brown, J. F., Tri-State College, Angola, Ind.

Brown, L., City of Seattle, Lighting Dept., Seattle, Wash.

Buchanan, E. C., The Pacific Tel. & Tel. Co., Portland, Ore. (Applicant for re-election.)
Burckett, D. M., Great Northern Railway, Seattle, Wash.
Burrow, P., Supt. of Power Plant, Dryden, Wash.
Bustillo, F. E., Mexican Light & Power Co., Mexico D. F., Mex.
Butler, W. C., The Pacific Tel. & Tel. Co., Seattle, Wash.
Butow, F. W. C., Pacific Coast Steel Co., S. San Francisco, Calif.
Butt, F. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Campbell, T. L., Toronto Hydro-Electric System, Toronto, Ont., Can.
Carrick, J. F. C., General Electric Co., Niagara Falls, N. Y.
Carter, T. B., Cumberland Tel. & Tel. Co., Louisville, Ky. (Applicant for re-election.)
Chambers, H. D., Puget Sound Power & Light Co., Seattle, Wash.
Christianson, E. C., Puget Sound Power & Light Co., Tacoma, Wash.
Cirella, L. E., Simplex Wire & Cable Co., Cambridge, Mass.
Cooper, R. F., Miller Rubber Co., Akron, Ohio
Crago, P. H., Union Switch & Signal Co., Swissvale, Pa.
Craven, F. E., Bell Telephone Co. of Pa., Philadelphia, Pa.
Crawford, J. M., General Electric Co., Schenectady, N. Y.
Crock, I. Z., New England Tel. & Tel. Co., Boston, Mass.
Crump, L. W., Puget Sound Power & Light Co., Tacoma, Wash.
Cunningham, K. G., Ohio Bell Telephone Co., Cleveland, Ohio
Curtis, G. V., General Electric Co., Schenectady, N. Y.
Cuthbert, J. T., Duquesne Light Co., Pittsburgh, Pa.
Davis, W., Toronto Hydro-Electric System, Toronto, Ont., Can.
Day, W. P., General Electric Co., Schenectady, N. Y.
de Lima, C. A., Westinghouse Elec. International Co., Mexico, D. F.
Deneen, R. J., Ohio Brass Co., Chicago, Ill.
de Vries, B. D., Duquesne Light Co., Pittsburgh, Pa.
Dibblee, J., (Member), Hydro-Elec. Pr. Commission of Ontario, Toronto, Ont., Can.
Diehl, W. A., National Malleable & Steel Castings Co., Cleveland, Ohio
Doane, P., New York Edison Co., New York, N. Y.
Dowe, G. P., The Canadian Crocker-Wheeler Co., St. Catharines, Ont., Can.
Drake, R. A., U. S. S. Arizona, San Francisco, Calif.
Duevel, C. O., Jr., Consumers Central Heating Co., Tacoma, Wash.
Duffy, L., Puget Sound Power & Light Co., Seattle, Wash.
Eveland, G. H., Feather River Power Co., San Francisco, Calif.
Fagan, H. J., 1555 Walton Ave., Bronx, New York, N. Y.
Falk, V. E., Stone & Webster, Inc., Boston, Mass.
Falor, H. L., Northern Ohio Power & Light Co., Akron, Ohio
Flory, C. L., Radio Corp. of America, Tuckerton, N. J.
Fontaine, J., North Carolina State College, Raleigh, N. C.
Forsyth, J. W., Engineer, City of Philadelphia, Philadelphia, Pa.
Free, J. E., General Electric Co., Philadelphia, Pa.
Fuhs, R. H., Indianapolis Light & Heat Co., Indianapolis, Ind.
Gale, Arthur P., Wisconsin Power & Light Co., Madison, Wis.
Gantenbein, E. F., Puget Sound Power & Light Co., Olympia, Wash.
Garner, F. E., Daven Radio Corp., Newark, N. J.
Ghen, M. W., Duquesne Light Co., Pittsburgh, Pa.
Giangrande, D. M., The New York Edison Co., New York, N. Y.
Gibney, E. L., Lighting Dept., City of Seattle, Seattle, Wash.
Gibson, F. C., Edison Storage Battery Co., Seattle, Wash.
Gillis, M. D., General Electric Co., Erie, Pa.
Gilson, W. J., Canadian & General Finance Co., Toronto, Ont., Can.
Goyne, T. S., Goyne Steam Pump Co., Ashland, Pa.
Graul, E. A., Duquesne Light Co., Pittsburgh, Pa.
Graves, J. M., (Member), Duquesne Light Co., Pittsburgh, Pa.
Hall, I. E., Roller-Smith Co., Bethlehem, Pa.
Hansen, T. A., Puget Sound Power & Light Co., Seattle, Wash.
Harkins, P. S., Bell Telephone Co. of Pa., Philadelphia, Pa.
Harrell, F. E., Reliance Electric & Engineering Co., Cleveland, Ohio
Hartle, W. G., General Electric Co., Schenectady, N. Y.
Haskens, A. J., Union Switch & Signal Co., Swissvale, Pa.
Helander, W. N., Puget Sound Power & Light Co., Olympia, Wash.
Hicks, L. V., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hillock, J. F., Duquesne Light Co., Pittsburgh, Pa.
Hite, J. W., Reliance Electric & Engineering Co., Cleveland, Ohio
Hoehn, E. H., Union Electric Light & Power Co., St. Louis, Mo.
Hults, The Ohio Public Service Co., Warren, Ohio
Hurlburt W. O., Gas & Electric Service Co., Chico, Calif.
Hyams, L. B., Gothem Electric & Supply Co., New York, N. Y.
Hyle, L. C., Emaus Telephone Co., Emaus, Pa.
Ishikawa, K., International General Electric Co., Schenectady, N. Y.
Jayne, J. K., Autocar Co., Brooklyn, N. Y.
Johnson, E. L., H. B. Squires Co., Seattle, Wash.
Johnson, R. H., Puget Sound Power & Light Co., Bremerton, Wash.
Johnson, R. R., Duquesne Light Co., Pittsburgh, Pa.
Keefer, J., Pacific Coast Steel Co., S. San Francisco, Calif.
Kellers, C. F., General Electric Co., Schenectady, N. Y.
Kepple, K. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Kilbury, W. A., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Kincaid, M. B., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Klingenberg, F., Thomas E. Murray, Inc., New York, N. Y.
Knaus, F., Lighting Dept., City of Seattle, Seattle, Wash.
Krauskop, V. O., American Electric Power Co., Philadelphia, Pa.
Laube, L. F., General Electric Co., Schenectady, N. Y.
Lavo, K. E., General Electric Co., Schenectady, N. Y.
Lindstrom, C. T., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Linton, S., Stone & Webster, Inc., Boston, Mass.
Loughridge, C. H., (Member), Consulting Engineer, Cleveland, Ohio
Manahan, W. T., Consolidated Gas, Elec. Lt. & Pr. Co. of Baltimore, Baltimore, Md.
Marsten, J., Freed-Eisemann Radio Corp., Brooklyn, N. Y.
Marthakis, G. S., General Electric Co., Schenectady, N. Y.
Martyn, C. A., Puget Sound Power & Light Co., Tacoma, Wash.
Mason, H. R., Ohio State University, Columbus, Ohio
McBride, B. V., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McCuaig, D. A., Stone & Webster, Inc., Boston, Mass.
McNichall, J. F., Gould Storage Battery Co., Depew, N. Y.
Means, L. H., General Electric Co., Schenectady, N. Y.
Merritt, D. F., Famous Players Lasky Co., Hollywood, Calif.
Merry, F. S., Toronto Hydro-Electric System, Toronto, Ont., Can.
Metcalf, J. I., Day & Zimmermann, Inc., Philadelphia, Pa.
Monroe, J. J., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Moore, H. A., (Member), U. S. Smelting, Refining & Mining Co., Logan, Utah
Moore, S. A., Holeproof Hosiery Co., Milwaukee, Wis.
Mueller, W. H., Pacific Tel. & Tel. Co., Seattle, Wash.
Muir, W. L., Puget Sound Power & Light Co., Olympia, Wash.
Murch, J. C., General Electric Co., Erie, Pa.
Neighbors, G. F., General Electric Co., Schenectady, N. Y.
Offutt, H. V., Asst. Vice-Pres., First National Bank; Kentucky Title Co., Louisville, Ky.
Osthoff, L. H., The Pacific Tel. & Tel. Co., Seattle, Wash.
Paradis, A., The Pacific Tel. & Tel. Co., Seattle, Wash.
Peck, F. M., Northern Ohio Power & Light Co., Akron, Ohio
Peck, J. L., General Electric Co., Erie, Pa.
Perks, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Perry, R. T., General Electric Co., Schenectady, N. Y.
Pfeifer, W. A., (Member), Tri-State College, Angola, Ind.
Phipps, P., Toronto Hydro-Electric System, Toronto, Ont., Can.
Pixton, W. G., General Electric Co., Schenectady, N. Y.
Piza, J. G., General Electric Co., Schenectady, N. Y.
Quallins, G. A., 237 W. 70th St., New York, N. Y.
Rasmussen, D., Duquesne Light Co., Pittsburgh, Pa.
Reading, A. L., (Member), West Kootenay Pr. & Lt. Co., Substation Trail, B. C.
Reed, R. B., Philadelphia Electric Co., Philadelphia, Pa.
Reid, A., Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
Richardson, T. P., Jr., A. A. Merrick Engineering Service, Tryon, N. C.
Robinson, G. W., General Electric Co., Schenectady, N. Y.
Robinson, R. B., Philadelphia Co., Pittsburgh, Pa.
Roth, J. D., General Electric Co., Schenectady, N. Y.
Roudebush, G. H., Ohio Bell Telephone Co., Cleveland, Ohio
Samson, R., Puget Sound Power & Light Co., Bellingham, Wash.
Sattenstein, S. L., Bethlehem Steel Co., Bethlehem, Pa.
Schlegel, R. D., Potomac Electric Power Co., Washington, D. C.
Schifreen, C. S., Philadelphia Electric Co., Philadelphia, Pa.
Schreiber, E. H., The Pacific Tel. & Tel. Co., Seattle, Wash.
Schroeder, J. P., Pacific Gas & Electric Co., San Francisco, Calif.
Shallenberger, D. K., Beechbottom Power Co., Power, West Va.
Sharrock, L. L., St. Lawrence County Utilities, Inc., Potsdam, N. Y.
Shaw, J. L., Bethlehem Steel Co., Lackawanna, N. Y.
Sherer, C. M., Pennsylvania Water & Power Co., Holtwood, Pa. (Applicant for re-election.)
Skinner, R. W., Louisville Gas & Electric Co., Louisville, Ky.
Smith, C. E., (Member), J. Livingston & Co., New York, N. Y.

Smith, P. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Smith, T. T., Puget Sound Power & Light Co., Seattle, Wash.
Snyder, J. N., Duquesne Light Co., Pittsburgh, Pa.
Spaulding, L. S., Electrician-Draftsman, Hazleton, Pa.
Spear, H. E., Puget Sound Power & Light Co., Tacoma, Wash.
Stacy, R. P., Duquesne Light Co., Pittsburgh, Pa.
Steel, E. T., Puget Sound Power & Light Co., Bremerton, Wash.
Steel, F. K., (Member), Great Northern Railway, Seattle, Wash.
Steinmetz, W. C., The Alaskan Railroad, Anchorage, Alaska
Stephenson, J., (Member), Hamilton By-Product Coke Ovens, Ltd., Hamilton, Ont., Can.
Storms, C. A., General Electric Co., Schenectady, N. Y.
Sumner, M. R., Philadelphia Co., Pittsburgh, Pa.
Sylvester, F. E., Great Western Power Co., Oakland, Calif.
Tennant, R. J. J., Duquesne Light Co., Pittsburgh, Pa.
Thedniga, H. H., Manufacturer's Agent, Seattle, Wash.
Thompson, L. A., Puget Sound Power & Light Co., Seattle, Wash.
Thomson, S. E., (Member), Hydro-Electric Power Commission, Niagara Falls, Ont., Can.
Tucker, J. R., Southern Pacific Co., San Francisco, Calif.
Uhlrig, H. W., General Electric Co., Schenectady, N. Y.
Van Huysen, J. W., Garland Affolter Engineering Corp., Seattle, Wash.
Vonsovich, L. J., 2207 Ellsworth St., Berkeley, Calif.
Walker, A. J., Wireless Specialty Apparatus Co., Jamaica Plain, Mass.
Walsh, F., Puget Sound Power & Light Co., Everett, Wash.
Walther, G. J., General Electric Co., Schenectady, N. Y.
Warren, P. L., Ohio Brass Co., Chicago, Ill.
Weckel, G. H., General Electric Co., Schenectady, N. Y.
Wells, D. V., Northwestern Light & Power Co., Sibley, Iowa
Wells, J. P., Century Electric Co., St. Louis, Mo.
White, E. L., Puget Sound Power & Light Co., Seattle, Wash.
Whiteman, W. A., Monongahela West Penn Public Service Co., Wellsburg, West Va.
Williamson, W. S., Prudential Insurance Co., Newark, N. J.
Willits, R. F., Public Service Electric & Gas Co., Camden, N. J.
Woodhouse, G. E., Hydro-Electric Power Commission, Toronto, Ont., Can. (Applicant for re-election.)
Wright, R. B., Puget Sound Power & Light Co., Seattle, Wash.
Yoder, N. W., Leeds & Northrup Co., Philadelphia, Pa.
Zierdt, C. H., Union Switch & Signal Co., Swissvale, Pa.
Total 204

Foreign

Cottier, J. P., Ohakune Borough Council, Ohakune, N. Z.
Dejong, F., Riejos of Puerza del Ebro, S. A., Barcelona, Spain
Della Riccia, A., (Member), Consulting Elec. Engineer, Brussels, Belgium
Kale, P. B., The Central Provinces Engineering Co. Ltd., Nagpur, India
Kothawala, K. R., Elec. Engr., Kishangash State, Kishangash, Rajputana, India
Lapiroff-Scoblo, M., (Fellow), Electrotechnical Inst., Moscow, Russia
Melsom, S. W., (Fellow), Callendars Cable Co., Belvidere, Kent, Eng.
Mori, H., Dept. of Communication, Bureau of Electricity, Tokio, Japan
Parker, W. A. H., West Gloucester Power Co., Ltd., Gloucester, Eng.
Santa-Maria, D., Engr. of Direction, de Servicios Electricos, Santiago, Chile, S. A.
Total 10.

STUDENTS ENROLLED

Angus, William M., Univ. of Toronto
Anspach, Russell J., Ohio Northern Univ.
Barry, Joseph F., Cornell Univ.
Bates, John A., Jr., Cornell Univ.
Blore, Stephen W., Univ. of Idaho
Brolin, Walter B., Northeastern Univ.
Burgan, Kenneth E., Municipal Univ. of Akron
Burnham, Robert F., Univ. of New Hampshire
Byerlay, Henry L., Detroit Inst. of Tech.
Caveny, Charles C., Univ. of Pittsburgh
Churchill, Paul K., Univ. of Southern California
Clark, James V., Denison Univ.
Conard, William, N. Y. Univ.
Cook, Harry W., State Univ. of Iowa
Copeland, Luther W., Georgia School of Technology
Crocker, George E., Calif. Inst. of Tech.
Cross, Rosamond D., Georgia Tech.
Doyal, George M., Georgia Tech.
Dunnigan, Francis A., Washington State College
Eaton, John R., Case School of Appl. Science
Edwards, Wilbur C., Georgia Tech.
Engel, George C., Stevens Inst. of Tech.
Faber, Benjamin W., Washington State College
Figg, Basil D., Michigan State College
Fixman, Isadore, Rensselaer Poly. Inst.
Gallaher, Burton M., Univ. of Tennessee
Garoutte, Charles D., Univ. of Colorado
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Yale University, New Haven, Conn	S. A. Tucker	G. C. Bailey	Charles F. Scott

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Watthour Meters.—Bulletin 71, 100 pp., entitled "Instructions for Sangamo D-5 Watthour Meters." Sangamo Electric Company, Springfield, Ill.

Tachometers.—Catalog 1700, 24 pp. Describes tachometers for recording and indicating purposes, applicable on all revolving machinery. The Bristol Company, Waterbury, Conn.

Motors.—Bulletin 323. Describes "Master" motors, consisting of a complete line of small motors to fit practically any current specifications. The Master Electric Company, Linden & Master Avenues, Dayton, Ohio.

Bus Connectors.—Catalog 26, 48 pp. Describes a unique line of high tension bus connectors. These devices are for connecting copper tubing and cable in all combinations. Many novel designs are included. Burndy Engineering Company, Inc., 10 East 43rd Street, New York.

Pyrometers.—Catalog 15, 80 pp. In addition to a comprehensive outline of the development of pyrometry, a chapter is devoted to the advantages of pyrometers for various industries and the economies effected. The Brown Instrument Company, Wayne & Windrim Streets, Philadelphia, Pa.

Welding Rods.—Bulletin, 24 pp., "Effect of Surface Materials on Steel Welding Rods." Includes a new arrangement of data on gas and electric filler rod, which shows by means of tables and specifications, uses and the comparative properties of the various types. Chicago Steel & Wire Company, 103rd Street & Torrence Ave., Chicago, Ill.

Oil Engines.—Catalog, 33 pp. Describes direct-injection oil engines for all purposes. The text matter, which consists of technical data and details of the "PO" oil engines of 55, 110 and 150 B. H. P. sizes, is profusely illustrated by forty-two illustrations of plant layouts, installation views, diagrams and engine details. Ingersoll-Rand Company, 11 Broadway, New York.

NOTES OF THE INDUSTRY

Ohio Brass Company Moves Chicago Office.—Announcement is made of the removal of the Chicago office of the Ohio Brass Company from 1217 to 1714 Fisher Building.

W. H. Perkins, who formerly represented the Trumbull Steel Company in the New England territory, is back again after a year's absence and in charge of their Boston Office at 141 Milk Street.

Packard Electric Company, Warren, O., announces the appointment of Harris & Butler, Real Estate Building, Philadelphia, as district managers for Packard transformers in the Philadelphia territory.

H. G. Pierce was made manager of the Berlin office of the International General Electric Company, succeeding L. A. Trone. Mr. Pierce has been with the International Company since 1917, when he had charge of sales in China.

Railway & Industrial Engineering Company, Greensburg, Pa., has purchased the property and building of the Penn Aluminum Company, adjoining their present plant. The building will be enlarged for additional storage space.

New Office for Delta-Star.—H. W. Young, president of the Delta-Star Electric Company, announces the opening of a new and larger office at 140 Cedar Street, New York, in charge of W. S. Nichols, assisted by P. H. Butler and A. R. Beger.

Personnel Changes in Timken Company.—T. F. Rose, formerly assistant manager of the Chicago branch of the Timken Roller Bearing Service & Sales Company, has been appointed branch manager of the Cincinnati office. H. C. Sauer has been appointed manager of the Detroit branch. Mr. Sauer was formerly assistant manager of the Cleveland branch. Fred G. Rumball, formerly branch manager of the Kansas City branch, has been promoted to the position of sales engineer, automotive division, of the Timken Roller Bearing Company. Mr. Rumball will have his headquarters at Cleveland with Edgeley W. Austin, assistant manager of sales. The position of branch manager at Kansas City will be filled by J. M. Carey, who has been promoted from the position of salesman under Mr. Rumball.

New A-C Starter.—A new starter is announced by the General Electric Company, Schenectady, N. Y., bearing the type designation CR-7055-A-1. It is a reversing primary resistor for squirrel cage induction motors. Two three-pole line contactors are provided with this starter. These contactors are electrically and mechanically interlocked and are mounted back-to-back on the panel. A magnetic time interlock provides a predetermined definite time of from one to three seconds between the closing of the line contactor and of the accelerating contactor. Two-point starting is provided by a resistor designed to conform to Electric Power Club classification No. 16. A temperature overload relay with an external resetting mechanism furnishes overload protection. The enclosing case is of sheet metal, semi-ventilated, and is provided with feet for wall mounting.

Synchronous Motor Control.—A complete self-contained oil-immersed automatic starter for 2300 volt synchronous motors has been developed by the Electric Controller & Manufacturing Company, Cleveland, O. This is built for across-the-line starting of slow speed motors and for reduced voltage starting of the higher speed motors. To start, a button is pushed, and as the motor approaches synchronous speed the field excitation is automatically applied. The reduced voltage starter consists of a welded boiler plate tank which contains an automatic double-throw switching mechanism, a power transformer for providing starting voltage, potential transformers for providing 220 volts for the master switch operating current and the current limit transition relay, which connects the motor to full voltage when it has been accelerated to approximately 85 per cent of synchronous speed. The equipment is complete in a single unit, which makes possible floor mounting of all the apparatus necessary for starting synchronous motors.

Building Program of $5,000,000 For Westinghouse.—The present building program for the expansion of facilities at various plants and offices of the Westinghouse Electric & Manufacturing Company will involve an expenditure of $5,525,000, according to T. P. Gaylord, acting vice-president of the company. The cost of the general office building now nearing completion at the Pittsburgh Works is $1,500,000. Additional construction is under way or will begin soon on the company's plants at Mansfield, Detroit, St. Louis, Springfield, Sharon and Derry.

Pyrex for High-Voltage Insulators.—The Corning Glass Works, Corning, N. Y., announces its entrance into the electrical transmission field with high-tension Pyrex insulators. The company states that many years of intensive research has proven that Pyrex insulators have the required qualities necessary for a perfect insulator. These qualities are said to be low temperature rise with uniform temperature throughout, transparency permitting ease of inspection, non-hygroscopic, permanent and uniform dielectric strength, quick drying surface, and the ability to withstand concentrated power arcs. Several thousands of these insulators are said to have been in service on the Montana Power system for about two years. At the present time the company is offering pin-type insulators of a one-piece design for operating voltages from 6,600 to 50,000. Development work is proceeding on suspension and flange or stack-type units and further announcements regarding these will be made later. Raymond W. Lillie is Manager of Power Line Insulator Sales, located at Corning Glass Works, 501 Fifth Ave., New York City. The main factory and offices are located at Corning, N. Y.

JOURNAL OF THE A·I·E·E·

JULY 1926

A E E I

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Salt Lake City, Utah, Sept. 7-10

MEETINGS OF OTHER SOCIETIES

National Electric Light Association

East Central Division, Cedar Point, Ohio, July 13-17
Rocky Mountain Division, Glenwood Springs, Col., September 13-16
New England Division, Poland, Maine, September 21-23

Illuminating Engineering Society, Spring Lake, N. J., September 7-10

Wisconsin Utilities Association, (Electrotechnical,) Eau Claire, Wis., September 3-4

Association of Edison Illuminating Cos., Quebec, September 27-October 1.

JOURNAL

OF THE

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Current Electrical Articles Published by Other Societies

Journal, Franklin Institute, April 1926
Latest and Future Development in Power Generation, by L. C. Loewenstein

Illinois Engineer, May 1926
Telephone Communication Over High-Voltage Power Lines, by C. A. Boddie
Use of Electricity in Agriculture, by E. W. Lehmann

Transactions, Illuminating Engineering Society, April 1926
Demonstration Method of Teaching Good Lighting Practise, by G. S. Merrill
Lighting Scheme for the Philadelphia Municipal Stadium, by G. B. Regar
Practical Illuminating Engineering, by A. L. Powell

Iron & Steel Engineer
March 1926—Requirements for Lightning Arresters and Factors Affecting Their Performance, by E. D. Tanzer,
Natural Electricity and Lightning Protection, by J. Slepian
Lightning Arrester Protection on 13,200-Volt and 2400-Volt Distribution Lines, by A. R. Wood
June 1926 — Economies of Steel Plant Railroad Electrification, by O. Needham and D. C. Hershberger
How Electric Industrial Truck and Tractor Equipment is Effecting Savings in the Iron and Steel Industry, by H. J. Payne
Rules for the Safe Operation of Electric Overhead Traveling Cranes
Report of Electric Heat Committee for 1926

Rochester Engineer, June 1926
Control Units, by G. R. Fessenden

South & Southwest Ry. Club, March 1926
Application and Maintenance of Motors and Control in Railroad Shops, by C. F. King, Jr.

# Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV July, 1926 Number 7

The Investigation of Engineering Education

On June 10, Dr. Jewett, National Secretary Hutchinson and the undersigned met in conference with Messrs. Wickenden and Hammond, representatives of the Society for the Promotion of Engineering Education, for the purpose of discussing the following findings and recommendations of the Board of Investigation and Coordination regarding Engineering Education:

"1. There is no present need for the further multiplication of degree-granting colleges of engineering. The moral influence of the colleges and of the national engineering societies should be used to discourage the multiplication of weak professional schools and to encourage the growth of schools devoted to vocational training for junior and intermediate forms of technical work.

"2. On the initiative of the S. P. E. E. the national engineering societies might properly cooperate with the colleges in defining an acceptable or recognized engineering college for the support of satisfactory educational standards among the colleges and for the guidance of the societies in applying the provisions of their constitutions and by-laws which relate to conditions of admission to membership and the recognition of student chapters and branches.

"3. Engineering colleges should be encouraged to give up the practise of awarding such professional degrees as "Civil Engineer," "Mechanical Engineer," and the like, for programs of academic work. On the initiative of the S. P. E. E. the national engineering societies might properly cooperate in recommending a basis for the awarding of professional degrees which would have the approval of the several professional societies and would be consistent with the requirements for entrance to a professional grade of membership.

"4. There is a strong sentiment in the professional societies in favor of engineering curricula which are only slightly or moderately differentiated from each other. The program of undergraduate work in the colleges should emphasize largely the broad foundations of engineering and should assume that much of the special training needed for particular types of engineering work should be obtained either by graduate study or in connection with active experience.

"5. It is desirable that there should be a standing council on engineering education; that the initiative toward this end should originate in the S. P. E. E., as representing the colleges; and that the national engineering societies should accept the invitation, if given, to appoint representatives in such a council."

The several conferees expressed themselves as being in sympathy with the above propositions. It was recognized, however, that this attitude would not commit either organization in an official way. The propriety of having national organizations of the engineering industries represented in the joint advisory council on engineering education was discussed, it being the sentiment that such representation would not be desirable at the outset because of the greater mutuality of interest existing between the professional societies and the engineering schools.

This conference was in response to a letter addressed by our Past President, Dr. Charles F. Scott, to Mr. Calvin W. Rice, Secretary of the Joint Conference Committee of the Founder Societies. I quote several passages from this letter:

"During the past two and one-half years this Society (S. P. E. E.) has been engaged in a comprehensive study of engineering education. Its broad purposes have been to elevate educational and professional standards and to bring about a closer relationship between the colleges, the engineering societies, and American industry. The Founder Societies have given support and rendered advice to this enterprise through a group of educational councilors. The societies have appropriated funds for conducting special studies of educational matters relating to the several major engineering fields. These studies have paralleled similar studies made by and in the colleges themselves.

"The Carnegie Corporation has financed the enterprise for a period of three years. We now approach the end of that period. Thus far we have secured the active and hearty cooperation of practically all of the engineering colleges and we have made a comprehensive and accurate analysis of the present and past state of engineering education. We have also reached definite conclusions upon which to base recommendations as to the future course of engineering education. It remains to put these recommendations into effect. We believe that the undertaking should continue beyond the stage of fact-gathering and analysis to which it has thus far been largely devoted and that its next stage should be one of effective action. We believe that the national engi-

neering societies should share with the colleges the responsibility for the support and direction of such effort.

"To this end we hope we may obtain from the Founder Societies endorsement of our purpose to continue the enterprise and to bring about constructive action. We therefore suggest that each of the Founder Societies participate in its financial support through a small appropriation. We feel that such support will be of great importance in two ways: first, in giving the societies a share in the direction of the enterprise, and second, in assisting us to obtain additional support from other sources. Since our undertaking has been essentially of the nature of engineering research it would seem appropriate for Engineering Foundation to aid in financing it by appropriation and assistance in obtaining contributions."

Dr. Jewett, Secretary Hutchinson, and the undersigned approved in principle Mr. Wickenden's findings and agreed to recommend them to Board of Directors of A. I. E. E.

The President of A. I. E. E. and its National Secretary attended a meeting of the Joint Conference Committee called by Secretary Rice for June 15, 1926. At this conference the following resolution was adopted:

VOTED: to approve the continuance of the research in the field of engineering education now being conducted by the Society for the Promotion of Engineering Education, which research would otherwise be terminated December 31, 1926, and each President in turn is to recommend to his Board a small appropriation, say approximately ten cents per student in the respective branch of engineering corresponding to the field of endeavor of each of the four Societies. This would approximate annual appropriations as follows:

American Institute of Electrical Engineers	$1,800.
American Society of Civil Engineers	1,600.
American Society of Mechanical Engineers	1,200.
American Institute Mining & Metallurgical Engineers	250.

It is further understood that this approval is limited to a program which it is expected would be concluded within two years.

This whole subject was laid before the Board of Directors of A. I. E. E. at its meeting at White Sulphur Springs on June 23. At this meeting, the following telegram was received and read:

Society Promotion Engineering Education rejoices in splendid cooperation already accorded and the support now proposed by engineering societies and Engineering Foundation in movement to broaden develop and enrich engineering education. Convention at University of Iowa earnestly hopes governing bodies of societies will approve recommendations of their Presidents.

(Signed) Charles F. Scott.

The Board of Directors recommended to the Finance Committee of A. I. E. E. to provide in its budget for the years 1927 and 1928 appropriations of approximately $2000 for the support of the splendid enterprise in which the membership of A. I. E. E. is deeply interested.

I do not hesitate to endorse every sentiment in this matter expressed by our Past President, Charles F. Scott.

M. I. PUPIN.

Some Leaders of the A. I. E. E.

H. B. Buck, twenty-ninth president of the A. I. E. E., 1916-1917, was born in New York City, May 7th, 1873. He graduated from Yale University in 1894 with the degree of Ph. B. and received his degree of E. E. from Columbia School of Mines in 1895. The year 1895-1896 was spent as a student in the shops of the General Electric Company at Schenectady, and during this period, Mr. Buck did much experimental work on a-c. apparatus for the great scientist, Doctor Steinmetz.

From 1896 to 1900, Mr. Buck was assistant to the chief engineer of the Lighting Department of the General Electric Company, Schenectady, in which capacity he had much to do with the introduction of high-tension, a-c. distribution in many of the large central stations of this country, he traveling extensively throughout the United States to accomplish this work. During that same period, he also had charge of the experimental work which led to the development of the oil switch and other high-tension devices which furthered power operation by alternating current.

In 1900 he was chosen chief electrical engineer of the Niagara Falls Power Company and allied interests at Niagara, having entire charge of electrical engineering in the design and construction of powerhouse No. 2, on the American side of the Falls and the Canadian Niagara Power Company's plant on the Canadian side; also the terminal stations at Buffalo, and engineering in connection with the distribution of Niagara power in Niagara, Tonawanda and Buffalo. In 1906, in cooperation with Mr. E. M. Hewlett, at Niagara Falls, Mr. Buck carried on experimental work on high-tension insulators which resulted in the development and introduction of the suspension insulators now in universal use.

Since 1908 Mr. Buck has been vice-president of Viele, Blackwell and Buck, New York City, engaged in the design and construction of hydroelectric and steam power plants and large transmission systems both in the United States and Canada. Among these might be mentioned work for the Great Western Power Company of California, the Appalachian Power Company, the Northern Ontario Light & Power Company, the Great Northern Power Company and many others.

In 1925 the International Commission made him consulting engineer on the investigation of the development of some 4,000,000 h. p. at various sites on the St. Lawrence River between Ogdensburg and Montreal.

Regenerative Braking for Direct-Current Locomotives

BY A. BREDENBERG, JR.

Non-member, A. I. E. E.

Synopsis—*This paper gives a comparative study of several d-c., regenerative braking systems now in successful operation. The general characteristics of regenerative braking, including advantages, limitations and functions are briefly discussed. The principal points covered in the descriptions of the various systems are: method of field excitation during regeneration, compensation for sudden changes in line voltage or grade, method of control, operating characteristics and relative complication of equipment.*

Several systems are described in which the regenerating motor fields are excited by a separate generator provided for that purpose, and then other systems are described in which the fields are excited by one or more of the traction motors. Under the former heading are included C. M. & St. P. freight locomotive with a line driven motor-generator set for excitation, the Mexican locomotive with a dynamotor-driven, motor-generator set for excitation and the axle generator system. The applications described under the latter heading are the C. M. & St. P. gearless passenger, the Paulista and the Spanish Northern locomotives.

A comparison is made of these two methods of field excitation, based on a six-motor, two-speed, 3000-volt locomotive. Curves are included illustrating the speed-braking characteristics and also the motoring characteristics. The conclusions drawn from this comparison are that, in general, the separate excitation system is to be preferred on account of the greater braking effort and greater speed range provided. Since the motor excitation system can be provided with less additional expense, it is desirable to consider this method when the expense of the separate excitation system does not seem justifiable.

It is not the purpose of this paper to give an exhaustive discussion of the question of regenerative braking, but to make a comparative study of some of the systems now in successful operation on direct-current locomotives.

General Characteristics

Whenever it is proposed to electrify a railroad, where grades exceeding 0.6 per cent form an appreciable part of the line, usually the possibility of applying regenerative braking is considered on account of its marked advantages. These are, briefly, as follows: (a) Reduced wheel- and brake-shoe wear; (b) increased safety due to reduced tire heating and brake-shoe wear and to the fact that duplicate braking systems are provided; (c) higher average speed descending grades, since a very uniform speed can be maintained; (d) elimination of delays due to inspections, worn out brake shoes, etc.; (e) saving of power returned to the line, and (f) increased comfort to passengers as a result of the uniform speed and elimination of noises and shocks caused by the air-brake system. Against these advantages must be balanced the increased weight, cost, and maintenance of the equipment.

Although regenerative braking may be used to reduce train speeds to a certain extent, and systems have been designed to slow down a train or car to very low speeds, yet the primary purpose of this method of braking as applied to heavy traction service is to hold the train at a uniform speed on a given down grade. Regenerative braking should not be overemphasized as an emergency braking system. This method of braking can only be applied to the locomotive, whereas, in the air-brake system, the brakes may be applied to every car in the train. Therefore, regeneration does not replace the air-brakes or lessen their required reliability but it should be considered as a means of braking, supplementing the air-brakes with some very decided advantages as outlined.

Of course, regenerative braking is particularly applicable to long heavy mountain grades and is generally used in such service because of its obvious advantages. It is applicable to comparatively light or short grades provided the results obtained are commensurate with the extra cost incurred.

In order to raise the voltage of a d-c. series motor to make it return power to the line, it is necessary to excite separately the series field and to control this excitation so that smooth operation is obtained regardless of changes in line voltage or grade.

Methods of Field Excitation

There are two general methods of exciting the motor fields and both of these have been successfully applied. One method is by the use of a generator which may be driven by a motor operating from line voltage or from a dynamotor. Also, it might be mechanically driven from an idle axle of the locomotive.

The other method is to use one or more of the traction motors to excite the fields of the remaining motors. This method may be sub-divided further according to the method of controlling the exciter field. Thus, in one case, the exciter field is controlled by contactors, resistors, etc., especially provided for that purpose, while in the other case, control of the exciter field is obtained by means of the same contactors and resistors that are used in accelerating the locomotive.

C. M. & St. P. Freight Locomotives

The method of exciting the regenerating motor fields by means of a motor-generator set operated from the line voltage was first put into commercial use on the

1. Railway Equipment Engineering Dept., General Electric Co., Schenectady, N. Y.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

Chicago, Milwaukee and St. Paul 3000-volt freight locomotives. By reference to Fig. 1, which shows the regenerative connections of one-half of one of these locomotives, it may be seen that the exciter is so connected that the exciter armature current is the sum of the motor field current and the regenerated current. Control of the exciter field is obtained by means of a motor-operated rheostat, automatically controlled by a current-limit relay which is connected in the exciter armature circuit. The current-limit relay thus is responsive to the sum of the motor armature and field currents. Control of the braking speeds is obtained by changing the setting of the current-limit relay by means of the braking handle on the master controller.

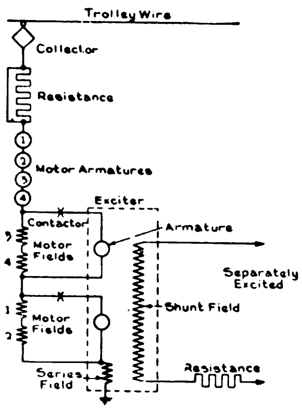

FIG. 1—DIAGRAM OF C. M. & ST. P. FREIGHT LOCOMOTIVE

Compensation for sudden surges in current, due to changes in line voltage or grade, is obtained by a combination of several factors, viz., the differential series field of the exciter, the exciter armature reaction, and the resistance drop in the exciter armature circuit. For example, assume a sudden decrease in line voltage. This will tend to rapidly increase the regenerated current and consequently the current through the exciter armature. The compensating factors will then operate as follows: The differential series field and the exciter armature reaction will tend to weaken the exciter field and reduce the exciter voltage, thus reducing the motor field current, while the increased resistance drop will cause the exciter armature circuit to absorb more of the exciter voltage and thus further reduce the field current and generated voltage of the traction motors. Likewise, a sudden decrease in regenerated current will be compensated for in just the opposite manner. Thus, the inherent characteristics of the exciter circuits prevent excessive surges of current and torque and allow time for the circuits to readjust themselves to the changed operating conditions.

MEXICAN LOCOMOTIVES

Another application of the method of exciting the motor fields by means of a separate motor-generator set is that of the Mexican Railway, 3000-volt locomotives. In this case, the regenerative exciter is driven by a 1500-volt motor, which is connected to the mid-point of a 3000/1500-volt dynamotor. Connections for this locomotive are shown in Fig. 2. Here the exciter carries the motor field current only. Control of locomotive speeds is obtained by adjusting the exciter voltage by means of a variable resistance in the exciter field circuit. This adjustment is obtained directly by means of the braking handle of the master controller.

Compensation against sudden surges in line current is provided for by balancing resistances which carry the sum of the field and armature currents. Thus, if the line voltage drops suddenly, it will tend to produce a rapid increase in regenerated current. The increase in current causes an increased voltage drop across the balancing resistance which causes a decreased voltage and current in the motor field circuit. This reduces the regenerated voltage of the motors, thus preventing an excessive change in regenerated current. Similarly, when passing from one control step to another, the balancing resistance aids in producing smooth operation by reducing current and torque increments between steps.

COMPARISON OF C. M. & ST. P. AND MEXICAN LOCOMOTIVES

By comparing these applications, it will be seen that in one case the exciter carries the sum of the motor armature and field currents while in the other case the exciter carries the field current only. This means that, in the latter case, the exciter armature current will be halved. At the same time, the exciter voltage will be increased as the exciter must overcome the voltage drop in the motor fields and also in the balancing resistance. Experience has demonstrated the fact, however, that the drop through the balancing resistance can be held to such a value that the net result is a reduction in kilowatt capacity required of the exciter.

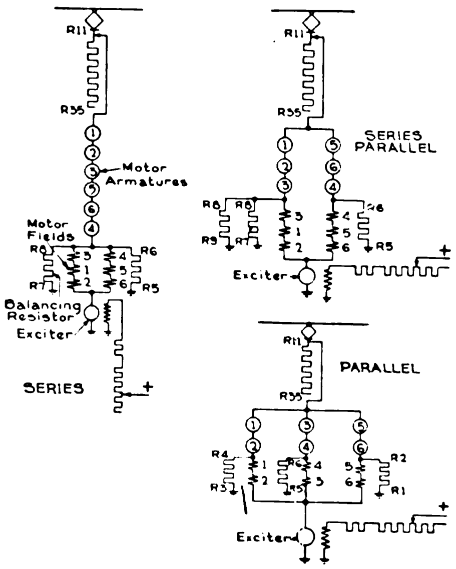

FIG. 2—DIAGRAM OF MEXICAN LOCOMOTIVE

In the first system described compensation is ob-

tained by means of exciter differential field, armature reaction and resistance drop. In the second system, a resistance alone is used since tests and operating data have demonstrated that a very effective compensation can thus be provided. The second system will tend to be less efficient on account of the losses in the balancing resistances. A much simpler control is thus provided, however, and furthermore it is very easy to make adjustments by providing taps in the balancing resistances.

Compared with the other type, the system used on the Mexican locomotives has the characteristic of relatively small changes in speed with regard to changes in the braking effort required. The result is that changes in grade or curvature will cause smaller speed changes in this case than in the C. M. & St. P. System. In brief, the Mexican system tends toward a constant speed characteristic while the C. M. & St. P. System tends toward a constant torque characteristic.

The ideal characteristic for regenerating motors would be a characteristic similar to that obtained in motoring operation with a series motor where the armature and field currents are equal throughout the operating range. This would give a very stable electrical characteristic but an extremely unstable speed characteristic, as the braking effort would decrease very rapidly with increases in speed.

The ideal characteristic from a mechanical standpoint would be one in which the speed on any controller notch is held constant regardless of changes in braking effort required. Such a characteristic would be approximated with constant field excitation. Such a system would be very unstable electrically, however, as very large changes in armature current would occur with small changes in speed. This would be particularly undesirable at high speeds on account of the relatively weak fields required.

In practise, a compromise must be made between these two extremes. From the standpoint of train operation, it is very desirable to obtain a uniform speed for any given controller notch. Some speed variation must be allowed, however, in order to obtain the desired stability of the motors. Such is the case with the two systems described above. In each case, for any given controller notch within the regenerating range of the motors with increases in speed a sufficient increase in braking effort is obtained to give mechanical stability, but, at the same time, the speed regulation is not made so close as to sacrifice the desired electrical characteristics.

With the more constant speed characteristic of the system used on the Mexican locomotives, very little manipulation of the master controller is required to hold the train at a practically constant speed. This has been demonstrated in actual operation on the Mexican Railway. The electrified section of this railway is 45 kilometers long and regeneration is obtained for about two-thirds of this distance, the grade being about 4.7 per cent the greater part of the way.

The principal advantage of the Mexican system is its simplicity. Compensation for line-voltage changes is obtained by means of a simple resistance, and control of the regenerating speeds is obtained by hand control of a resistance in series with the exciter field. No relay or motor-driven rheostat is used. This will reduce the first cost of the system and keep the maintenance required down to a minimum.

Development of Method of Control of Exciter Field

The steps in the development of the method of controlling the exciting generator field included experiments with the sensitive type of regulator used with stationary units. Later, the motor-operated field rheostat was used and finally direct hand control of the field was adopted, compensation against voltage and speed fluctuations being obtained by the inherent characteristics of the motor field circuits without the addition of any regulator or moving parts.

Axle Generator System

The axle generator system may be considered as a motor-generator set system in which the motor of the motor-generator set is replaced by the axle driving mechanism. The same method of control may be used in either case.

The principal differences between an axle generator system and the corresponding motor-generator set system are that the axle generator is necessarily a slow-speed machine, it varies in speed with the speed of the locomotive, and the driving torque of the axle generator is available to aid in braking the train.

Assuming that the same connections are used for an axle generator system as are used on the Mexican locomotive (Fig. 2), it may be readily seen that, with an increase in speed due to an increase in the grade, the regenerated voltage and current will tend to increase due to the increase in speed of the motors themselves and also to the increase in speed of the axle generator which thus tends to increase the motor field current. This helps to give a very close speed characteristic for any given excitation of the axle generator field, such being desirable provided the electrical stability of the motors is not lessened.

Regarding the added braking effort of the exciter, this might prove an advantage in freight service where it is often desired to handle a considerably heavier train down grade than could be hauled up the same grade by one locomotive. In this case, however, it will probably be necessary to use the air brakes on the train in conjunction with the regenerative braking so that little would actually be gained from the additional braking effort obtained from the axle generator. Furthermore, there must be an idle axle available to drive the exciting generator. This is usually the case with passenger

locomotives. On freight locomotives, however, there are very often no idle axles, as illustrated by the Mexican and Spanish Northern locomotives and the Paulista freight locomotives, where every axle drives a traction motor.

Another limitation of the axle generator is that, due to its low speed, it must be of relatively large size. In addition, it must deliver practically the same output over a wide range of speeds, which will tend to compromise the design and complicate the control.[7] Furthermore, the axle generator is mounted close to the track and thus is subject to more abuse, dust particles, etc., than a generator mounted in the locomotive cab.

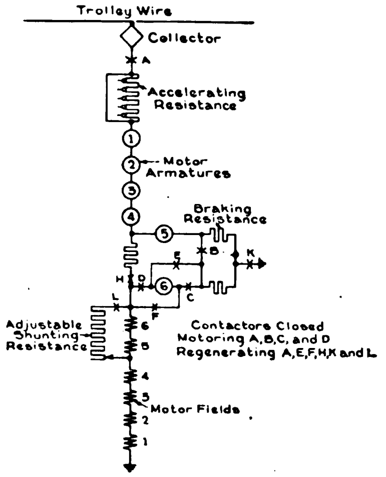

FIG. 3—DIAGRAM REGENERATING CONNECTIONS OF C. M. & ST. P. GEARLESS PASSENGER LOCOMOTIVE

C. M. & ST. P. GEARLESS PASSENGER LOCOMOTIVES

In order to eliminate the use of a separate generator for field excitation, the method of using one or more traction motors as a regenerative exciter was developed. The first application of this system to heavy-traction service was on the C. M. & St. P., 3000-volt, gearless, passenger locomotives. Fig. 3 shows the regenerating connections for one-half of the locomotive. The two halves may be operated in series or in parallel when regenerating so that two combinations of regenerating motors are obtained, one with eight motors in series and the other with two parallel groups, of four motors in series, in each. In each six-motor group, two of the traction motors are used to excite the fields of all six motors. Control of the excitation is obtained by means of a variable resistance, which shunts the fields of the exciting motors. This resistance is adjusted by means of contactors controlled by the braking handle of the master controller.

From the connections, it will be seen that the sum of the field and armature currents of the regenerating motors passes through the two exciter armatures which are connected in multiple and that an external resistance is connected in series with each of the exciter armatures. This system thus provides an inherent regulation against line-current surges which is in effect a combination of the C. M. & St. P. freight and the Mexican systems. That is, the sum of the armature and field currents of the regenerating motors passes through balancing resistances and also through the exciter armatures. An effective means of compensation against surges is thus provided.

A further simplification of the apparatus required for regeneration may be obtained with the traction-motor exciter system by using the same resistances and contactors for controlling the exciter during regeneration that are used during acceleration of the locomotive. This system is now in successful operation on the Paulista locomotives (four-motor, 3000-volt) and on the Spanish Northern locomotives (six-motor, 3000-volt). On the Paulista locomotives, one traction motor is used to excite its own field and the fields of the other three motors which are connected in series to the line. On the Spanish Northern locomotives one traction motor is used to excite its own field and the fields of the other five motors which are connected in series to the line.

PAULISTA LOCOMOTIVES

Fig. 4 shows the schematic connections of the Paulista locomotive both motoring and regenerating. It will be seen that there are two motor combinations motoring, one with all four motors in series with 750 volts applied per motor and the other combination with two groups of two motors in series in each with 1500 volts applied per motor. There is one regenerating combination with

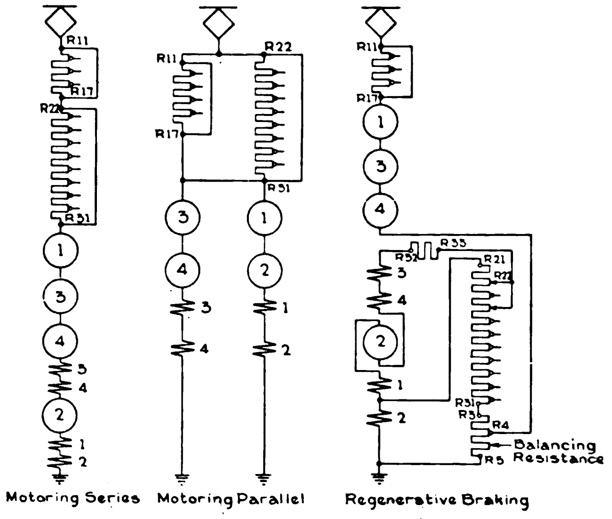

FIG. 4—DIAGRAM OF SCHEMATIC CONNECTIONS OF PAULISTA FREIGHT AND PASSENGER LOCOMOTIVE

the three regenerating motors connected in series with a normal voltage of 1000 volts per motor. By referring to the resistance symbols it will be seen that part of the accelerating resistance is connected in series with the regenerating motors. This resistance is used in connecting the motors to the line when establishing the regenerative connection. It is short-circuited during regeneration. The remainder of the accelerating resistance is connected in the motor field circuit and is

thus used to control the regenerative operation. Some additional resistance and additional contactors are required but it is to be noted that an appreciable saving in equipment is made by using the accelerating resistance and contactors for control of the exciter field.

Practically the same method of compensation for line current surges is used as on the Mexican locomotives. A balancing resistance is connected in the circuit so as to carry the sum of the line current and the exciter field current. This exciter field current is also part of the regenerating motor field current so that the compensation is obtained in two ways; directly by the effect of the balancing resistance on the regenerating motor fields, and indirectly by the effect of the balancing resistance on the exciting motor field.

Spanish Northern Locomotives

On the Spanish Northern locomotives there are two motoring combinations, one with all six motors in series

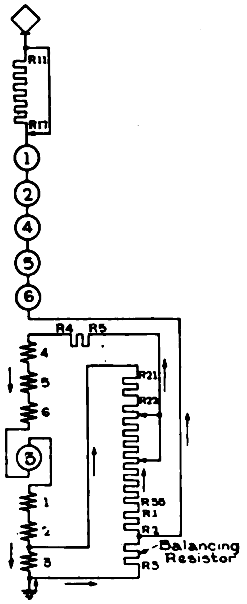

Fig. 5—Diagram of Regenerating Connections of Spanish Northern Locomotive

with 500 volts applied per motor and the second with two parallel groups of three motors in series in each with 1000 volts applied per motor. Fig. 5 shows the regenerating connections of this locomotive. One of the six motors is used to excite its own field and the fields of the other five motors which are connected in series to the line with a normal voltage of 600 volts per motor. The regenerating system is otherwise identical with that of the Paulista locomotives.

Comparison of Methods of Field Excitation

In order to obtain a comparison of the system using a separate generator for field excitation and that using traction motor excitation a study was made of the operating characteristics of a locomotive similar to the Spanish Northern, six-motor, two-speed, 3000-volt locomotive as compared with the same locomotive with a motor-generator set for field excitation. For motor excitation, then, there will be one regenerating combination with one traction motor exciting the other five, all connected in series. For separate excitation there will be two regenerating combinations, one with all six motors in series and the second with two parallel groups of three motors in series in each, these combina-

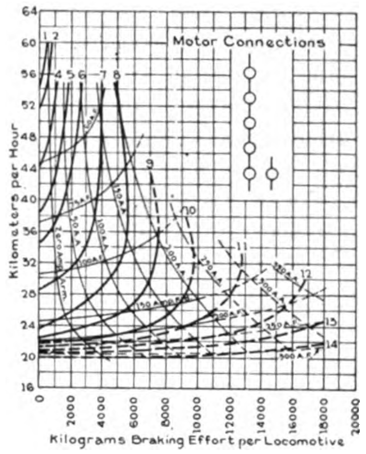

Fig. 6—Speed-Braking Effort Curves for 86-Ton, 6-Motor, 3000-Volt Locomotive with Traction Motor Excitation

tions being the same as those obtained while motoring.

In comparing the operating characteristics of these two systems of regeneration, the main points to be con-

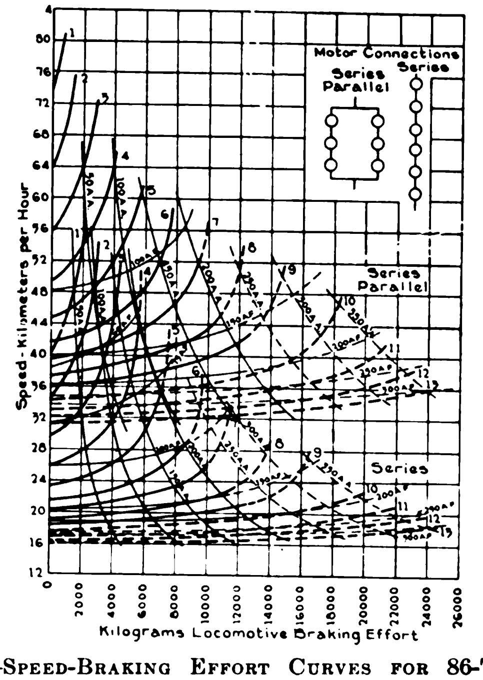

Fig. 7—Speed-Braking Effort Curves for 86-Ton, 6-Motor, 3000-Volt Locomotive with Separate Excitation

sidered are as follows: range of operating speeds, train weights which may be handled, slope of grades, mileage on which regeneration can be used, and reliability.

Figs. 6 to 8 inclusive illustrate the speed-braking effort characteristics obtained with the two systems. Figs. 6 and 7 give the relation between speed and

braking effort for each step of the braking handle on the master controller, and Fig. 8 is a composite diagram which shows the range of speeds and braking efforts which may be obtained in each case. The shaded areas in Fig. 8 give the continuous operating ranges while the unshaded areas give the ranges within which the locomotive may regenerate for short periods. This diagram also shows the speed-traction effort curves for motoring operation in each of the two motoring connections. In each case the full field and two reduced field characteristics are given. The tractive effort and speeds at the continuous current rating are also indicated.

Two regenerating speed ranges are obtained with the separate excitation system whereas one speed range is

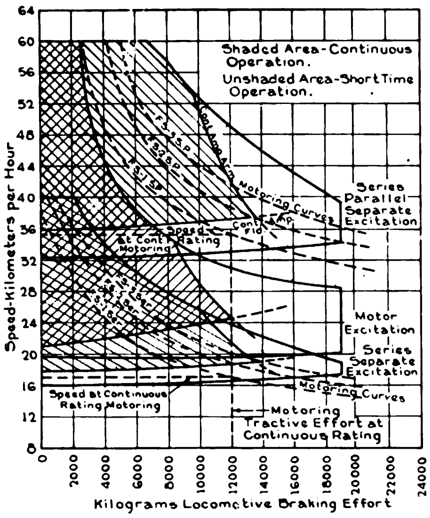

Fig. 8—Comparison between Separate and Traction Motor Excitation for 86-Ton, 6-Motor, 3000-Volt Locomotive

obtained with motor excitation, this latter speed range being intermediate to the two speed ranges with separate excitation.

In analyzing these curves, it is to be noted that with the same line voltage, the same motor combination, and the same armature and field current, a slightly higher speed will be obtained when regenerating than when motoring. The reason for this is the reversal of the effect of resistance drop in the motor circuits. Under the same conditions the braking effort regenerating will be appreciably greater than the corresponding tractive effort motoring on account of the reversal of the effect of the motor losses on the torque at the driving wheels. Furthermore, with a given torque at the driving wheels, it will be possible to handle a considerably heavier train down grade than up grade since the train and curve friction oppose the locomotive ascending the grade while they assist the locomotive when descending.

With the separate excitation system, therefore, the regenerating speeds will be a little higher than the motoring speeds with the same motor combination, voltage, and currents. With motor excitation of fields, in this particular case, the regenerating speed at the continuous-current rating of armatures and fields will be about 70 per cent of the corresponding motoring speed. As a rule, the double-speed range is to be preferred unless it is desired to descend the grade at a lower speed than used in ascending. In the latter case the speed range of the motor excitation system will probably be more suitable.

From an analysis of the curves, it may be seen that for a given armature and field current of the regenerating motors a greater braking effort is obtained with the separate excitation system than with the motor excitation system. The reason for this is that, in the former system, the full braking effort of all six motors is available while in the latter the full braking effort of five motors is available and a fraction of the full braking effort of the exciting motor. The result is that greater train weights can be handled down a given grade with the separate-excitation system than with the motor-excitation system.

The following conclusions in regard to operating characteristics may be stated as a result of the comparison of these two systems:

1. With motor excitation in general, on all grades, the same train can be handled down hill as up hill, but at reduced speeds. This reduction in speed will be comparatively small for light grades but will increase as the grade increases.

2. With separate excitation at continuous current, armatures, and fields, a considerably heavier train may be handled down hill than up hill and at a slightly greater speed. The percentage difference in the size of the train thus handled decreases as the grade increases.

3. With separate excitation, a train may be handled down grade at a considerably higher speed than this train can be hauled up the same grade, assuming that the safe operating speed is not exceeded. The percentage difference in these speeds decreases as the slope of the grade increases.

This study indicates that motor excitation may best be applied to a line with comparatively light grades; *e. g.*, one and one-half per cent and under. It will still be applicable to heavier grades if these grades are short and little time is lost on account of slower speeds, or if the slower speed obtained will not handicap the schedule speed desired.

Regeneration with separate excitation is particularly applicable to heavy grades; *e. g.*, two per cent and over, when the length of these grades is an appreciable part of the total length of the line. It is also preferable to use this system for lighter grades when it is necessary to take advantage of the highest speeds possible down grade.

Concerning reliability of operation, there will be little difference if any, between the two systems, assuming that the same rugged type of equipment is used in each

case and that the same method of compensation is used as has already been described.

It is evident that the additional expense of providing for regeneration is less with motor excitation than with separate excitation since in the former case less additional equipment is required.

It is to be noted that the foregoing comparison covers the specific case of a two-speed, six-motor locomotive. The same general considerations would apply to a similar comparison for any two-speed locomotive. For locomotives with more than two motoring speeds or combinations, there will be cases where motor excitation cannot be so readily applied on account of the limited speed range which can be obtained. This would be the case, for example, with a three-speed locomotive such as the Mexican locomotive. The logical regenerating combination in this case would be that of one motor acting as an exciter for the other five motors in series. The speed range thus obtained would be quite low in comparison with the highest motoring speed which is obtained with three parallel groups of two motors in series in each. Other combinations could be worked out for this type of locomotive, but with a reduction in braking torque which would, of course, be undesirable. To other types, such as the C. M. & St. P. gearless passenger locomotive, motor excitation can be more readily applied. This locomotive has four motoring combinations; viz., with twelve, six, four and three motors in series across the line. Two regenerating combinations are obtained with eight regenerating motors in series and two parallel groups of four motors in series. Thus, a better speed-range regenerating is obtained than with the six-motor, three-speed locomotive cited above.

It is not within the scope of this paper to discuss all possible combinations to which motor excitation may be applied. From the foregoing discussion, however, the conclusion may be drawn that this type of regenerative braking may be readily applied to two-speed locomotives in general and in some cases to locomotives with a greater number of motoring combinations.

In the foregoing discussion, it has been attempted to present the characteristics of certain types of regenerating systems which have been successfully applied to d-c. locomotives. In general, it may be stated that a system with a separate generator for excitation of the motor fields is to be preferred as this gives the same motor combinations regenerating as motoring and furnishes the full torque of each motor for braking the train. Since the motor excitation system can be provided with less additional expense, however, it is desirable to consider this method when the expense of the separate excitation system does not seem justifiable. In any application, before a decision is reached as to the type of braking system to be used, a thorough study should be made of all the contributing factors.

The High-Speed Circuit Breaker in Railway Feeder Networks

BY J. W. McNAIRY[1]

Non-member

Synopsis.—*A method of isolating grounded sections of extensive feeder networks supplying power to railways without disturbing the power supply to other sections has long been desired by railway engineers. This has been successfully accomplished by utilizing the inherent characteristics of the magnetic type of high-speed circuit breakers in the manner described in this article. These characteristics are (a) high-speed operation, (b) discriminating characteristic, (c) reduction in trip point with reduction in line voltage, (d) polarized characteristic.*

A description of an experimental investigation on an equivalent network for a representative section of feeder system, made up by using reactors and resistors, has been given. Complete selective operation, isolating defective feeder without disturbing the power supply to interconnected feeders, was obtained for all locations of the short circuit.

Breakers of the type used successfully on d-c. networks can be applied to a-c. networks and the advantages of high-speed protection realized on this type of system. High-speed operation is very effective in reducing telephone interference during short circuits on the a-c. railway system.

Introduction

The development of the high-speed circuit breaker and its application to the d-c. railway system has contributed greatly toward reduced maintenance and increased reliability of the power supply of this system. The effectiveness of the high-speed operation of this device in reducing the duration of short circuits and limiting the current, thereby eliminating flashovers of commutating apparatus and reducing the damage from arcs at points of fault, has been well recognized for a number of years. The elimination of flashovers and the reduction in the damage to windings of motors and other apparatus, connecting cables and mechanical equipment coming into contact with fallen contact lines or faulty cables, has reduced to a minimum the duration of power interruptions from this source.

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With a few minor exceptions, high-speed circuit breakers applied to d-c. railway networks have been of the magnetic type, one form of which is shown by Fig. 1. This type involves the principle of a contact arm held in the closed position against a strong spring by a holding armature across the poles of an electromagnet. A tripping coil is interposed between the holding coil and the armature and is so connected that current through this coil exerts a m. m. f. to reduce the flux in the retaining armature, at the same time increasing the flux through a suitable magnetic by-pass circuit without an appreciable change in the flux through the

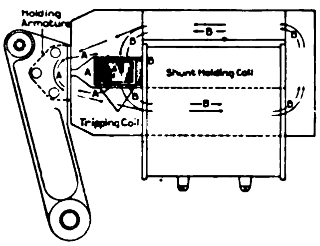

Fig. 1a

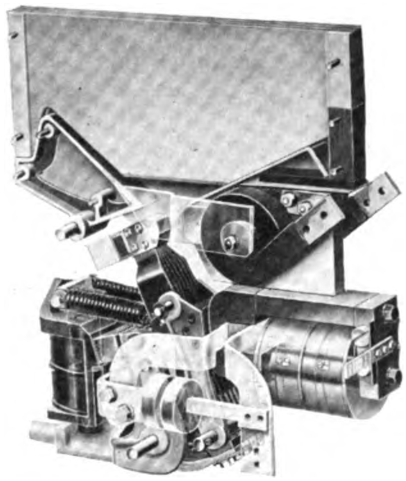

Fig. 1 b

1a—Magnetic Circuit of the Holding and Tripping Coils of the High-Speed Circuit Breaker

1b—Phantom View of a 600-Volt, D-C., High-Speed Circuit Breaker

core of the main holding coil. As the tripping current is increased, the flux is shifted in this manner from the holding armature to the magnetic by-pass circuit without the necessity of changing the flux interlinking the main holding coil. The effectiveness of this arrangement is such that the armature is released practically instantaneously when current in the trip coil reaches a predetermined value, regardless of the rate at which this current is increasing.

There are certain inherent characteristics in this type of circuit breaker which introduce possibilities for selective operation between breakers applied to a d-c. railway network, in case of short circuits, in such a way as to isolate defective feeder sections without the interruption even momentarily, of the power supply, to interconnected sections. The results obtained by proper utilization of these characteristics are comparable to those obtained on the usual a-c. networks by selective relay systems of the various well-known types.

The remainder of this article furnishes a detailed explanation of these characteristics and the methods of utilizing them, together with a description of the results obtained during an experimental investigation on a representative network.

Characteristics of the Magnetic Type High-Speed Circuit Breaker

The following inherent characteristics of the magnetic type of high-speed circuit breaker contribute most to the solution of problems of selective operation on a d-c. railway network:

a. High-speed operation

b. Discriminating characteristic providing a reduction in the trip point during a rapid current rise

c. Reduction in trip point with a reduction in line voltage

d. Polarized characteristics.

I. High-Speed Operation

In order to fully protect commutating apparatus in the d-c. railway substation, machine breakers must operate sufficiently fast to prevent flashover in case of short circuits inside of the station. While short circuits inside of station feeder breakers occur infrequently, without high-speed operation of protecting breakers, the current is relatively great and the resultant damage to substation apparatus is likely to be serious. This consideration automatically precludes the use of relays or any other selective system which delays the operation of such circuit breakers even slightly under short-circuit conditions.

The selective operation of the magnetic type of high-speed breaker is based upon an arrangement whereby the current is limited by the breaker or breakers supplying the faulty feeder directly, before the trip point of similar breakers supplying interconnected feeders, or the machine breakers in the substation is reached. During d-c. transients with an initial current rise of hundreds of thousands of amperes a second, the speed of operation of the breakers feeding such a short circuit must be relatively high. This is essential in order that advantage may be taken of conditions or arrangements whereby the trip current of one breaker is reached in advance of the others. These breakers must operate fast enough to limit the current before the trip point of the remaining breakers is reached. The speed of operation of the magnetic type of high-speed breaker designed to operate sufficiently fast to prevent flashovers of commutating substation apparatus is sufficient for such an application.

II. Discriminating Characteristic

The discriminating characteristic of the magnetic type of high-speed circuit breaker is obtained by connecting

an inductive shunt in multiple with the tripping coil, the total current through the breaker being distributed between these two circuits. The distribution of a slowly rising current between the trip coil and shunt is determined by the resistance, (and of a rapidly rising current by the inductance,) of the two parallel circuits.

The trip point of a circuit breaker so equipped can therefore be made a function of the rate at which the current is increasing.

Calculations of Current Distribution Between Tripping Coil and Its Shunt

Where the constants of the external circuits are

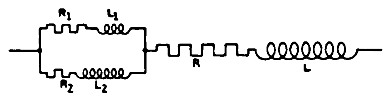

Fig. 2—Graphical Representation of the Resistance and Inductance of the Trip Coil of a High-Speed Circuit Breaker in Parallel with its Shunt and the Combination in Series with a Feeder

known, the current through the trip coil at any instant can be calculated as follows:

Referring to Fig. 2,

L_1 = Inductance of tripping coil
L_2 = Inductance of tripping coil shunt
L = Inductance of the external circuit
R_1 = Resistance of tripping coil
R_2 = Resistance of tripping coil shunt
R = Resistance of external circuit
I_m = Final current external circuit
= E/R where E applied voltage
t = time

$$I_1 R_1 + L_1 \frac{d I_1}{d t} = I_2 R_2 + L_2 \frac{d I_2}{d t} \qquad (1)$$

$$I_2 = I - I_1 \qquad (2)$$

$$\frac{d I_2}{d t} = \frac{d I}{d t} - \frac{d I_1}{d t} \qquad (3)$$

L_1, L_2, R_1 and R_2 are negligibly small in comparison with L and R;

$$\therefore I = I_m \left(1 - e^{-\frac{R}{L} t}\right) \qquad (4)$$

Substituting (4) in (2):

$$I_2 = I_m \left(1 - e^{-\frac{R}{L} t}\right) - I_1 \qquad (5)$$

Also from (4):

$$\frac{d I}{d t} = I_m \frac{R}{L} e^{-\frac{R}{L} t} \qquad (6)$$

Substituting (6) in (3):

$$\frac{d I_2}{d t} = I_m \frac{R}{L} e^{-\frac{R}{L} t} - \frac{d I_1}{d t} \qquad (7)$$

Substituting (5) and (7) in (1):

$$L (L_1 + L_2) \frac{d I_1}{d t} + L (R_1 + R_2) I_1 = I_m (L_2 R - R_2 L) e^{-\frac{R}{L} t} + I_m R_2 L \qquad (8)$$

Solving for I_1:

$$I_1 = \left[\frac{I_m (L_2 R - R_2 L)}{L (R_1 + R_2) - R (L_1 + L_2)} \right] e^{-\frac{R}{L} t} + \frac{I_m R_2}{R_1 + R_2} + c\, e^{-\left(\frac{R_1 + R_2}{L_1 + L_2} t\right)}$$

Substituting the value of c, when at $t = 0$, $I_1 = 0$:

$$I_1 = \left[\frac{I_m (L_2 R - R_2 L)}{L (R_1 + R_2) - R (L_1 + L_2)}\right] \left[e^{-\frac{R}{L} t} - e^{-\frac{R_1 + R_2}{L_1 + L_2} t}\right] + \frac{I_m R_2}{R_1 + R_2} \left[1 - e^{-\frac{R_1 + R_2}{L_1 + L_2} t}\right]$$

The time of maximum I_1 can be found from the relation:

$$\frac{d I_1}{d t} = I_m \left(\frac{R_1 + R_2}{L_1 + L_2}\right) \left(\frac{L_2 R - R_2 L}{L(R_1 + R_2) - R(L_1 + L_2)}\right) e^{-\frac{R_1 + R_2}{L_1 + L_2} t} - I_m \left(\frac{R}{L}\right) \left(\frac{L_2 R - R_2 L}{L (R_1 + R_2) - R (L_1 + L_2)}\right) e^{-\frac{R}{L} t} + \frac{I_m R_2}{L_1 + L_2} e^{-\frac{R_1 + R_2}{L_1 + L_2} t} = 0$$

Or:

$$t = 2.3026 \left(\frac{L (L_1 + L_2)}{R (L_1 + L_2) - L (R_1 + R_2)}\right) \log_{10} \frac{(L_1 + L_2)(L_2 R - R_2 L)}{L (R_1 L_2 - R_2 L_1)}$$

The curves of Fig. 6 were calculated in this manner.

Transient Currents During Short Circuits and Under Normal Loads

The ratio of inductance to resistance of the usual railway circuit fed by a given circuit breaker involving the motors of cars or locomotives under maximum normal load conditions is usually considerably higher than that of the feeder circuit alone when a short circuit occurs at the maximum distance from the circuit breaker. A typical comparison is shown by the curves of Fig. 3. By taking advantage of this difference the magnetic type of high-speed circuit breaker can be equipped with an inductive shunt proportioned to trip the breaker at current values considerably lower than the steady load setting with a short circuit through the maximum length of feeder without danger of too frequent operation by transient currents encountered under normal load conditions.

In addition, the mechanical speed at which the magnetic type of circuit breaker opens after the trip point is reached is affected, to some extent, by the amount the trip coil current is increased in excess of that required for tripping the breaker. The force for accelerating the contact arm of the circuit breaker is the difference between the tension of the main springs and the holding effect of the armature flux. As the current

through the tripping coil is increased, a greater resultant force is available for accelerating the contact arm mechanically. The curve of Fig. 4 shows this relation between the force available for accelerating the contact arm and the current through the trip coil.

The inductive shunt in multiple with the trip coil is, therefore, not only effective in reducing the trip point

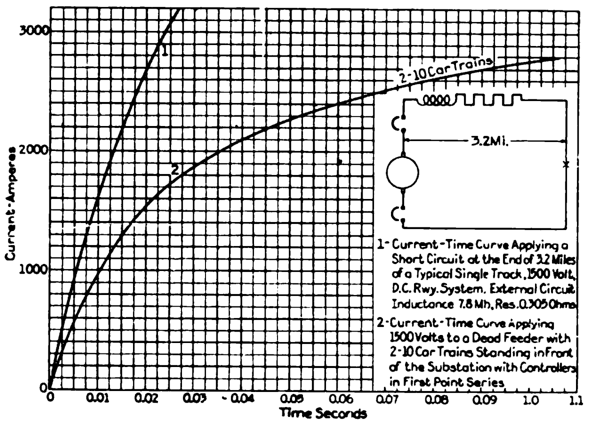

Fig. 3—Curves Showing the Difference in Rate of Current Rise Caused by Applying a Short Circuit at the Distant End of a Feeder and Energizing a Dead Feeder with Load in the Other Substation

of the circuit breaker under short circuit conditions, but is also effective in forcing a greater percentage of the line current through the trip coil after the trip point is reached with a consequent greater mechanical speed of operation of the circuit breaker under conditions where selective operation is desired.

A breaker of this type can be made to operate fast enough, in many instances, to limit the maximum current during a short circuit to a value below the normal overload setting. Such a breaker will "discriminate"

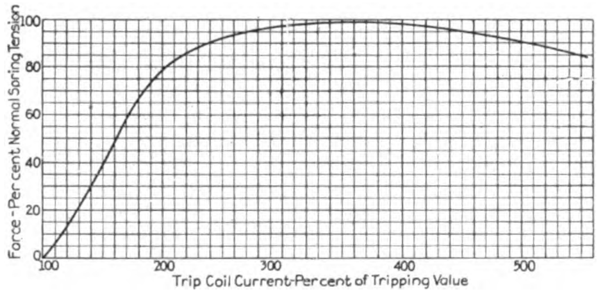

Fig. 4—Resultant Force for Accelerating Contact Arm of the Magnetic Type of High-Speed Circuit Breaker

between normal overloads and short circuits, and this characteristic is frequently referred to as the discriminating characteristic of the circuit breaker. The amount of discrimination is limited only by the transient currents, encountered under normal load conditions.

This discriminating characteristic contributes greatly to the selective operation between breakers, both in substations and in the complete feeder network.

Selective Operation Between Feeder and Machine Breakers

For selective operation in the substation, it is the practise to equip the feeder breakers with inductive shunts which impart a decided discriminating characteristic. The high-speed breakers for machine protection have no discriminating characteristic; that is, their trip point is independent of the rate at which the current is rising. A short circuit on the feeder of a substation so equipped, in most cases, will be cleared by the feeder breaker without tripping the machine breakers and interrupting power to the station bus and other feeders. This statement applies for a majority of short circuits where only one machine is operating in the substation and both machine and feeder breakers carry the same short-circuit current because of the reduction in trip point and faster operation of the feeder breaker.

Where the total machine capacity connected to the station bus is considerably in excess of the capacity of the feeder as is usually the case during important traffic periods of the large systems, short circuits within several hundred feet of the station on the ordinary feeder will open the feeder breakers without operating the machine breakers.

Selective Operation Between Breakers in the External Network

By examining Fig. 5, the function of the discriminating breaker in the external net work may be better understood.

Nos. 1, 2, 7, and 8 are substation feeder breakers and Nos. 3, 4, 5, and 6 are sectionalizing tie breakers.

Assuming a ground occurring at S on feeder B near

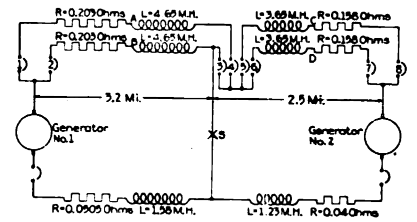

Fig. 5—Equivalent Network for a Typical Double-Track, 1500-Volt, D-C. Railway System, Showing Location of Circuit Breakers

the tie station, the rate of increase of current and the current at any instant through breaker No. 3, due to the short circuit, will be the sum of currents through the three breakers, Nos. 1, 7, and 8. Breaker No. 3 will, therefore, trip at a very much lower value than that required to trip either of the three breakers Nos. 1, 7, or 8, and will operate fast enough to limit the total current to a value considerably below the total required for tripping any of these three breakers feeding the short circuit through the tie station.

The short circuit, under such a condition, will be cleared by breaker No. 3 at the tie station and breaker No. 2 at the substation without interruption of power

to feeders *A*, *C*, or *D*. The discriminating characteristic is effective under these conditions in reducing the trip point and in speeding up the operation of breaker No. 3 so that the short-circuit current is limited to a value considerably below that necessary for tripping the other feeders.

It also reduces the trip point of breaker No. 2 sufficiently to operate it even though the resistance of the feeder limits the current to a value below the steady overload setting.

It can be stated in general that as the number of feeders interconnected through a tie station is increased, the selective operation between the breakers feeding a short circuit directly and the breakers feeding interconnected feeders is more easily obtained. This may be explained as follows: With a certain number of interconnected feeders, when a short circuit occurs on one feeder a certain proportion of the current on this feeder will flow from each other feeder. With a larger number of interconnected feeders the current in this feeder will be larger in proportion to the current in each of the other feeders. Also the current in this feeder will more quickly rise to the tripping point of this feeder's breaker. And this in effect means that the selective action of the system increases when the number of feeders is increased.

III. Reduction in Trip Point with Reduced Line Voltage

The holding coil of the magnetic type of high-speed breaker can be excited from the main feeder circuit when desired. When so connected, the trip point is a function of the line voltage. When breakers having their holding coils so excited are connected in the feeder network at some distance from the substation during a short circuit, the trip point of any breaker will depend on its distance from the fault, the nearest breaker having the lowest trip point. Breakers which are identical in every respect, connected in the same feeder at some distance from each other and subjected to the same short-circuit current, can be operated selectively in this manner in such a way that only the breakers adjacent to the fault open.

Under such conditions when a short circuit occurs at a sufficient distance from the substation to include a sectionalizing breaker, such as on a feeder near the sectionalizing tie station of Fig. 5, the current rise is sufficiently slow to allow time for the desired change in the holding-coil current and results in the operation of the tie breaker before the short-circuit current reaches the trip point of a similar breaker near the station, the holding-coil current of which is not appreciably affected by the short circuit.

The curves of Fig. 6 may be taken as typical and apply to the system shown by Fig. 5 with a short circuit on feeder *A*, with power fed from station No. 1 only, breakers No. 1, 2, 3, and 4 only closed.

The rate at which the holding current is reduced under such conditions is easily controlled by regulating the time constant of the holding-coil circuit, and by choosing the portion of the saturation curve of the holding-coil magnetic circuit over which the breaker operates under normal conditions. The breaker can be designed with a highly saturated holding magnetic circuit, so that the trip point is not greatly affected by voltage reductions occurring in normal service, but will have its trip point lowered very rapidly by voltage reductions in excess of a predetermined maximum.

In general, exciting the holding coils from the line does not place objectionable limitations on the transfer of power through a tie station. Referring again to Fig. 5, this point may be illustrated by the following limiting cases:

(1) With a tie station at the extreme end of a double-

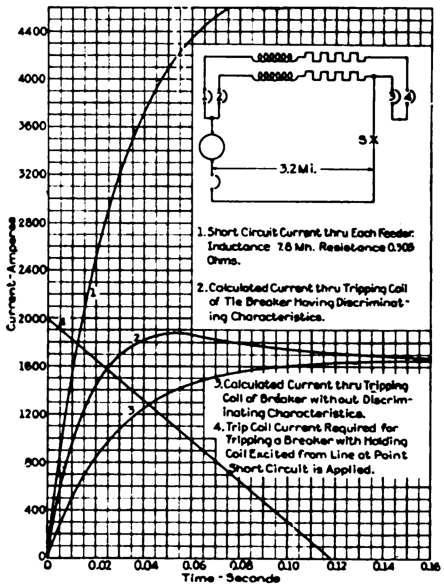

Fig. 6—Current-Time Curves Applying a Short Circuit Opposite a Sectionalizing Tie-Station 3.2 Mi. from Substation on a Double-Track System with Stub-End Feed. Breakers No. 2 and No. 3 Tripped

track system, stub-end feed, the tie breakers will carry only one-half the load under the worst conditions when the load is all on one feeder.

(2) On a large system with many feeders interconnected through a tie station, an excessive load on any one feeder will not greatly reduce the voltage at this point because of the large number of feeders in multiple.

(3) Where heavy loads occur on all feeders near a tie station simultaneously—a condition which results in the greatest voltage reduction—the exchange in current through the tie breakers will be small and the reduction in trip point will not be objectionable. The effects of reduction of voltage at the tie station under normal conditions on the trip points of breakers the holding coils of which are excited from the line is therefore of no great importance for the usual applications.

Protection of Extremely Long Feeders

In addition to the selective possibilities of such an arrangement when applied to large network, reduction in trip point with reduction in line voltage is useful for applications involving unusually long feeders where short circuits at the extreme distance from the station may result in a current rise and a final current no greater or even less than that encountered under normal load conditions. If such a feeder is sectionalized at some distance from the station by a high-speed breaker with holding coil excited from the line, the trip point will be lowered sufficiently to operate on short circuits at the extreme end of the line, thereby preventing annealing of feeder copper or other damage which might otherwise occur if the short circuit is allowed to persist.

IV. Polarized Characteristics

The direction of current required for tripping the magnetic type of breaker is fixed by the polarity of its holding coil.

Referring again to Fig. 5, all of the holding coils of the sectionalizing tie breakers 3, 4, 5, and 6 are excited from the station bus. The polarity of these breakers is fixed so that they trip on current flow from the tie bus to the feeder only. A short circuit occurring in the vicinity of the sectionalizing tie station, such as at *S*, reduces the trip point of all breakers located at this point. The direction of the short-circuit current is correct to trip No. 3 breaker, but assists in holding in breakers 4, 5, and 6. The short circuit under such conditions will, therefore, be cleared by breaker No. 3 without having interrupted the tie between feeders *A*, *C*, and *D*. The polarized characteristic is, therefore, of great assistance in preventing the operation of the breakers feeding power to the tie bus.

Tests on Equivalent Network

A series of tests was made on the equivalent network of Fig. 5 to demonstrate the selective possibilities of the magnetic type of high speed circuit breaker on a representative system.

For approximately uniform spacing between substations and sectionalizing tie stations, selective operation is more easily obtained on networks of the general form of Fig. 5 as the number of tracks and feeders increase. The transient current through that section of the individual feeders between the substation and the fault is not greatly affected by the number of parallel feeders, and the performance of station feeder breakers clearing short circuits on the feeder to which they are connected is therefore not affected. At the sectionalizing tie station the ratio of current rise in the breaker feeding the short circuit direct to the current rise in the several feeders feeding the short through the tie station is increased as the number of feeders is increased, this greater difference resulting in more positive selective operation.

The section of double-track system, the equivalent circuit for which is shown on Fig. 5, was, therefore, taken as representative of the more difficult type of system for selective operation and was used for the experimental investigation.

Equivalent circuits were set up for each feeder using cast-iron resistors and air-core inductance coils.

While both mutual and self-inductance of the parallel copper conductors comprising each feeder of network are easily calculated, calculations of inductance of the rails of the track return are difficult because of skin effect and variations in magnetic permeability.

The values on which the calculations for the equivalent network were based were taken from the data obtained during a series of short circuit tests on an actual system involving a rate of increase of current of the same order of magnitude as that of the equivalent system. The method consisted in calculating the inductance of the copper conductors of the feeder on which the tests were made and determining the inductance of conductors which at the rail locations gave a total inductance equal to that shown by initial current rise.

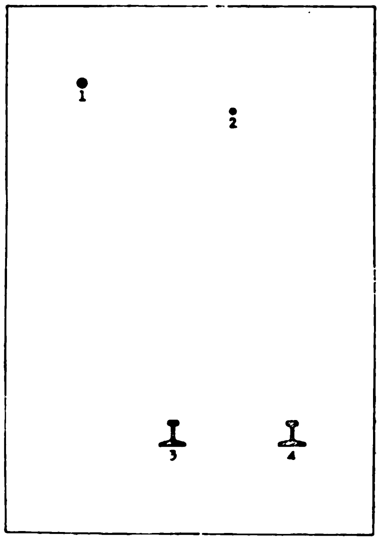

Fig. 7—Cross Section of a Feeder, Trolley Wire and Rails Identified for Calculating the Rate of Current Rise

Air-core inductance coils were necessarily used to represent the total inductance of the positive and negative sections of the feeders.

The self-inductance of these coils was adjusted to give a counter e. m. f. of inductance on the initial current rise equivalent to the total calculated induced voltage of the complete feeder with the same current rise. This voltage is generated both by the self-inductance of the conductors and by the mutual inductance from the other conductors.

The rate at which the current increases in each conductor was determined by solving the following simultaneous equations.

Referring to Fig. 7, in which the conductors are given

numbers that are used as subscripts in the following equations, let E = voltage, L = self inductance indefinite radius, M = mutual inductance:

$$L_1 \frac{dI_1}{dt} \pm M_{1-2} \frac{dI_2}{dt} \pm M_{1-3} \frac{dI_3}{dt} \pm M_{1-4} \frac{dI_4}{dt}$$

$$= L_2 \frac{dI_2}{dt} \pm M_{2-1} \frac{dI}{dt} \pm M_{2-3} \frac{dI_3}{dt} \pm M_{2-4} \frac{dI_4}{dt} \quad (1)$$

$$L_3 \frac{dI_3}{dt} \pm M_{3-1} \frac{dI_1}{dt} \pm M_{3-2} \frac{dI_2}{dt} \pm M_{3-4} \frac{dI_4}{dt}$$

$$= L_4 \frac{dI_4}{dt} \pm M_{4-1} \frac{dI_1}{dt} \pm M_{4-2} \frac{dI_2}{dt} \pm M_{4-3} \frac{dI_3}{dt} \quad (2)$$

$$E = L_2 \frac{dI_2}{dt} \pm M_{2-1} \frac{dI_1}{dt} \pm M_{2-3} \frac{dI_3}{dt} \pm M_{2-4} \frac{dI_4}{dt}$$

$$+ L_4 \frac{dI_4}{dt} \pm M_{4-1} \frac{dI_1}{dt} \pm M_{4-2} \frac{dI_2}{dt} \pm M_{4-3} \frac{dI_3}{dt} \quad (3)$$

$$\frac{dI_1}{dt} + \frac{dI_2}{dt} = \frac{dI_3}{dt} + \frac{dI_4}{dt} \quad (4)$$

The inductive voltage in the positive and negative conductors is then calculated and the air-core coils adjusted for an equal voltage during the initial current rise.

The equivalent circuit involving air-core inductance and cast-iron resistors approximates the actual circuit only because, in the actual system, the time constants of the individual parallel conductors are not exactly the same and as a result the voltage induced by the flux of mutual inductances varies as the current increases. The rate of change of current $\frac{di}{dt}$ decreases more rapidly in those conductors having a relatively high resistance than in those of lower resistance. This is apparent since the voltage for increasing the current is

$$E_L = E - RI \pm M_1 \frac{dI_1}{dt} \pm M_2 \frac{dI_2}{dt}$$

The mutual inductance (M) is relatively small. E = voltage applied to any conductor and I = current.

The error introduced by the approximate method of using the self-inductance of air-core coils to represent the total inductance of the feeder is well within the limits of accuracy of calibration of commercial breakers for the circuit in question.

Separate calculations for each location of the short circuits were made because of differences in magnitude and direction of the mutual inductance effects with short circuits at different locations. The air-core inductances were adjusted accordingly for each test. The values given on Fig. 5 apply for short circuit at the tie station and were modified slightly for short circuits at other locations.

During the tests the holding coils of substation feeder breakers were excited from an independent constant potential source while sectionalizing tie breakers were excited from the line.

The resistance of the individual feeder of this network

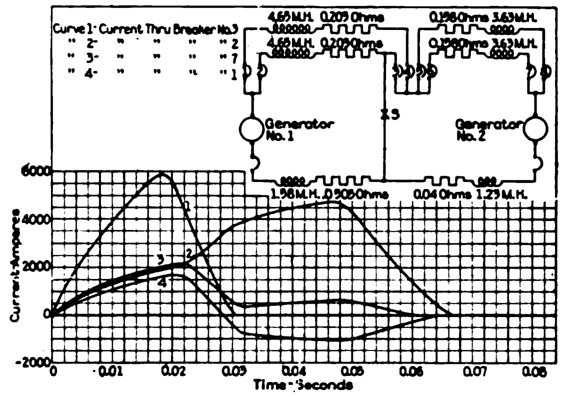

Fig. 8—Current Through Various Breakers During Short Circuit on Feeder Near the Tie Station of Typical Double-Track, 1500-Volt, D-C. Railway System. Breakers Nos. 2 and 3 Tripped

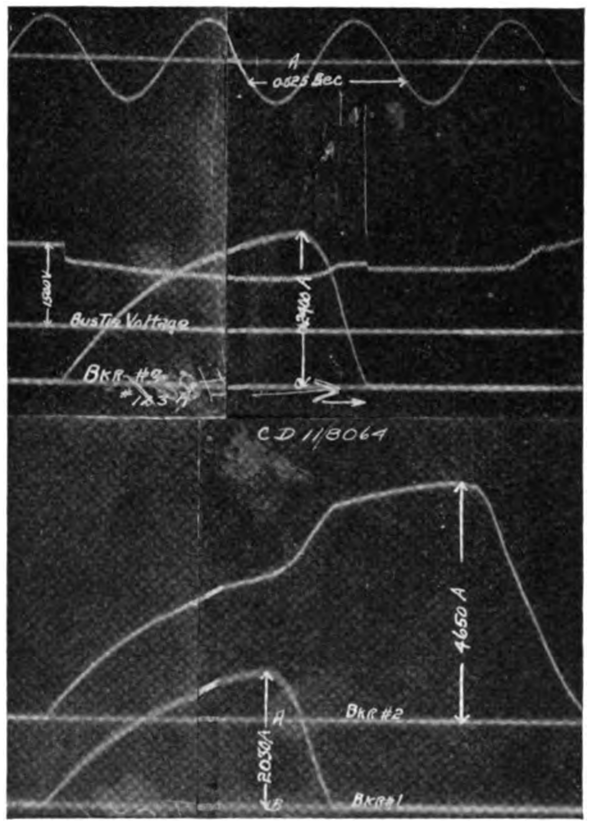

Fig. 9—Oscillogram Obtained when Applying a Short Circuit to the Equivalent Circuit of a 1500-Volt, Double-Track System, Stub-End Feed at the Maximum Distance from the Substation. Short Applied at S, Fig. 5, with Substation No. 1 Supplying Power; Breaker No. 4 Closed. Breakers Nos. 2 and 3 Opened by the Short Circuit

is such that the maximum current through each feeder with a short circuit at the sectionalizing tie station is less than the normal load setting required (6000

amperes). The maximum load condition in the individual feeders on a single breaker determined from the train schedules is encountered when restoring power to a dead feeder on which two ten-car trains are standing immediately in front of the substation with their controls in the first point series. The transient currents for these two limiting conditions are shown by the curve of Fig. 3. The current rise when closing the circuit of the two ten-car trains with the control in the first point was interpolated from oscillograms obtained during a series of tests made on a 600-volt system.

Breakers having identical constants were selected for

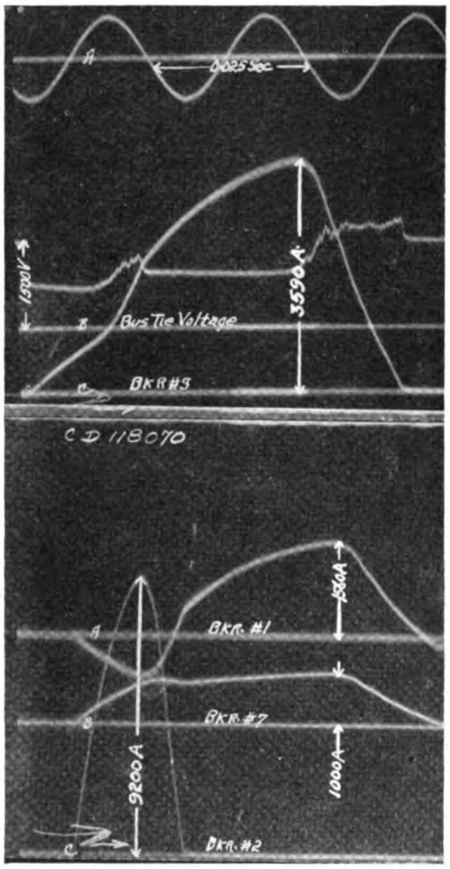

Fig. 10—Oscillograms Obtained when Applying a Short Circuit to the Equivalent Network Shown in Fig. 5. Directly in Front of Substation No. 1 on Feeder *B*, with All Breakers Closed. Breakers Nos. 2 and 3 Opened by the Short Circuit

all locations on the experimental network. The sectionalizing tie breakers were duplicates of the substation feeder breakers with the exception that their holding coils were excited from the feeders, the holding coils of substation feeder breakers being excited from an exciter bus.

A 1500-kw., 1500-volt generator was used as a power supply for each substation. All breakers were set for a steady overload of 6000 amperes. Selective operation completely isolating the faulty feeders without interrupting power supply to interconnected feeders was obtained for all locations of short circuits applied to the experimental network during the series of tests.

Referring again to Fig. 5, the most important locations tested were as follows:

1. Short circuits on all feeders both directly in front of substations and the sectionalizing tie station,

2. Short circuit on feeder *B* at the tie station while carrying a 2000-ampere load in the center of feeder *D*,

3. Short circuits one-half way between substations and tie stations,

4. Short circuit at the substation and at the tie station with a stub-end feed from a substation to the tie station.

The curves of Fig. 8 were taken from oscillograms of a short circuit at *S* of Fig. 5. Several of the actual oscillograms are shown on Figs. 9 and 10. It is interesting to note that as the short is disconnected from the the tie bus the current increases rapidly through breaker No. 2 speeding up its operation.

While it was not possible to simulate all of the conditions of load and short circuits encountered during the operation of such a system, the results of the tests indicate that it is possible to obtain a high degree of selective operation on d-c. railway feeders by the proper utilization of the inherent characteristics of the magnetic type of high-speed circuit breakers.

Several important installations involving a complete equipment of high-speed breakers designed for selective operation based on the principles discussed in this article have been made in the last few years.

The High-Speed Circuit Breaker In A-C. Railway Network

The discussion in the preceding paragraphs of this article has been confined to the d-c. railway network. A method of operation has recently been developed whereby the same type of high-speed breakers applied successfully to the d-c. railway system for a number of years may be applied to the a-c. network.

By the proper application of a-c. breakers of this type many of the advantages of high-speed protection can be realized on a-c. railway feeder networks. The duration of short circuits and resultant damage to apparatus, particularly in case of an arc, can be limited to a small percentage of that resulting under similar conditions with the usual slow-speed protective apparatus. High-speed protection is also of particular value in eliminating telephone interference during a-c. short circuits.

Furthermore, by taking advantage of the characteristics of the magnetic type of high-speed breaker, a high degree of selective operation can be obtained on a-c. circuits, isolating short circuits in a fraction of the time required with the usual type of protective system involving slow-speed breaker, inverse time relays, pilot wires, and the like.

The Effect of Internal Vacua
Upon the Operation of High-Voltage Cables

BY WILLIAM A. DEL MAR[1]
Fellow, A. I. E. E.

***Synopsis.**—It has been known for some time that the internal mechanical pressure of cables is a factor in the quality of the insulation, and that the oil used in impregnating paper for cable insulation has a high thermal expansion which may alter the internal pressure of cables with varying temperature.*

This paper considers the rate of pressure equalization in cables and the relative effects of slow equalization upon long and short cables, indicating that there may be considerable difference in dielectric properties depending on the length and past history in regard to temperature cycles.

Means of overcoming these differences are suggested.

The paper is suggestive rather than demonstrative and it is proposed to publish a sequel giving experimental proofs of the facts stated.

CABLE failures have often occurred which have not been explained to the satisfaction of both manufacturing and operating companies. Their outstanding feature from the manufacturers' standpoint has been the fact that individual lengths of cable withstand severe and prolonged high-voltage tests sometimes extending over a week or more, even after removal from the ducts, but when joined into a long cable, they have been, nevertheless, unable to operate at their normal voltage.

This has naturally led to the belief on the part of the manufacturers that in operation the cables must be subjected to more destructive potentials than they experience in the tests, or in other words, that the trouble is due to transient high voltages.

The only alternative is that, in some way, the joining together of a number of dielectrically strong lengths can result in a dielectrically weak cable.

Until recently, this latter alternative seemed scarcely worth consideration since it was outside the range of reasonable probability, whereas the theory of transients seemed to have some foundation in actual circumstances such as the concentration of failures at certain points, regardless of time or place of manufacture of the cable.[2]

The point of view of the user usually seems to have been that the actual evidences of severe over-voltage are negative, whatever the theoretical evidences in their favor might be. They have discounted the proofs of excellence of the individual lengths of cable, and explained the failures on the assumption that the cables are either impregnated with chemically unstable oil or that the cable is incompletely impregnated, the evidences of which are likely to be found in the cables that fail. This theory has not satisfied the manufacturers because cables impregnated with identical compound have been known to operate satisfactorily at higher electric stresses than those in the cables that failed. The manufacturers agree that practically perfect impregnation is essential to obtaining high dielectric strength but have not considered deficiencies in the impregnation or unstable oil to have been always the root of the trouble.

New information has now come to light, however, which explains how a number of good lengths of cable can be joined together into a bad cable, and the evidence is stronger than that which has been adduced in favor of the theories of abnormal voltage, or of defective cable.

The difference between the short length and the continuous cable, as manufactured in the past, is that the former has its ends open to the atmosphere so that the inside of the cable is at atmospheric pressure, whereas the latter, except near its ends, has an internal pressure independent of that of the atmosphere, by virtue of the continuity of the sheaths and joint sleeves, and the viscosity of the compound.[3]

On this difference, in our opinion, hangs the explanation of many mysterious cable failures.

Causes of Vacua in Cables

Oils, such as are used for impregnation, have an extraordinarily high coefficient of thermal expansion, usually of the order of 0.09 to 0.1 per cent by volume, per deg. cent. This is about ten times that of the metals used in a cable. In order to visualize the effect of this, we may assume that all of this change in volume is concentrated at one end of the cable, and consider what happens when a length of, say, 400 ft. is cooled. If the cable is completely filled when it leaves the factory, which may be assumed to be at about 25 deg. cent., and is then put in a duct at 0 deg. cent., the volume of oil will have shrunk 2.5 per cent so that 10 ft. of the cable will be completely deprived of oil.

In actual fact, this shrinkage will not be concentrated at one place but it will be none the less real and, in the aggregate, will be equivalent to the 10 ft. of cable. Where the distance from the center of a cable to its open ends is several miles the time required for internal readjustment of pressure, with heavy petrolatum compound, may be several years, especially if the

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1. Chief Engineer, Habirshaw Cable and Wire Corporation.

2. There is no doubt that transients have been a contributory cause of trouble, especially on large systems.

3. Cable compounds being very viscous, flow slowly, so that in the case of a petrolatum-impregnated cable, the readjustment of internal pressure is necessarily a very slow process, varying from practically zero speed with hard compounds and solid conductors to practically infinite speed with thin liquid compounds and hollow conductors.

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cable is lightly loaded. It is thus a matter of vital importance to load high-voltage cables, when impregnated with stiff compound, either prior to or upon the application of the voltage, and to maintain a load sufficient to liquefy the compound until internal pressures have been adjusted.

The contraction of compound in a cable is very beautifully shown by impregnating a piece of cable in a light-colored oil, and transferring it while hot to a dark-colored oil in which it is allowed to cool. The outside of the cable will be the first to lose its heat and the oil will, therefore, solidify there first. Hence, as the oil contracts, it will draw away from the center.[4] The dark grease used for cooling will, however, be sucked into the hollow so that the cable in cross section will present the appearance of a hollow ring of light color with a dark core. A small amount of dark compound will also be found in the outer layers due to diffusion. If the cable were allowed to cool in the open air, instead of in dark oil, the core would be free of oil except for that held in the paper by capillarity. Other vacuous spots will form in the compound as it contracts, either as bubbles or streaks.

Lead, which is used universally for cable sheaths, is peculiar in being almost entirely lacking in elasticity; that is to say, when it is stretched, it does not return upon removal of the stretching force. When a cable is put on a reel at the factory, its sheath is stretched on one side, and when the cable is straightened, to go into a duct, the stretched sheath does not contract, but wrinkles, thereby increasing the internal volume. The amount of this increase may, under favorable conditions, be as high as ½ per cent, so that in a case where the oil constitutes ⅓ the cubic contents, the increased volume would take oil from about 1½ per cent of the cable, an amount of similar order of magnitude to the disappearance of oil due to contraction.

Thus, there are two causes of vacua in cables which are of somewhat similar order of magnitude, both operating simultaneously and of such magnitude they might desaturate a 400-ft. length of cable to the extent of leaving the equivalent of 15 ft. of cable without oil and with a vacuum in its place. Thus, a petrolatum-impregnated cable having atmospheric pressure at 25 deg. cent. when reduced to 0 deg. cent. shows an internal vacuum of 22 or 23 in., as measured by a pressure gage attached to one end. In this condition, ionization will occur at about ⅓ the voltage which would be required at atmospheric pressure.

It is not only in theory or laboratory tests that this phenomenon occurs. The lead sleeves of a large number of splices on high-tension lines have been known to collapse, proving the existence of very low pressure within the cable. Vacua of 15 to 20 in. have been noted in splices of installed cables, and in such vacua, ionization starts at 40 to 60 per cent of the voltage required at atmospheric pressure.

When high-tension cables are installed, it has been frequently observed that air is sucked in when the caps are broken. This absorption of air continues for hours at a diminishing rate. If the joints are applied before the completion of this action, the cable will necessarily start its working career with a partial vacuum.[5]

Harmful Effect of Vacua

Having shown that vacua should exist in cables and then that they do exist, the next question is, do they do any harm?

Again the answer is in the affirmative.

Partial vacua ionize at much lower voltages than air at atmospheric pressure. Hence, a cable, having a partial vacuum within it, will show evidences of ionization at abnormally low voltages, so that ionization may occur even at working voltage or less.

The effect is not a mere corona glow, but a series of active streamer discharges, such as are familiar to us in vacuum tube lamps. These streamers emit rays, probably the ultra-violet, which have the effect of converting petrolatum compound into a solid, flaky substance, often known as *wax* or *X*.[6] Recent analyses have indicated that this substance has the approximate chemical composition,

$$(C_{12}\,H_{28}\,O)_n$$

It is apparently highly polymerized but of unknown degree of polymerization.[7] It is not a wax.

If petrolatum be placed in a vacuum tube so as to be out of the way of the terminals, but yet impinged upon by the discharge, the surface will be converted into *X*. This interesting laboratory experiment, due to Mr. E. C. Willman, of Cleveland, enables one to see, in process, the phenomenon which is known in cables only by its results.[8] It has been persistently denied by the manufacturers that the presence of this *X* is necessarily an indication of imminent failure of a cable and they are supported in this contention by tests on short lengths which continue in operation at very high stresses even after the practically complete conversion of the

4. The same phenomenon may be observed by heating a small beaker of grease to the melting point and allowing it to congeal. When solid, the surface will be funnel-shaped instead of practically flat as when water congeals.

5. A collapsible cap filled with compound may be placed over the ends of a cable when the seals are broken, which will prevent access of air and fill the voids with compound. Such a cap should be left on for several hours, preferably overnight. The use of such caps both in factory and field is the subject of a patent application.

6. Ultra-violet rays have a similar effect upon most oils. In the case of some vegetable oils, the effect is so pronounced that it has been made the basis of a commercial lacquering process.

7. Some experimenters report a very small proportion of nitrogen, but we regard this as too minute to be more than an impurity.

8. It was formerly thought that *X* was due directly to the electric stress, but it has not been found possible to produce it by stress alone, in the absence of electric discharges.

oil into X, yet cable users have known that, in some way, X formation and cable failure go together. These views are reconciled by the fact that short lengths of cable, such as are tested in laboratories by the manufacturers, will not fail due to X because their internal pressure quickly becomes atmospheric whereas long (installed) lengths are more liable to failure because, with stiff compounds, low pressures persist due to the slowness of pressure equalization. Furthermore, X formation increases vacua because X is less bulky than oil, and as mixed with the residual oil it forms a paste which is stiff and resistant to pressure equalization. If conditions are such as to create X, but yet maintain atmospheric pressure, the cable often will not fail.

A number of short lengths (10 ft. under lead) of cable were submitted to an accelerated aging test, one-half the cables being sealed hot, so as to have partial vacua within them when cool, and the other half allowed to cool with the compound at atmospheric pressure. The preliminary results show the vacuous cables have a much shorter life than those at atmospheric pressure, but difficulties in maintaining the seals have vitiated all experiments as far as quantitative results are concerned. The experiments are, therefore, being continued and Mr. C. F. Hanson expects to report them at a later date.

THE WAY TO AVOID HARMFUL VACUA

We have seen the cause of vacua in cable, and their baneful results. The next question is, naturally, how can they be avoided?

Before answering this, it should be borne in mind that an installed cable ordinarily has an internal pressure entirely independent of the atmosphere because its sheath and the sleeves of its joints are sufficiently thick and rigid to resist considerable pressure.[9] In order to maintain the inside of the cable throughout at atmospheric pressure, there must be the equivalent of openings to the atmosphere, compounds sufficiently fluid to transmit the pressure from these openings at a speed comparable with that at which thermal contraction occurs and longitudinal oil ducts of sufficient cross-sectional area to assist this action. In most cases the normal spaces between strands will suffice, but for very high voltages, a hollow core or special duct is desirable.

In order to provide the equivalent of openings in the cable or joint these must either be open to the air, or provided with a closed but collapsible part. The reservoir of liquid or semi-liquid oil applied to splices in an invention first used at Cleveland meets the latter requirements,[10] while the liquid oil reservoir system, developed in Italy, meets the former, although neither appear to have been intended for the specific purpose described above.

It should be remembered that pressure equalization is very slow with viscous oils, and differences of pressure should not be allowed to accumulate, but rather should be given an opportunity to equalize as they are forming.

In conclusion, we summarize the following characteristics as among the most essential for the successful performance of high-voltage cables:

1. The compound should be sufficiently fluid or soft at all operating temperatures to permit readjustment of internal hydrostatic pressure at a speed comparable with that at which this pressure is disturbed by temperature variations.
2. Access to the atmosphere or to atmospheric pressure should be provided at points sufficiently close to ensure the communication of such pressure to all of the compound in the cable.
3. Oil ducts (special or incidental) must be provided to assist the transmission of this pressure along the cable.
4. The saturation of the cable should be as perfect as possible so as to provide a minimum of oxygen to be absorbed by the compound.
5. The compound should be as immune as possible from deterioration by the rays generated by electrical discharges.

In addition to these characteristics, which are related to the subject matter of this paper, the cable should have, of course, suitable dielectric strength, dielectric loss and flexibility.

NEW MACHINE MINES COAL BY ELECTRICITY

A new-type electrically driven mining machine is being now tried out in various coal regions of the country. It is a powerful machine that cuts its way into the face of a bed of coal, breaks the coal loose and loads it into mine cars without the exercise of manual labor or the firing of a single ounce of powder or dynamite, such as often cause mine explosions. In a test run, this machine was able to bore its way into a coal seam at the rate of one foot in ten minutes and at a total mining cost of half that prevailing in the hand-working sections of the same mine. The entry driven in coal by the machine is 6 ft. high and 11 ft. 6 in. wide. —*Soc. of Elec. Dev.* May 30th, 1926.

9. A pressure of 35 to 45 lb. per sq. in. will start expansion of 8 64 to 10 64 in. pure lead cable sheath.

10. The Cleveland reservoirs were designed for the purpose of exerting atmospheric pressure "on the mobile compound to prevent the formation of voids during temperature changes," (Report of Underground Systems Committee, N. E. L. A., 1924) but as only the joint compound was mobile, the cables being impregnated with petrolatum jelly compounds, the reservoir appears to have been intended primarily as a protection for the joint rather than for the cable.

11. Emanueli, *Transactions* of the First World Power Conference, 1924, Vol. III, p. 1269, states: "The possibility of manufacturing cables destined to work at such high pressures (130 kv.) depends on careful reduction to a minimum of the gas which is occluded between successive layers of the insulating material," and *Jour.* I. E. E., Jan. 1926, p. 127, referring to the 130 kv. cable in Italy, "Its construction differs from that of an ordinary cable only in the fact that air or gas bubbles are entirely eliminated from the insulation."

Rectifier Voltage Control

BY D. C. PRINCE[1]
Fellow, A. I. E. E.

Synopsis.—*Lack of voltage control is one of the objections which have been made to the use of rectifiers. The author describes a method of voltage control for rectifiers based on the use of a saturated core interphase transformer. Saturation of this device produces a gradual change from two three-phase rectifiers operating in parallel to one six-phase rectifier which has a higher inherent voltage ratio. The theory of operation is discussed and supporting oscillograms and observed regulation curves are shown.*

A RECTIFIER is a kind of electric valve which allows current to flow from an alternating supply into a d-c. load circuit. The instantaneous alternating voltage varies all the way from $\sqrt{2}$, the effective value in one direction, to the same amount in the other direction. There is, therefore, nothing startling in the idea that any voltage between these limits can be communicated to the load circuit. The problem is rather one of practicability than of possibility.

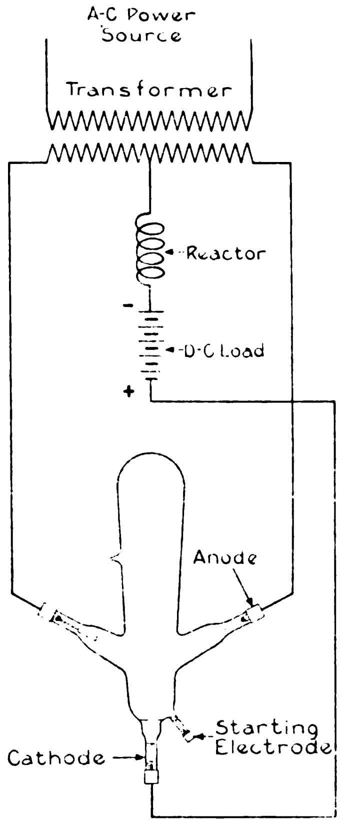

FIG. 1

The voltage communicated to the load circuit is not an instantaneous, alternating value but is an average over a considerable part of a cycle. Consider a simple, single-phase rectifier as shown diagrammatically in Fig. 1. The corresponding wave diagram is shown in Fig. 2. Current flows from the most positive anode to the cathode so that the cathode potential is below the most positive anode only by the amount of the arc drop which is practically constant and relatively negligible in rectifiers having any considerable output voltage.

This diagram assumes no inductance in the transformer or primary supply. The cathode traverses the series of positive lobes of two sine waves displaced 180 electrical deg. This potential is impressed upon the load and d-c. reactor. The counter e. m. f. load chosen will offer no impedance to the alternating components of the irregular cathode voltage. The inductance will offer no impedance to the d-c. component. The voltage wave is thus resolved into its components. The direct component is the average of voltage for a series of half cycles in one direction

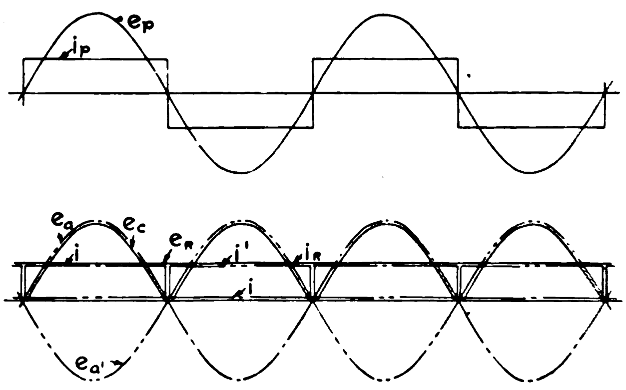

FIG. 2

and is the same as the average of one-half cycle. Its value is $\frac{2\sqrt{2}\,E}{\pi}$ where E is the effective secondary voltage to neutral.

If there were more phases, each anode would be the most positive for a shorter time and so the average voltage impressed on the load circuit would have to be taken for a shorter time. Fig. 3 shows some of the secondaries of a p-phase rectifier. The direction of each coil is the phase vector direction for that phase. For p phases, each anode will be most positive for the fraction of a cycle $\frac{2\pi}{p}$, that is, beginning at an angle $\frac{\pi}{p}$ before the maximum and ending $\frac{\pi}{p}$ after the maximum. The developed voltage wave is shown in Fig. 4.

1. Research Laboratory, General Electric Co., Schenectady, N. Y.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

The average voltage, G, is found most easily by integrating the wave, that is; finding its area divided by the base.

$$G = \sqrt{2}\,E \times \frac{p}{2\pi}\int_{-\frac{\pi}{p}}^{+\frac{\pi}{p}} \cos\theta \, d\theta$$

$$= \frac{\sqrt{2}\,E\,p}{2\pi}\left[\sin\theta\right]_{-\frac{\pi}{p}}^{+\frac{\pi}{p}} = \sqrt{2}\,E\,\frac{p}{\pi}\sin\frac{\pi}{p} \quad (1)$$

For various numbers of phases, this equation gives the series of values in Table I. It is seen at once that

TABLE I

p	2	3	4	6	∞
G/E	0.90	1.17	1.27	1.35	1.41

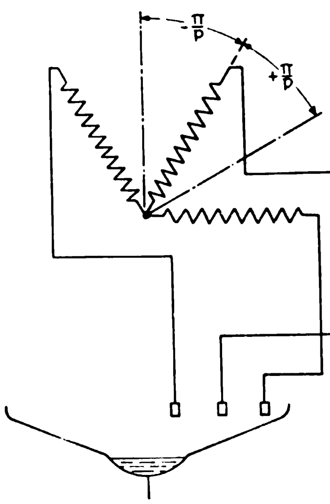

FIG. 3

by increasing the number of phases there results an increase in the average voltage. This indicates how voltage control may be approached. A method of changing smoothly the number of phases from two to

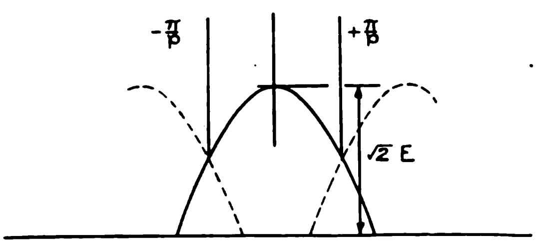

FIG. 4

six would give an increase of fifty per cent in the output voltage.

Two three-phase rectifiers may be connected to a three-phase supply as shown in Fig. 5. These rectifiers have separate inductances in series with their cathodes but feed a common load. Since the two inductances absorb the pulsating components of the voltages of their respective rectifiers, there is nothing to prevent their feeding the load in parallel, each supplying one-half of the current all the time. If the switch S be closed, this condition is changed. There is no longer any impedance to prevent a current shift from one rectifier to the other. Current will naturally flow from the anode with the highest voltage, regardless of its location in a particular rectifier, so that six-phase operation replaces three-phase.

Fig. 6 is a wave diagram of the change. With the

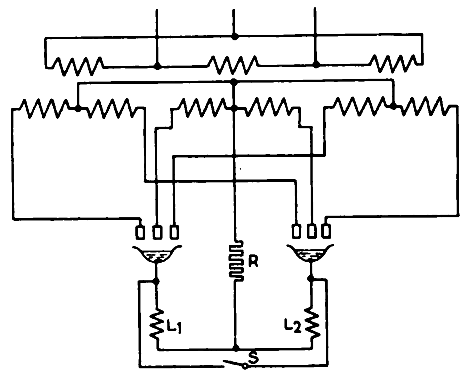

FIG. 5

switch open, the two cathodes have potentials e_1, e_2 averaging e_a. With the switche S closed, the two cathodes follow the potential of the most positive anode, giving the wave e_6 shown by the heavy line.

Instead of the abrupt change from two three-phase rectifiers, the transition might have been made gradually. The two inductances L_1, L_2 may be so interwound that they present large impedance to current changes between rectifiers but low impedance to changes of the total current. The load voltage will then be the average

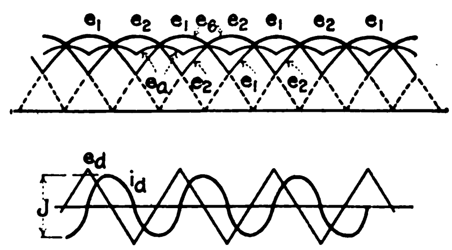

FIG. 6

e_a of the rectifier voltages, but only so long as both are carrying current. Should one stop carrying current, it could no longer influence the average voltage, for both windings of the choke system must carry a variable current in order to supply the inductive drops necessary for the voltage equalizing action.

The inductances, L_1 L_2, are not infinite, so that the tendency of the rectifier having higher voltage to take current from the other will cause a circulating current between the two rectifiers. In Fig. 6, e_d is the difference in voltage, i_d the circulating current. As long as this circulating current is less than the load current supplied by either rectifier, there can always be sufficient current changes to set up the difference voltage and preserve the average. If, however, the interchange

current becomes equal to the load of one rectifier, one will momentarily be carrying all the current, and the voltage will no longer be the average, but will be the voltage of the higher rectifier.

With a further increase in interchange current, there will be a longer period during which there is no drop across the inductances L_1 L_2 and the output potential will follow the higher rectifier for a longer time. Fig. 7 shows the waves under this condition. A value of difference current has been used which has an amplitude equal to the entire rectified current, J. With this

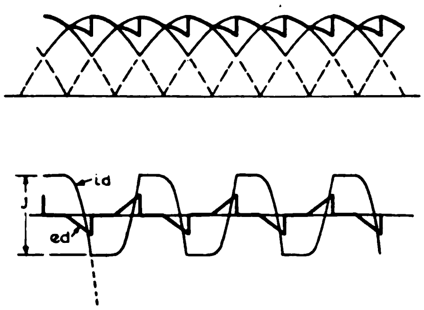

Fig. 7

value, the load current is divided between the two rectifiers half the time and carried by one for half the time. To maintain the difference voltage, the difference current would have had to continue as shown by the dotted extension, but this it could not do because the current from one rectifier could not drop below zero.

Saturation forms a ready means of altering the interchange current as desired. Fig. 8 is a diagrammatic representation of a saturation regulator adapted

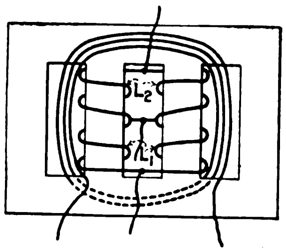

Fig. 8

for this use. It consists of a four-legged core on which two sets of windings are placed. One winding consists of two circuits surrounding the two central legs individually and connected so that the upper and lower halves of each will function as L_2 and L_1, respectively. The flux required for the difference voltage circulates in these two central legs and does not traverse the other two. The second winding used to saturate the core surrounds both central legs. The flux linkages are thus so balanced that current changes in either winding will induce no voltages in the other.

To increase the interchange current which is the exciting current in the central windings a direct current is passed through the outer winding. The flux produced by this current passes in one direction through the central legs and returns through the outer legs. It, therefore, saturates the central legs which carry the alternating flux, and this saturation increases the interchange current and thereby the output voltage.

The direct current required to saturate the core may be obtained from the rectifier output in which case a

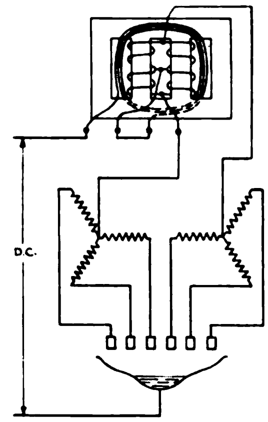

Fig. 9

compound rectifier results, or it may be obtained from a separate source controlled through a voltage regulator. The complete circuit diagram for compounding on load is shown in Fig. 9.

If rectifier transformers and supply lines had no inherent regulation, it would always be possible to secure the increases shown in Table I by changing the equivalent number of phases. There is, however, a considerable amount of regulation in the transformer which tends to be greater with increased numbers of equivalent phases. Take the case of the three-phase rectifier shown diagrammatically in Fig. 10, having all the inductance X concentrated in the anode leads and an infinite choke L to keep the total current constant.

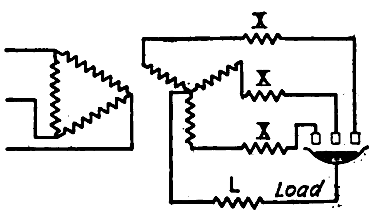

Fig. 10

When the voltages of a_1 and a_2 pass through equality, current will begin to change from a_1 to a_2. While the change is taking place the two anodes are at the same potential since otherwise they would not divide the current. The voltage difference between the two phases is absorbed in the inductances X. The current and voltage appear as shown in Fig. 11.

The rate at which current transfer will take place is proportional to the voltage causing the transfer, which is the vector difference between the phase voltages. At each transfer some of the average voltage

is lost as shown by the crosshatched areas in Fig. 11. The curve of current transfer is a sine wave which lags 90 deg. behind the phase-voltage difference because the drop is inductive. At any instant the value of the rising current to one anode is independent of load because no current change takes place in the load circuit. When all the current has transferred in angle u the

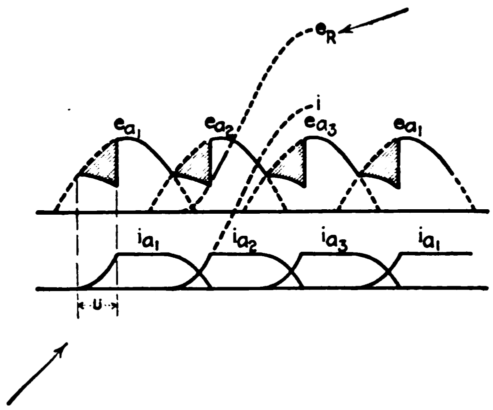

FIG. 11

change ceases. The greater the load, the greater will be the angle u.

It appears from Fig. 12 that the general expression for the phase-difference voltage is

$$\frac{e_d}{2} = \sqrt{2}\, E \sin \frac{\pi}{p} \tag{2}$$

This voltage produces a current

$$i = \frac{\sqrt{2}\; E \;\sin \dfrac{\pi}{p}}{X} \,(1 - \cos \theta)$$

At the end of the lap angle u, the load of direct-current J is reached so that

$$J = \frac{\sqrt{2}\, E}{X} \sin \frac{\pi}{p} \,(1 - \cos u) \tag{3}$$

The curve of instantaneous lost voltage is the same

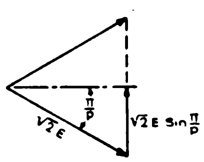

FIG. 12

as the half difference voltage used in making the current transfer. The average loss in output voltage represented by the hatched area is the wave e_R which has the same phase as the current i. Its value is

$$e_R = \frac{p}{2\,\pi} \int_0^u \sqrt{2}\, E \sin \frac{\pi}{p} \sin \theta \, d\,\theta$$

$$= \frac{p}{2\,\pi}\, \sqrt{2}\, E \sin \frac{\pi}{p}\, (1 - \cos u) \tag{4}$$

The open-circuit voltage has already been found to be

$$G_0 = \sqrt{2}\, E \frac{p}{\pi} \sin \frac{\pi}{p} \tag{1'}$$

so that the voltage under load is

$$G = G_0 - e_R$$

$$= \sqrt{2}\, E \frac{p}{\pi} \sin \frac{\pi}{p} \left(1 - \frac{1 - \cos u}{2} \right)$$

$$= G_0 \left(1 - \frac{1 - \cos u}{2} \right)$$

Equation (**3**) connecting J and $(1 - \cos u)$ can be used to replace the latter by the former. This results in

$$G = G_0 \left(1 - \frac{J\, X}{2\, \sqrt{2}\, E \sin \dfrac{\pi}{p}} \right) \tag{5}$$

It would be advantageous to arrange this equation so that the performance of the device might be compared with that of more familiar apparatus. Let it be assumed that there will be a four per cent drop in the transformer when carrying an ordinary sine wave a-c. load equal to its rating for use with a rectifier. Then the short-circuit current per phase is $\dfrac{E}{X}$ or $25 \dfrac{W}{p\,E}$ where W is the rated output of the rectifier.

Equating these two values and solving for X gives

$$X = \frac{p\, E^2}{25\, W}$$

and the output voltage equation may now be written

$$G = G_o \left(1 - \frac{J\, p\, E}{50\, \sqrt{2}\, W \sin \dfrac{\pi}{p}} \right) \tag{6}$$

or making use of equation (**1'**)

$$G = G_0 \left(1 - \frac{\pi\, J\, G_0}{100\;\; W\;\; \sin^2 \dfrac{\pi}{p}} \right) \tag{7}$$

In the derivation of these equations it was assumed that all the reactance was in the secondary windings of the transformer with no mutual reactance. This is convenient and gives results of the right nature. The magnitude of the results may be wrong, however, for, unless all of the leakage reactance is actually located in the manner represented in Fig. 10, the inductance of the paths taken by the commutating currents may be appreciably less than the value obtained by considering short-circuit conditions in the transformer. This is due to the fact that in the latter case the currents have a mutual reaction which can greatly increase the apparent reactance.

The commutating currents on the other hand usually are not required to flow through circuits with much coupling between sections. No advantage of this kind occurs in the single-phase rectifier, but in the three-phase case, the reactance presented to the commutating currents is approximately half that determined by short-circuit measurements. The advantage in the six-phase case is hard to determine exactly. If the transformer

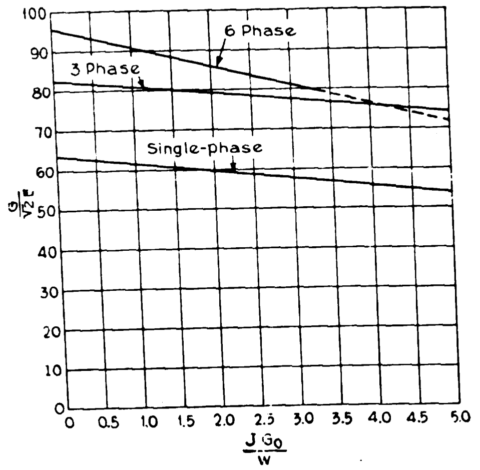

Fig. 13

has a primary and tertiary winding and all the reactance is in the primary, the advantage may be as high as six to one, but as a conservative estimate, let it be assumed that the reactance will be 40 per cent of the value determined from the simple measurements.

Fig. 13 indicates the regulation curves given by equation (7) and takes into account the corrections just described. The regulation curve for the compound rectifier will fall between the curves for the six-phase and three-phase rectifiers. By increasing the saturation of the interphase transformer as the load is increased, it may be made to give high reactance at low loads and small reactance at heavy loads. As a result the output voltage will approach that of a six-phase rectifier under heavy loads and will be nearer to that of a three-phase rectifier under light loads. It will be seen that the range of voltage available for compounding is somewhat limited if only the three and six-phase circuits are used. It is probable, however, that the limits are sufficiently wide for the great majority of applications. A much larger variation can be obtained by going from the single-phase to the six-phase connection. This transition is entirely practical but uses slightly more material than the three-phase to six-phase case and is therefore not desirable as long as the latter arrangement can be made to give the required characteristics.

Under extremely light loads, the direct current through the interphase transformer will be so small that it would be impractical to supply a transformer having sufficient exciting reactance so that its exciting current would always be smaller than the load current. Therefore, the effect of the interphase transformer will be lost as zero load is approached and the no-load voltage will be that corresponding to six-phase operation.

As long as the instantaneous current in the interphase transformer does not fall to zero, its reactance does not appear in the a-c. circuits. As soon as the current in one branch of the interphase transformer is actually interrupted, however, this transformer acts just as though it were inserted in the anode leads. Fig. 14 shows the circuit through which the transient current flows which accomplishes the commutation of the output current between anodes. The exciting inductance of the interphase transformer is added to the leakage reactance of the windings of the main transformer to obtain the value of X used in calculating the regulation curve. The result will therefore be a six-phase regulation curve dropping much more rapidly than that corresponding to the main transformer alone and the rapidity with which the voltage decreases will be dependent upon the exciting reactance of the interphase transformer.

After sufficient load current is flowing so that the interphase transformer is carrying current continuously, the output voltage will be that corresponding to the three-phase rectifier. As more load is applied the output current flowing through the saturating winding of the interphase transformer will decrease the reactance of the main circuit. The exciting current will then rise until it is as large as the load current and continuous choke action will be lost. The voltage will then be displaced from the three-phase value in the direction of the potential corresponding to six-phase operation. By this means the voltage may be held constant over the greater part of the load range or may even be made to increase slightly with load.

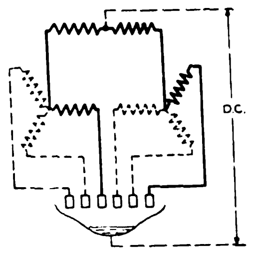

Fig. 14

In Fig. 13 part of the curve for six-phase operation is shown dotted. In this range the voltage is no longer given by equation (7) because the load is so great that three anodes carry current simultaneously during part of the time. Due to lack of complete data on the reactance of the circuits traversed by the commutating currents, it is not worth while to calculate the voltage under these circumstances. The three-phase rectifier curve will have a similar limit of applicability, but this limit is not reached in the range shown in Fig. 13.

Figs. 15, 16, 17 and 18 indicate the results of experimental work which serves as a check on the theory of

operation of rectifiers with compounding. Fig 15 shows the wave shapes obtained with an oscillograph when an experimental rectifier was operating as two separate three-phase units connected in parallel through an un-

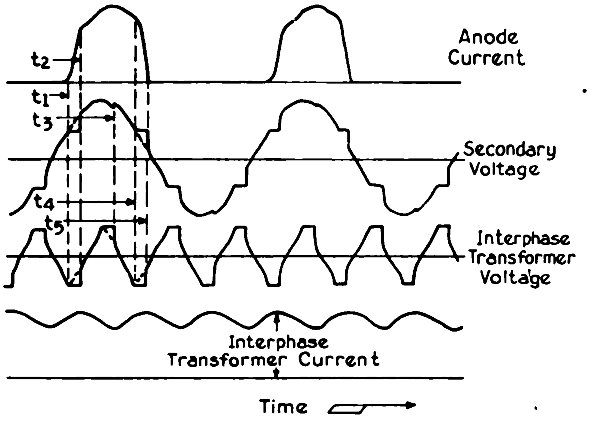

FIG. 15

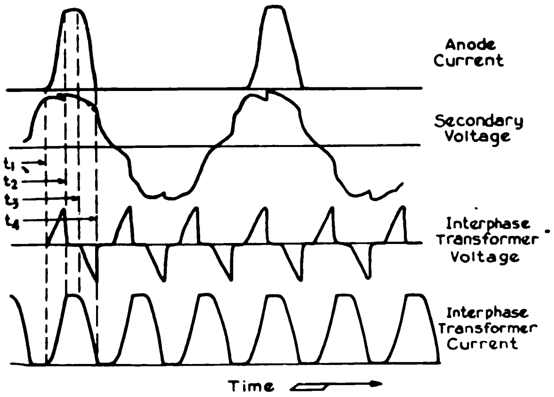

FIG. 16

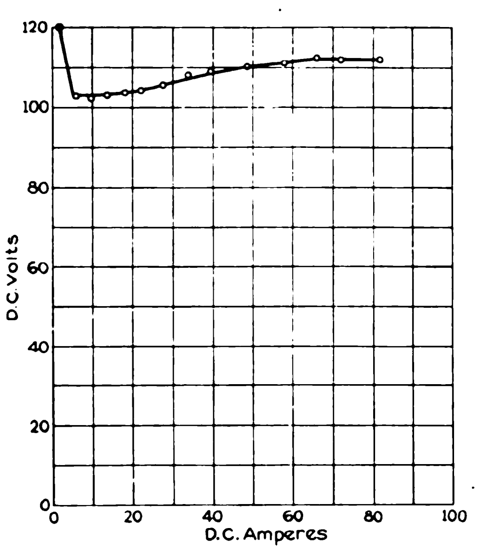

FIG. 17

saturated interphase transformer. At time, t_1, the secondary voltage of the phase being measured became equal to that of the preceding phase in the same three-phase group, and it began to conduct current. Between t_1 and t_2 both phases were conducting current and the reactive drops caused by the changing currents averaged the induced voltages of the two phases so that their terminal voltages were nearly constant. At time, t_2, the current transfer was completed and the terminal

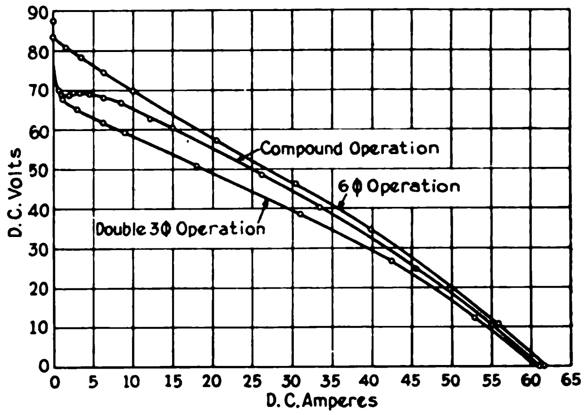

FIG. 18

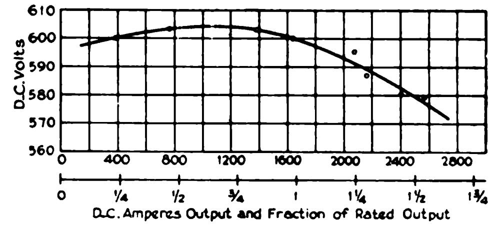

FIG. 19

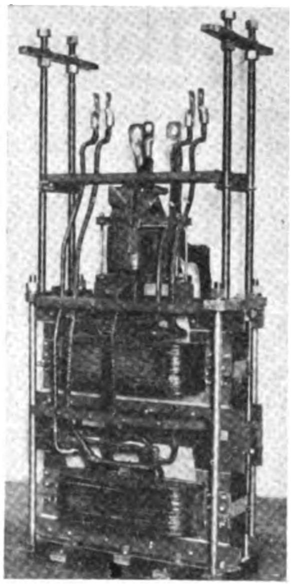

FIG. 20—INTERPHASE TRANSFORMERS

The 180-cycle units are provided with series d-c. saturating coils and variable gap in the d-c. core circuit.

voltage of the incoming phase again became equal to its induced voltage. Between t_4 and t_5, the current left the phase under observation, and this time the reactive drop prevented the terminal voltage of the phase from falling as rapidly as the induced voltage until after the

transfer was completed. The dotted lines indicate the form of the secondary voltage and interphase transformer voltage waves, if they had not been distorted by the reactive voltages during current transfer. The slight irregularity in the secondary voltage wave at time t_3 was caused by commutation of currents in the second three-phase group of windings and was present because of the coupling between the two groups through the transformer primary windings.

Fig. 16 shows the wave shapes obtained with the core of the interphase transformer saturated. The operation is now that of a six-phase rectifier. Current is building up in the phase under observation between t_1 and t_2 and decreasing between t_3 and t_4. Not more than two anodes carry current simultaneously, and between t_2 and t_3 only one anode is conducting. The interphase transformer now carries pulses of current of the same shape as the anode pulses, but, since it carries the current of all the anodes, the pulses will be closer together. There is a voltage across the interphase transformer only during the time the current is transferring between anodes, which transfer must occur through it. As the reactance of the interphase transformer influences the period of commutation, it is apparent that the output voltage can never rise to the six-phase voltage corresponding to the transformer by itself. Instead, the output voltage will approach this value as the reactance of the choke is decreased by saturating it more and more, but can never reach it.

Fig. 17 shows an experimental compounding curve obtained from a small rectifier. After the first sudden drop to the normal three-phase voltage at six amperes, the voltage rises steadily with increase in load to 70 amperes, after which it again falls. To obtain this curve no changes were made other than changes in load. This rectifier had insufficient capacity to stand loading to short circuit. Accordingly, additional reactance was added enabling the curve of Fig. 18 to be taken. In Fig. 18 the load is increased to short circuit under three conditions, with no saturation of the interphase transformer, with the compounding apparatus in operation, and with the interphase transformer short-circuited. Although the compound curve never equals the six-phase curve except at short circuit, the six-phase voltage is approached sufficiently to give flat compounding from light load to 6½ amperes which is 10 per cent of the current under short circuit.

Tests which have been made on the performance of a 1000-kw., 600-volt, 12-phase rectifier further substantiate the correctness of the theories herein set forth. Fig. 19 is a regulation curve obtained with this rectifier adjusted to give substantially flat compounding out to full load, 1667 amperes. Fig. 20 is a photograph of the interphase transformer. Since the set is twelve-phase, there are three interphase units. The two lower units combine each two groups of three phases and have direct current saturating windings. The small top unit combines the two six phase groups into one twelve-phase unit.

Polarization of Radio Waves

BY E. F. W. ALEXANDERSON[1]

Fellow, A. I. E. E.

UNTIL rather recently, the practise of radio communication was confined to the use of long, earth-bound waves. These waves are preferred on account of the regularity of day and night operation and the absence of fading. The characteristics of the earth-bound wave were extensively explored and there was a tendency to generalize these results assuming that they apply to all radio wave transmission.

Usually the earth-bound wave is thought of as a moving electromagnetic field with horizontal magnetic lines sweeping parallel to the earth and vertical electrostatic lines terminating in the conducting earth. This theory has been supported by a great deal of practical evidence. Attempts to measure horizontally electrostatic lines have always given negative results and it almost seemed obvious that this should be so. It, therefore, seemed quite unnecessary to speak of polarization of radio waves, since the waves were supposedly always vertically polarized due to their nature of being earth-bound.

A great amount of data was collected and among these were some surprising observations. For instance, it seemed as if the wave did not always come in from the proper direction but wandered around, seeming to come at times from the side and sometimes even from behind. This led to a good deal of discussion, but no plausible explanation was found. Yet the evidence was accepted as incontrovertible that such direction changes did exist because the observations were confirmed by so many competent observers.

Recent investigations of the phenomena of radio wave propagation, however, have led to another explanation, the conclusion being that the observed irregularities were not actually changes in direction but changes in the plane of polarization. Whether such an explanation had been considered at some earlier date the author does not know, but if it was tentatively advanced, it was undoubtedly discarded on the ground of the experimental evidence, showing that the horizontal electrical lines did not exist. As a matter of fact the

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polarization theory did not originate with the study of long-wave phenomena and it requires a new conception of wave propagation, developed through recent work on short waves.

Observations on Short Waves

Our first experience in signaling with horizontally polarized waves was gained as a result of an incident in an investigation which had been organized to study directive radiation with short waves. One of the several directive antenna systems which were used was a combination of two large, square, vertical loops, tuned for a wavelength of 50 m. Each loop consisted of eight sections of conductor, separated by eight condensers so that each section was independently tuned. The composite antenna thus had four vertical conductors, two in each loop, and the object of the test was to regulate the direction and phase of the currents so that the composite antenna would give a unidirectional radiation in the plane of the loops. The only practical way to adjust the phase of the currents proved to be to make measurements of the composite radiation within a few hundred feet of the antenna. When the radiation diagram so obtained was in agreement with the theoretical expectations, it was assumed that the system was properly tuned. The experimental station at Schenectady was in radio communication with the stations of the Radio Corporation of America, at Riverhead, Long Island, and Belfast, Maine, where the signals were measured to ascertain whether the directive characteristics were the same at distant points as near the station. In one case it was found that no radiation whatever could be observed in the field around the station. But investigation showed that, by accident, one of the loops had been reversed so that while current was flowing in all the vertical conductors as indicated by the ammeters, the resultant effect in radiation was zero. No sooner had these facts been ascertained than a communication was received from Long Island that the signals were 50 per cent stronger than in previous tests. In view of the absence of any radiation near the station this surprising result called for further analysis. It was thus found that while the currents in the vertical conductors were in such a direction as to neutralize each other, the two top conductors carried current in the same direction. These conductors being horizontal, it followed that the radiation must have been horizontally polarized and that the failure of the local instrument to indicate any radiation was due to the fact that it was sensitive only to vertical radiation.

Since then, a number of antenna forms for horizontally polarized radiation have been tested and used in commercial service by the Radio Corporation of America. The practical conclusion reached through these tests, as well as the findings of the government laboratories and many amateurs, is that in most cases horizontal transmission and reception with short waves is superior to the old methods of using vertical polarization.

When one attempts to discuss the phenomena of wave polarization, he finds many theoretical and practical aspects and many questions which may be asked. For instance:

How does the wave acquire a horizontal polarization when it is radiated vertically and why does the wave become vertical when it is radiated horizontally?

Does the wave always twist in space or only under some circumstances, and what are these circumstances?

Why is horizontal polarization the rule on short waves and so difficult to discover on long waves?

How strong is static in the horizontal plane?

What relation has polarization to fading?

Does a wave fade in the horizontal and the vertical plane at the same time?

Can direction finders be made to compensate for errors due to polarization?

Many such questions may be asked and only a few can be answered definitely. If the idea of wave polarization is to be more than an empty phrase, we must try to form in our minds a picture of what the wave itself consists before we can intelligently discuss the peculiarities of its behavior.

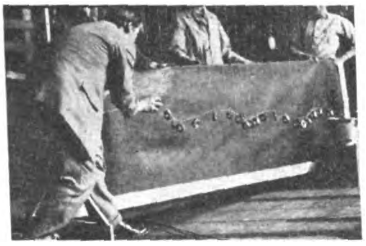
Theory of Wave Motion

This subject is being approached from two angles: One, the classical theory of light radiation in the ether; the other, the electromagnetic theory as we know it in electrical engineering. Both of these theories have their difficulties. The only positive knowledge we have of electricity is the electronic theory. We know that the electron is the smallest element of matter. We know its mass, its electric charge and how fast it travels. But we do not know what magnetism is. As a matter of fact there is good reason to believe that there is no distinct force that can be called a magnetic field. Modern science also denies the existence of ether. We have tentatively substituted a conception of electromagnetic field, in which the energy appears sometimes in electric form and at other times in magnetic form. This is a mathematical rather than a physical substitution, but it is convenient because it permits us to use the equations for the electric and magnetic fields as used in electrical engineering. However, it is not an explanation. To an electrical engineer, a magnetic field is very real and in its nature is quite different from an electrostatic field. From this point of view, it requires a good deal of imagination to conceive that a magnetic field is nothing but a manifestation of a moving electrostatic field. Yet we may be forced to change our conception to that extent. This means the return to Faraday's idea of tubes of force which are material bodies with mass and elasticity.

The ordinary antenna consists of a vertical wire in which electrons periodically move up and down, and the space field, which accompanies the electrons, moves up and down with them. This moving space field is a physical reality. It has a mass and kinetic energy

stored in its motion and it has elasticity. A physical model of such a field can be built. The field itself extends into space but the different portions of the field do not move simultaneously. This elastic, electric body moves in the only way in which one may conceive of a structure maintaining a periodic motion, that is, in waves proceeding from the center. The magnetic field is nothing but the kinetic energy of this moving structure. The electromotive forces which, according to our well-known equations, are induced by the change in the magnetic field, are nothing but the elastic forces which react against the inertia of this electrical body.

With this picture in mind, it is not difficult to see the physical meaning of wave polarization. The ordinary radiator has a vertical conductor in which the electrons move up and down and the accompanying fields move up and down with them within a radius of one-quarter wave length. The inertia of this moving field, close to the conductor, is propagated through an elastic medium in accordance with ordinary laws of wave motion. In the wave which thus proceeds from the origin, every element oscillates in a vertical plane.



Mechanical Model Showing How a Plane Wave Changes Into a Spiral

Thus the vertically polarized radiation is closely analogous to a wave on the surface of water.

The radiator of horizontally polarized waves consists of a closed loop conductor in the horizontal plane. In this conductor the electrons circulate first in one direction and then in the other.

Mechanical Model for Studying Wave Polarization

A mechanical model has been built for the study of wave polarization in the laboratory. The model consists of weights suspended in such a way as to make them free to move in all directions. Twenty-two of these weights are arranged in a row and connected by rubber bands. Each weight is suspended from a yoke and an equal weight hung on the other side of the yoke to serve as a counter weight. A screen is set up so as to hide the counterweights and avoid confusion in observing the wave motion. This model was set up especially to study the twisting of the plane of polarization and the experiment has strikingly confirmed the theory which it was intended to illustrate. This theory is briefly as follows:

Let us assume that the medium through which the radio waves pass has such characteristics that the velocity of propagation for a vertically polarized wave differs slightly from the velocity of the propagation for a horizontally polarized wave. For the present purpose, it is not necessary to try to explain the reason for this difference in velocity, but we may assume that the reason for it is the electrostatic or magnetic earth field or a retarding effect due to the closeness of the earth. Whatever the cause, we may assume that such a difference of velocity exists and the mechanical model has been constructed so as to reproduce such conditions. Thus wave motions in the horizontal or vertical planes can be studied independently, and these two wave motions may be adjusted for different velocities. A wave started in the vertical plane maintains itself vertically and a wave started horizontally maintains itself horizontally. If, however, a wave is started in a plane 45 deg. between the vertical and the horizontal, it is found that the wave motion proceeding therefrom assumes the shape of a spiral. The straight-line oscillation of the first weight is passed along as an elliptical motion which gradually widens into a circle. Then this circle again narrows down to an ellipse and finally to a straight line at right angles to the original line of oscillation. This is exactly in accordance with the theory. The point where the wave has shifted its plane of polarization 90 deg. is the point at which the faster of the two waves is half a wave length ahead of the slower wave. From this point on, the wave proceeds, repeating this peculiar spiral motion.

The fact that the twisting of the wave is due to different velocities in the two planes of polarization can also be demonstrated by this model. For such a purpose, the tension of the rubber bands between the counter weights is changed. The effect of this is to change the velocity of propagation in the vertical plane, whereas the velocity in the horizontal plane has not been affected because only the vertical motion is transmitted to the counter weights by the suspension yokes. The system can thus be adjusted so that the velocities in the horizontal and the vertical planes are exactly equal. After this has been done, it is found that the tendency to spiral motion disappears and the wave remains strictly in the plane in which it has been started.

While this mechanical experiment brings out no new facts unknown to the classical theory of wave motion, it helps us to visualize the main phenomena in the radio wave propagation which we are trying to explain. The phenomenon of a constantly shifting plane of polarization, discovered experimentally in the tests between Schenectady and Long Island, can thus easily be explained.

This conception of the wave motion also is a help in explaining the phenomenon of fading. There is much experimental evidence that fading is a phenomenon of wave interference. In other words, the fading is due to the fact that the radio waves arrive at a certain point through two paths. The waves will sometimes add to each other and sometimes neutralize one another. If

one bears in mind the observations on the mechanical model and the fact that the waves in the two planes can be traced through, separately and distinctly, one may conclude that the two paths of the radio wave which produce fading are not necessarily two separate physical paths but may be the two paths in the horizontal and the vertical plane of polarization. For further illustration of this, a detector may be introduced into the mechanical model. If this detector is placed at a certain distance from the origin it is found that it gives no response when the system is adjusted for different velocities of propagation, whereas when the system is adjusted for equal velocity in the horizontal and vertical plane it gives a maximum response. Thus the phenomenon of fading has been reproduced mechanically through polarization in a single wave path.

By this, it is not suggested that in actual radio transmission the mechanical equivalent is sufficient to explain the fading. However, it is offered for what it may be worth as a help to interpret the many observations in actual radio transmission which are being accumulated.

Irregularities of Direction Finders

It has been known almost since the beginning of transatlantic communication with long waves that measurements of direction of wave propagation with rotating loops show peculiar irregularities from the time of sunset. It has also been known among aviators that direction finder bearings on an airplane are correct only if the plane flies in the line towards the observing station. If the plane flies at right angles, the direction finder gives false orientation as high as 45 deg. or more. This false orientation is greater if the antenna is trailing horizontally. It is therefore attempted to keep the

Transmitting Loops Used in Tests which Revealed Horizontally Polarized Radiation

antenna as nearly vertical as possible by a weight.

A third set of observations has been brought out through the research work in Schenectady on horizontally polarized waves radiated by horizontal loop. Measurements with a direction finder receiver usually give bearings approximately at right angles to the place where the station really is, but sometimes it gives no direction indication at all. Other measurements indicate that the direction of wave propagation is almost perpendicularly vertical. The observation that the wave appears to come straight down from above suggested an explanation that wave components radiated directly upwards had been reflected straight down by the Kennelly-Heaviside layer. However, in view of the other facts to be considered this explanation seems less likely.

Putting all these facts together it seems now that the old observations on the long wave, the airplane, and our recent work on the horizontal loop all may be explained as a characteristic behavior of the horizontally polarized wave. In all three cases, while the wave appears to come in from unexpected directions, it actually does not. When in the third case there is no direction indication whatever, and the wave appears to come in from above, this also is an illusion. The question is, what really does happen?

Transmitting Antenna for Horizontally Polarized Waves and Receiving Instrument Indicating Apparent Wave Direction at Right Angles to True Direction of Propagation

This is the problem on which the experiment with the mechanical model can throw some light. For this purpose let us return to the idea that the radio wave is a mechanical wave motion in the elastic electric medium. In the mechanical model, the weights represent the mass and the rubber bands the elasticity of this medium and the vertical as well as horizontally polarized wave can easily be reproduced. But in order to imitate a wave motion over the surface of the earth, one must also in some way imitate the presence of the earth. The earth is a conductor and therefore the elastic strains represented by the rubber bands cannot exist in the earth. On the other hand, displacement currents in the electric medium can induce conduction currents in the earth. These conduction currents are electrons in motion which can be represented by weights not tied together by rubber bands in the horizontal plane, whereas they are electrically associated with the electric medium above. To imitate this condition, weights may be hung by vertical rubber bands so that they are elastically associated with the wave medium but not connected to each other. If, now, a horizontally polarized wave is sent forth through this system, it is found that the wave motion is propagated to the vertically suspended weights producing elastic strains in the vertical rubber bands. It must be remembered

that the elastic strains represent electromotive forces and these elastic strains so produced are of the same character as if they were a part of a vertically propagated wave motion. No such wave motion actually exists and these strains are only the electromotive forces which induce currents in the ground. If we now assume that a receiving antenna is set up in the form of a vertical loop with its plane at right angles to the wave motion, the primary wave motion does not induce any currents in the loop. However, the secondary electromotive forces, which induce currents in the ground, are in the plane of this loop and tend to induce such currents in the loop. In other words we may say that,

Exploring Antennas

inasmuch as the currents induced in the ground are at right angles to the wave motion, the loop is in the plane of those ground currents which, in their turn, induce currents in the loop.

If this theory is correct, it should be found that false indications of the direction finder and the apparently vertical wave propagation can be observed only in the proximity of the ground. Thus, if observations are made in airplanes high enough from the ground, the horizontally polarized wave should show a horizontal plane of polarization with a true direction of propagation.

Some measurements have been made which confirm these conclusions. By making frequent measurements to within ten miles of the station a set of tests was made exploring the characteristics of a wave radiated from a horizontal loop. The composite picture which was obtained from this test was a continuously twisting plane of polarization with alternate points of plane and circular polarization. At intermediate points, the polarization was elliptical. The plane polarization was indicated by sharp directional bearings and circular polarization was indicated by equal intensity from all directions. The observations indicating plane polarization gave bearings sometimes towards the transmitting station and sometimes at right angles.

Beside these measurements around the vertical axis, observations were made with the loop in the horizontal plane. On flat fields the horizontal position gave nearly zero response. At the top of a steep hill and a high bridge, the response in the horizontal plane was equal to the vertical.

These results indicate the presence of a horizontal and a vertical wave component with different velocity of propagation. Whenever the two waves are in phase, they give plane polarization. When they are 90 deg. out of phase, they give circular polarization. The observation with the loop in the horizontal position on the top of the hill and the bridge shows that even a moderate elevation is sufficient with short waves to reach the point at which the horizontal electromotive forces are not short circuited by the ground.

All this leads the author to believe that horizontal polarization is not confined to short waves only. Direct observation of horizontal polarization at long waves could be made only at great heights but indirect observations through the effect of ground currents can be made by ordinary direction finders at any wave length. If this theory is correct it means that the irregularities of direction finder indications recorded on long waves can be explained by the presence of horizontally-polarized wave components.

JORDAN RIVER TO PRODUCE ELECTRICITY TO REVIVE PALESTINE

The waters of the Jordan River, in Palestine, once were regarded as having power to revive the souls and spirits of men; today the river is helping to revive industry in the Holy Lands. Bernard Flexner, president of the Palestine Economic Corporation, has announced that the new corporation will help finance the hydroelectric station on the Jordan which will supplement the electric power produced by oil-engine driven generators at the ancient towns of Tel Aviv, Haifa and Tiberias.

The hydroelectric plant will be connected by transmission lines with the lines from the oil-engine stations to establish the beginning of a power system that some day may serve the whole of the Holy Lands. Factories there are now operated by electric power and the use of electric appliances in the homes is becoming more and more common.

TREMENDOUS WASTES DUE TO BAD LIGHT

The bugaboo of bad light in schools and factories is no imagination, according to Guy A. Henry of New York, general director of the Eyesight Conservation Council of America. Speaking at Boston May 28 he stated that one-third of the six million retarded pupils in American schools were in their present condition because of neglected eyesight that could be partially corrected by proper illumination. Factory waste chargeable to poor lighting, he declared, totals thirty million dollars of industrial waste and industrial accidents due to poor lighting cause an annual loss of 300 million dollars.

Abridgment of

Lightning and Other Experiences with 132-Kv.-Steel Tower Transmission Lines, and its Bearing on Tower-Line Design from the Continuity of Service Standpoint

BY M. L. SINDEBAND* and P. SPORN*
Member, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*A large number of transmission lines have been erected without adequate consideration having been given to the ability of the line to stay in circuit electrically during the occurrence of lightning or other disturbance conditions. These come, however, within the range of the transmission engineer's field of action.*

The author's experience with a 55-mi., 132-kv. transmission line since 1917 to date is cited, the particular line being one which has been very successful from a standpoint of continuity of service. Further experience with other lines built with variations on the original design and placed in service in 1924 and 1925 is given. A detailed analysis is given of eighty-eight cases of lightning trouble on one of these lines during 1925, the various steps taken to reduce the frequency of this trouble, the effect of increased clearances and separations, of additional insulators, of flux control units, and of arcing horns and shields on the amount of trouble and on the damage to insulator and conductor are discussed both from the standpoint of actual experience and from the laboratory analyses and investigations made.

A general discussion of the ground wire and its effect on lightning voltages is given and the arguments for and against it are discussed. The importance of paying attention to the mechanical side of the ground wire and the effect of such attention on continuity of service is pointed out.

A summation is given of the analysis and experience of the authors in operation of 132,000-volt lines as applied to transmission line design from the standpoint of continuity of service.

LIGHTNING disturbances, if they are electrostatic disturbances, are, of course, beyond the control of the engineer but the effects of these disturbances on the transmission system are partly within his control and are within his province of action, and any transmission line that is not designed with a view to properly standing up under lightning conditions, has, of course, not been adequately designed. It is an undoubted fact that a good many lines have been designed in the past, and even in the last five years, where the factor of the ability of the line to stay in circuit under lightning disturbances has not been adequately taken into consideration and it has taken actual operating experience to disclose that fact.

132-Kv. Lines Considered

The author's first extensive experience with a 132-kv. line was with the 55-mi. transmission line built on double-circuit steel towers and running from the Windsor Power Plant of the Ohio Power Company and of the West Penn Power Company, located approximately 12 mi. north of Wheeling, W. Va., to Canton, Ohio, the line running in an approximately straight northwestern direction. A sketch of this tower as well as pertinent design data is shown in Fig. 1. This line is equipped with two-ground wires, 3/8 in. diameter Siemens-Martin, and was placed in operation late in 1917. The line is insulated with 10 disk units at suspension points and 12 units at dead-end points. When this line was put into operation there were operating four 30,000-kv-a. steam turbine units at the Windsor Plant and these constituted practically 80 per cent of the capacity connected to the 132-kv. transmission system of which these two lines formed a part. The line has had altogether 41 interruptions due to lightning since it was put into service, and divided by years as follows:

1917	2	1921	4
1918	4	1922	6
1919	3	1923	4
1920	5	1924	6
1925	7		

In 10 per cent of the cases both lines were affected. All but four of these interruptions were such that they did not affect in any way the insulators or the conductor nor did it require any work to repair these. On the four other occasions mentioned the insulator string was flashed and damaged to a point necessitating a change and the conductor dropped to the ground. The ground wire was removed from over all the railroad crossings on the Windsor-Canton line during 1924, the work being completed by the end of August. In 1925, 12 mi. of ground wire were removed at each end of the line, this being done as a precautionary measure. The wire was actually not in very bad condition but atmospheric conditions at both ends of the line were rather bad and there was danger of deterioration developing to a point that would be dangerous. Up till now this wire has not been replaced. It will be noticed from the operating record that the number of interruptions apparently did not in any way increase due to the removal of this ground wire although perhaps a sufficient time has not elapsed for this point to be known definitely. Thus much is known, however; all the trouble encountered in 1925 was on sections where ground wire was installed. It will be noted that in general the history of operation of this line has been a highly successful one, and that the line has given such uniform continuity of service as to make possible the supplying of a load to the City of Canton amounting to well over

*Both of American Gas & Electric Co., 30 Church St., New York, N. Y.

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60,000 kv-a. dependent entirely upon the transmission line for its power.

During 1923 and 1924 the construction of three additional lines in Ohio was undertaken as follows:

1. A 73-mi., double-circuit line from the Philo Plant of the Ohio Power Company, located at Philo, Ohio, on the Muskingum River, south of Zanesville, and running to Canton, Ohio.

2. A 15-mi., single-circuit line, but strung on the same type of towers as the Philo-Canton line, running from Philo to Crooksville, Ohio.

3. A 45-mi., single-circuit line from Fostoria, Ohio, running approximately southwest to Lima, Ohio. This line, too, was to be built on a double-circuit transmission tower with only a single-circuit strung.

During 1924 and 1925 there was again constructed a 129-mi. line of the same type of structure, with only a single-circuit strung but utilizing 397,500-cir. mil., A. C. S. R. instead of 336,400 A. C. S. R. used on the three lines previously mentioned. This line runs from Lima, Ohio, to the Twin Branch, Indiana, plant of the Indiana & Michigan Electric Company which is located on the St. Joseph River, approximately 8 mi. east of the city of South Bend.

The tower utilized on all these lines is shown in Fig. 2. Comparing Figs. 1 and 2, it will be noticed that a number of changes were made between 1915 when the Windsor-Canton tower was designed and 1922 when the Philo-Canton tower was designed. It will be seen that the height of the bottom crossarm was raised from 50 ft. to 64 ft., the vertical crossarm spacing was raised from 12 ft. to 13 ft. and the height of the upper crossarm was raised from 74 ft. to 90 ft. Further, while the Windsor-Canton tower was designed and erected with two ground wires, the Philo-Canton and other towers were all designed for but one possible ground wire and none was actually installed. A large number of factors brought about this change in the design:

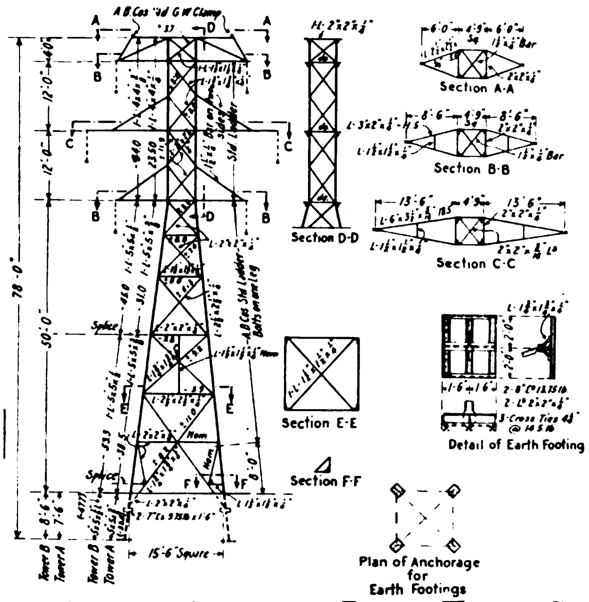

FIG. 1—STRAIGHT SUSPENSION TOWER—WINDSOR-CANTON LINE (1916)

1. In the first place, transmission line construction costs increased greatly between 1917 and 1922. The increase was not only brought about by the increased cost of materials and the higher cost of labor, but also by the increasing cost of right of way. A definite conviction had come about that lines were costing too much and that an attempt should be made to lower the cost, and the most logical and natural suggestion was the lengthening of the average span, making possible, of course, fewer points of anchorage along the right of way, fewer points of suspension and less steel in towers, etc.

2. It seemed logical to conclude that a line with fewer points of support, that is a line with fewer insulators in it, would be better electrically.

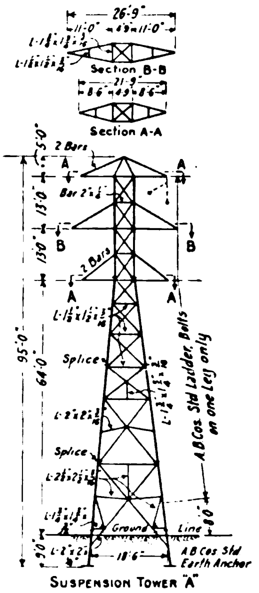

FIG. 2—STRAIGHT SUSPENSION AND SMALL ANGLE (FIVE DEG.) TOWER

Philo-Canton, Philo-Crooksville, Fostoria-Lima, Twin Branch-Lima: Lines (1923-1925)

3. By lengthening the spans, it was possible to take full advantage of the additional mechanical strength obtainable in a steel-reinforced aluminum cable which, from a conductivity standpoint, it was possible to purchase on a cheaper basis at the time these lines were built than straight copper.

4. The experience that had been obtained both in the operation of the Windsor-Canton line and in the operation of a large number of 66,000-volt lines, some of which had been equipped with ground wires and others of which were not, as well as the correlation of similar operating experience of other engineers over that same section of the country, seemed definitely to indicate that the ground wire was doing more harm

than good on the lines about which anything was known, on operating voltages up to and including 132,000 volts. Definite examples extending over years were cited by the operating people to show that removal of the ground wire over sections of line where such ground wire had been giving trouble due to the ground conductor getting entangled in the main conductors under storm conditions or to breakage in other ways, had materially improved system operation and caused in no case any increased trouble. In fact, there did not seem to be any cases of trouble that could definitely be ascribed to the omission of such ground wires. In short, operating experience, although perhaps not properly evaluated, seemed to show that the ground wire was doing more harm than good and that an improvement in operation could be obtained by its omission. It was known, of course, that where the ground wire had given trouble it was brought about by mechanical weakness and that it was possible to install a ground wire free from such trouble, but when the expense of this was taken into consideration and balanced against the then existing experience, it did not seem worth while to make this additional expenditure.

The Philo-Canton and Philo-Crooksville lines were put into service in September, 1924, the Fostoria-Lima line was put into service August 1924, and the Twin Branch-Lima line was put into service September 1925, all of them being put into operation initially at the rated voltage, that is 132,000 volts, with the exception of the Fostoria-Lima line, which was operated at 66,000 volts until September 1925 when it was cut over to 132,000 volts. Very little trouble was experienced with the Philo-Canton line during 1924 although definite records are not available. It is believed, however, there were actually no flashovers. The history of this line during 1925 is shown in the tabulation under Table I which gives in as complete detail as was possible to obtain, 88 cases of trouble on the line. The experience falls naturally into four groups:

1. The group covered by cases 1 to 15 inclusive
2. The group covered by cases 16 to 35 inclusive
3. The group covered by cases 36 to 68 inclusive
4. The group covered by cases 69 to 88 inclusive

Analysis of the Four Groups

An examination of the first 15 cases of trouble shows that all but one case of trouble were exclusively in the top conductor. In 11 of the 15 cases one or more insulators were shattered and in 13 of the 15 cases considerable damage was done to the conductor. The question of the arcing and the points between which the arc took place has never been definitely cleared up although the table attempts to show how this actually happened. A check-up on this information, however, disclosed that the field inspectors in many cases were able to get no definite evidence and in a good many cases guessed as to what happened, very often not guessing correctly. However, the information was the best obtainable and has been allowed to stand for whatever light it may throw on the situation. It is perhaps pertinent to point out that the question of field information in all these cases is generally the most difficult question to take care of and is one of the reasons, perhaps, why so much loose thinking has been done on the subject.

The second group, covering cases 16 to 35, embodies experience on the same line with the so-called flux control units. The theory underlying it has been set forth by Mr. A. O. Austin in a group of papers which are given in the bibliography. The underlying idea is that an insulator placed at the end of the horn and mounted below the insulator string will give a screen effect and will prevent the formation of so-called streamers on the conductor and subsequent ionization and eventual breakdown of the air surrounding the insulator. Regardless of the apparent weakness of the theory, it was nevertheless decided to give this system a trial in view of the fact that information (and this information again had to be obtained in a hurry with no chance for proper investigation or check-up) given by other operating companies having systems of the same voltage was very emphatic in the statement that the application of this system had resulted in an almost complete elimination of the flashovers on their systems. It therefore seemed advisable, while the lightning season was on and in view of the fact that this equipment could be installed in very quick time, to give it a trial and find out exactly what it was worth. Consequently the two top conductors of the Philo-Canton

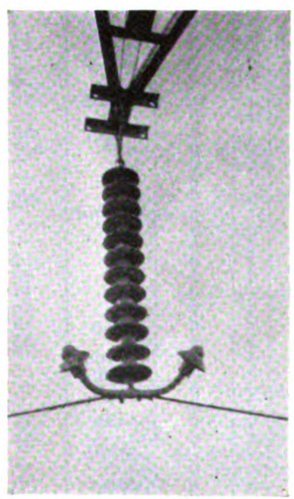

Fig. 3—Installation of "Flux-Control" on Philo-Canton Line

The change to 12 units was a later change, the original installation consisting of 9 units

line were equipped with these controls, one of the 10 units being removed to allow its installation without lessening the ground clearance. A typical view of such an installation is shown in Fig. 3. It shows,

TABLE I
REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Pole or Tower No.	Type	Circuit No.	Angle & degree	Type insul. assem.	Units in string	Cross arm ext.	Ground wire	Top, middle or bottom conductors	Arcing protection	Damage to insulator
1	134	C	1	R-29	Strain	12	No.	No.	Top	2 horns	East string flashed—4 units shattered
2	133	A	1	0	Susp.	10	"	"	"	None	Three top units shattered
3	133	A	2	0	"	10	"	"	"	"	Entire string flashed
4	211	B	1	0	"	10	"	"	"	"	None
5	176	B	1	0	"	10	"	"	"	"	Entire string flashed top & bot. units shattered
6	130	B	2	0	"	10	"	"	"	"	Entire string flashed two top units shattered
7	230	B	1	0	"	10	"	"	"	"	Entire string flashed top unit shattered
8	230	B	2	0	"	10	"	"	Top & mid.	"	
9	227	A	1	0	"	10	"	"	Top	"	Entire string flashed top unit shattered
10	230	B	1	0	"	10	"	"	Mid.	"	Entire string flashed top unit shattered
11	202	A	1	0	"	10	"	"	Top	"	Entire string flashed two top units shattered
12	203	A	2	0	"	10	"	"	"	"	Entire string shattered
13	234	B	2	R-7	"	10	"	"	"	"	Entire string flashed none shattered
14	152	C	1	0	Strain	12	"	"	"	2 horns	None
15	152	C	2	0	"	12	"	"	"	"	
16	126	B	2	0	Susp.	9	"	"	"	Flux con.	Two insulators shattered
17	125	A	1	0	"	9	"	"	"	"	Top insulator flashed
18	125	A	2	0	"	9	"	"	"		Top insulator flashed
19	85	C	2	L-15	Strain	12	"	"	"	None	Two units shattered on Philo side
20	100	A	2	0	Susp.	9	"	"	"	Flux con.	Entire string flashed—two top units shattered
21	167	B	2	0	"	9	"	"	"	"	Two top units shattered
22	167	B	1	0	"	9	"	"	"	"	None
23	176	B	2	0	"	9	"	"	"	"	Entire string flashed—two top units shattered
24	194	B	2	0	"	9	"	"	"	"	Top unit shattered
25	201	C	2	L-30	Strain	12	"	"	"	None	Two units shattered on Philo side
26	202	A	1	0	Susp.	9	"	"	"	Flux con.	Entire string flashed—2 top units shattered
27	203	A	1	0	"	9	"	"	"	"	Entire string flashed—1 top unit shattered
28	207	C	2	R-14	Strain	12	"	"	"	None	5 units shattered on inside string
29	209	B	2	0	Susp.	9	"	"	"	Flux con.	Entire string flashed—2 top units shattered
30	211	B	1	0	"	9	"		"	"	Two top units flashed
31	206	C	1	0	Strain	12	"		"	None	One string of insulators burned into
32	206	C	2	0	"	12	"		"		Several insulators flashed
33	50	A	2	0	Susp.	9	"		"	Flux con.	Entire string flashed—2 top units shattered
34	49	A	2	0	"	9	"		"		2 top & 2 bot. units shattered
35	66	A	2	0	"	9	"		"	None	Entire string flashed—3 units broken
36	249	B	2	0	"	9	"		"	Flux con.	Entire string flashed—top unit shattered
37	271	B	1	0	"	9	"		"	"	Entire string flashed—2 top units shattered
38	150	A	2	0	"	9	"		"	"	Top unit flashed
39	223	B	2	0	D-susp.	. .	"		"	"	Bot. unit broken—top unit flashed
40	271	B	1	0	Susp.	9	"		"	"	Entire string flashed—2 top units broken
41	249	B	1	0	"	9	"		"	"	Entire string flashed—2 top units broken
42	197	B	2	0	"	9	"		"	"	Top unit shattered
43	88	A	2	0	"	9	"		"	"	Top unit shattered
44	69	B	2	0	"	9	"		"	"	Top unit burned
45	40	A	2	0	"	9	"		"	"	Entire string flashed—3 top units broken
46	NSS	SS	1	. .	Switch	9	"				. .
47	NSS	SS	1	. .	Bus		"		. .		. .
48	110	B	1	0	Susp.	9	"		Top	Flux con.	Entire string flashed—3 top units broken
49	237	C	2	0	Strain	12	"		Mid.	Arcing horns	1 string burned off—all but 3 units burned
50	272	B	2	L-1-38	Susp.		"		Top	Flux con.	2 top units broken—3 units flashed
51	167	B	2	0	"	9	"		"	"	Top unit broken
52	19	B	1	0	"	9	"		..	..	Entire string flashed—top unit broken
52	19	B	1	0	"	9	"		Mid.	None	Entire string flashed—top unit broken
52	19	B	1	0	"	9	"		Bot.	"	Entire string flashed—top unit broken
53	19	B	2	0	"	9	"		Top	Flux con.	Entire string flashed—2 top units broken
54	19	B	2	0	"	9	"		Mid.	None	Entire string flashed—top unit broken
55	153	A	1	0	"	9	"		Top	Flux con.	Entire string flashed—4 bot. units broken
56	210	B	2	0	"	9	"	No	"	"	2 top units flashed
57	166	C	1	0	D-susp.	9		"	"	"	2 top units broken
58	172	C	2	0	Strain	12	No	"	"	None	None
59	212	C	2	0	Strain	12	No	No	Top	None	2 units broken—1 flashed—both strings
60	NSS	Sub	1		Pillar	3		"	Top No. 1	"	
61	57	A	2	0	Susp.	9	No	"	Top	Flux con.	1 unit broken
62	270	C	1	0	Strain	12	"	"	"	None	None
63	200	C	1	0	"	12	"	"	"	"	1 unit broken
64	260	A	1	0	Susp.	10	"	"	Mid.	"	Top unit broken—3 units flashed
65	260	A	2	0	"	"	"	"	"	"	Top unit flashed
66	262	B	1	0	"	"	"	"	Bot.	"	2 units broken
67	262	B	1	0	"	"	"	"	Mid.	"	4 units broken
68	262	B	2	0	"	"	"	"	"	"	2 units broken
69	46	B	2	0	"	"	"	"	"	"	Entire string flashed—top & bot. units broken
70	132	A	2	0	"	"	"	"	"	"	Entire string flashed
71	132	A	2	0	"	"	"	"	Bot.	"	Entire string flashed top & bot. units broken
72	132	A	1	0	"	12	Yes	"	Top	Flux con.	Entire string flashed
73	132	A	1	0	"	10	No	"	Mid.	None	Entire string flashed—top unit broken
74	93	B	1	0	"	12	Yes	"	Top	Flux con.	4 top units broken
75	93	B	1	0	"	10	No	"	Mid.	None	Entire string flashed—top & bot. units broken
76	93	B	2	0	Susp.	10	No	No	Mid.	None	Entire string flashed—top unit broken
77	93	B	2	0	"	12	Yes	"	Top	Rings & horns	None
78	199	C	1	0	Strain	"	No	"	"	"	Entire string flashed—5 units broken
79	229	B	1	0	Susp.	"	Yes	"	"	Flux con.	6 units flashed
80	229	B	2	0	"	"	"	"	"	Rings & horns	Entire string flashed
81	230	B	2	0	"	"	"	"	"	Flux con.	Top unit broken
82	262	B	2	0	Susp.	12	Yes	No	Top	Flux con.	2 top units broken
83	276	A	2	0		12	Yes	No	Top	Flux con.	Entire string flashed—2 units broken
84	207	C	2	R-15	Strain	"	No	"	"	Ring & horn	1 unit broken—4 units flashed
85	151	C	2	0	"	"	"	"	"	"	None
86	232	B	2	0	Susp.	"	Yes	"	"	Flux con.	None
87	234	B	1	R-7	"	"	No	"	Bot.	None	Bot. unit broken
88	275	B	2	0	"	"	Yes	"	Top	Ring & horn	Entire string flashed—1 unit shattered

however, 12 units in the string, this being a change which will be discussed later. The original installation, however, went in with nine disk units.

An examination of cases 16 to 35 shows that the installation of these controls in no way minimized the trouble nor was there any change in shifting of the trouble from the top conductor to the other two conductors; in other words, all cases of trouble in this group were exclusively in the top conductor. The one marked change was that the shattering of the insulators seemed to be confined more closely to the two top units, the control assembly acting apparently as a not overwell designed horn and as such being subject to considerable burning of its own. This is shown in

TABLE I Continued
REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Damage to arcing protection	Damage to conductor	Power arcover string	Arc			
				From	To	From	To
	¼" burned off ends both arcing horns	None	Yes	Horn	Horn	..	
1	....	Pitted aluminum over wide stretch	“	Cond.	Brace	..	Cage
2	....	Cond. badly burned—4 str. steel holding	“	“	“	..	“
3	....	Badly burned 25′ north of clamp 3 str. stl. Holding	No	“	“	..	“
4	....	None	Yes	Clamp	Top cap	..	
5	....	Badly pitted 45′ toward Canton	“	Cond.	“	..	
6	....	Outer layer A1 burned toward Philo 12′	“	“	Cage	..	Top cap
7	....	Outer layer A1 burned toward Philo 12′	No	“	“	..	Brace
8	....	3 strands A1 burned 3" from clamp	Yes	“	Top cap	..	
9	....	Outer layer A1 burned 12′ toward Philo	“	Cond.	“	..	
10	....	Alum. burned thru stl. core not dam.	“	“	“	..	
11	....	Top layer alum. burned 5′ toward Philo	“	“	Cage	..	Top arm
12	....	Top layer alum. burned 5′ toward Philo	“	“	Top arm	..	
13	None	Cond. badly burned in loop	No	Loop	Cage	..	Top arm
14		Cond. badly burned in loop	“	“	“	..	“
15	Flux control insul. broken—arm burned	Aluminum burned thru	Yes	Fluxcont.horn	Top	..	
16	....	Conductor pitted	“	Cond.	Cage	..	
17	....	Conductor pitted	“	“	“	..	
18	....	None	“	“	Top arm	..	
19	1 flux control unit shattered hole burned in arm	Cond. damaged 25′ toward Philo	“	“	Cage	..	Top arm
20	1 flux control unit shattered	None	“	F C A	Top cap	..	
21	....	Cond. damaged 7′ toward Philo	No	Cond.	Cage	..	
22	....	Cond. damaged 6′ toward Canton	Yes	“	Top	..	
23	1 flux control unit burned	Cond. damaged 30′ toward Canton	“	Flux cont. arc	Top cap	..	
24	....	Cond. badly burned in loop	“	Loop	“	..	
25	Flux control arm pitted	Cond. badly burned 15′ toward Canton	“	Cond.	Cage	..	Top arm
26	1 flux control unit damaged	None	“	flux cont. arm	“	..	
27		Cond. badly burned in loop	“	Cond.	Top arm	..	
28	1 flux control unit & arm burned	Cond. burned both sides of clamp	“	F C A	Cage	..	Top arm
29	1 flux control unit broken	Cond. damaged 25′ toward Canton	“	“	Top	..	
30	....	Cond. badly burned in loop	“	Loop	Top cap	..	Top arm
31	....	Cond. badly burned in loop	“	“	Top arm	..	
32	1 flux control unit shattered	Cond. damaged 20′ toward Philo	“	Cond.	“	..	
33	1 flux control unit shattered arm burned	Cond. damaged 10′ on Canton & 4′ on Philo side	“	F C A	Cage	..	Top arm
34	....	Cond. pitted 10′ toward Canton	“	Cond.	Top arm	..	
35	1 flux control unit shattered—arm burned	Cond. burned 2′ from clamp	“	F C A	Cage	Cond.	Top cap
36	1 flux control unit shattered	Cond. burned 10′ toward Philo	“	Clamp		..	“
37	1 flux control unit shattered—arm burned	None	“	C C A	Cage	Cond.	“
38	1 flux control unit shattered end of arm	None	“	“	“	..	“
39	1 flux control unit shattered hole burned in arm	Cond. damaged both sides	“	“	“	Cond.	“
40	1 flux control unit shattered	Cond. damaged 2′ toward Philo	“	“	“	“	“
41	1 flux control unit shattered	None	“	“	..	..	“
42	1 flux control unit shattered hole burned in arm	None	“	“	..	..	“
43	1 flux control unit flashed	None	“	“	Cage	..	“
44	1 flux control unit shattered arm burned off	Cond. damaged 10′ toward Philo	“			..	“
45	....	....		?	?	?	?
46	....	....					
47	1 flux control unit shattered arm burned	Cond. burned 15′ toward Canton	Yes	F C A	brace & cage	Cond.	Top & cap
48	Arcing horn tower end 1" burned off	Cond. slightly pitted in loop	Yes	Horn	Horn	..	Tower cap
49	None	Cond. slightly pitted	“	Clamp		Cond.	Top cap
50		Cond. badly burned on Philo side	“	Cond.	Cage	..	“
51	Flux control unit flashed—arm burned	Cond. pitted 328′ toward Philo	“	“	..	..	“
52	....	Cond. pitted 320′ toward Philo	“	“	..	..	“
52	....	Cond. pitted 175′ toward Philo	“	“	..	..	“
52	None	Cond. burned 2′ toward Philo	“	“	..	..	“
53	....	Cond. burned 2′ toward Philo	“	“	..	..	“
54	Flux control arm burned off	Cond. damaged 10′ toward Canton	“	F C A	Cage	Cond.	“
55	Flux control unit burned	Cond. damaged 5′ toward Philo	“	Cond.	Top cap		Hanger
56	Flux control unit shattered	None	“	F C A	Top arm		Top cap
57	....	Loop badly burned	No	Loop	Cage		Top arm
58	....	Loop burned	Yes	Clamp	Tower yoke		Tower cap
59			Yes	Blade contact	Ground Steel		
60	None	Cond. burned toward Canton	No				
61	....	Loop and 10′ of cond. toward Philo dam	Yes	Cond.	Midarm Brace		
62	....	None	“				
63	....	Cond. burned both sides of clamp	Yes	Cond.	Top cap		
64	....	None		Not determined			
65	....	Cond. burned 20′ toward Canton	“	Cond.	Top cap		
66	....	Cond. burned 20′ toward Canton	“	“	“		
67	....	Cond. burned 20′ toward Canton	Yes	“	“		
68	....	None	“				
69	....	Cond. burned 15′ toward Philo	“	Cond.	Top cap		Bot. top Phase
70	....	Cond. burned 15′ toward Philo	“	“	“		Mid. phase
71	None	None	“	“	“		
72	....	None	“	“	“		
73	None	None	“				
74	....	None	“	Clamp	Top cap		
75							
76	....	Cond. damaged 15′ toward Philo	“	Cond.	Top cap		
77	....	Cond. damaged 15′ toward Philo	“	Mid. cond.	Top cond.		
78	Ring marked—3"	None	“	Ring	Top caps		
79	None	Cond. damaged 40′ toward Philo	“	Cond.	Top arm		
80	None	Cond. damaged 15′ toward Philo	“	Ring	Horn		
81	None	Cond. damaged 30′ toward Philo	“	Cond.	Top cap		
82	....	Cond. damaged 3′ toward Canton—6′ toward Philo	Yes	Cond.	Top cap		
83	2 flux control units broken	Cond. dam 2′ toward Philo	Yes	F C arm	Top arm		
84	None	Loop & cond. toward Canton pitted	No	Loop	Top cap		
85	None	Cond. pitted in loop	“	“	Top arm		
86	1 flux control unit broken	None	“				
87	....	Cond. slightly damaged	Yes				
88	None	Cond. burned 5′ toward Philo	“	Ring	Horn		

Figs. 4 and 5, which are quite typical as to what happened to some of the horns after flashover.

The next group, which covers cases 36 to 68, covers a period during which a new series of changes was made on the line in an attempt to see whether, without resorting to a ground wire, flashover could not be prevented or reduced to a point where its effect would be harmless or practically so. In view of the fact that the

TABLE I Continued
REPORT ON INSULATOR FLASHOVERS, PHILO-CANTON LINE, 1925

Case No.	Date of failure	How trouble was located	Line opened automatic or manuel	No. times line opened	Line out at (time)	Line in at (time)	Did line open at both ends	Means taken to correct	Weather Conditions
1	3–26	Call by employee	Auto.	1	5:48 P M	5:51 P M	Yes	Remove arc horns	Rain & Lightning
2	3–26	Call by employee	"	1	5:52 P M	5:53 P M	"	Flux control	" "
3	3–26	Call by employee	"	1	"	"	"	Flux control	" "
4	4–2	Call by farmer	"	1	6:00 P M	6:33 P M	"	Flux control	" "
5	4–16	Normal patrol	..	0	..	..	..	Flux control	" "
6	4–19	Normal patrol	Auto.	1	11:28 A M	11:29 A M	Yes	Flux control	Rain, Light, Wind
7	4–25	Normal patrol	"	1	8-22 P M	8:31 P M	Canton	Flux control	Rain & Lightning
8	4–25	Normal patrol	"	1	"	8:30 P M	"	Flux control	"
9	4–25	Normal patrol	"					Flux control	"
10	4–25	Normal patrol	"					Flux control	"
11	4–25	Special patrol	"					Flux control	"
12	4–25	Normal patrol	"	1	8:24 P M	8:30 P M	Philo	Flux control	"
13	?	Normal patrol	"					Flux control	"
14	5–16	Call by employee	"	1	9:28 P M	9:23 P M	Canton	Remove arc horns	"
15	5–16	Call by employee	"	1	"	"	Yes	Remove arc horns	"
16	5–16	Normal patrol	"	1	7:45 P M	7:47 P M	"	Flux control	"
17	?	Call by employee	"	1	9:26 P M	9:28 P M	"	Flux control	"
18	?	Call by employee	"					Flux control	"
19	5–21	Special patrol	"	2	3:52 P M	3:55 P M	Yes	Remove arc horns	"
20	5–23	Call by employee	"	1	9:26 P M	9:27 P M	"	Flux control	"
21	5–21	Normal patrol	"	1	3:52 P M	3:53 P M	"	Flux control	"
22	5–21	Normal patrol	"					Flux control	"
23	5–21	Normal patrol	"	1	3:54 P M	3:55 P M	Yes	Flux control	"
24	5–23	Normal patrol	"	1	9:26 P M	9:27 P M	"	Flux control	"
25	5–23	Normal patrol	"	1	10:25 P M	10:26 P M	"	Remove arc horns	"
26	5–21	Normal patrol	"	1	10:43 P M	10:44 P M	"	Flux control	"
27	5–21	Call by employee	Auto.(#2)	1	10:51 P M	10:52 P M	"	Flux control	"
28	6–6	Normal patrol	Auto.(#2)	1	12:02 P	12:04 P	"	Remove arc horns	"
29	6–6	Normal patrol	Auto.(#1)	1	12:04 P	12:05 P	"	Flux control	"
30	?	Normal patrol	Auto.(#1)	1	12:04 P	12.06 P	"	Flux control	"
31	6–6	Normal patrol	Auto(#1,2)	1	12:06 P	12:08 P#2	"	Remove arc horns	"
32	?	Normal patrol	Auto.(#2)	1	132 P	1:33 P	"	Remove arc horns	"
33	6–6	Normal patrol	Auto.(#2)	1	158 P	1:59 P	"	Flux control	"
34	?	Normal patrol	Auto.(#2)	1	2:04 P	2:05 P	"	Flux control	"
35	3–26	Normal patrol	Auto(#1,2)	4			"	Flux control	"
36	6–24	Normal patrol	Auto.	1	11:30 P M	11:32 P M	"	Add units X-arm ext. R.& H.	"
37	7–2	Normal patrol	"	2	10:29 A M	10:31 A M	"	Add units X-arm ext. R.& H.	"
38	6–27	Call by employee	"	1	3:12 P M	3:13 P M	"	Add units X-arm ext. R.& H.	"
39	"	Normal patrol	"	1	"	"	"	Add units X-arm ext. R.& H.	"
40	7–2	Normal patrol	"	2	10:29 A M	10:31 A M	"	Add units X-arm ext. R.& H.	"
41	"	Normal patrol	"	2	"	"	"	Add units X-arm Flux control	"
42	7–7	Normal patrol	"	1	2:47 P M	2:48 P M	"	Add units X-arm R. & H.	"
43	"	Normal patrol	"	1	2:52 P M	2:53 P M	"	Add units X-arm flux control	"
44	"	Normal patrol	"	1	2:54 P M	2:55 P M	"	Add units X-arm R. & H.	"
45	7–4	Normal patrol	"	4	4:10 P M	4:12 P M	"	Add units X-arm flux control	"
46	7-6 to 11	Redman	..	..	..	..	..	..	"
47	7-6 to 11		..	..	..	..	..	..	"
48	7–2	Normal patrol	Auto.	2	10:29 A M	10:31 A M	Yes	Add units X-arm ext. R.&H.	"
49	7–10	Report by Hare	"	1	3:36 A M	3:37 A M	"	None	"
50	7–10	Report by Hare	"	1	3:52 A M	3:53 A M	"	Add units X-arm ext. R.& H.	"
51	7–10	Normal patrol	"	2	4:02 A M	4:03 A M	"	Add units X-arm flux control	"
52	7–10	Normal patrol	Manuel	1	8:00 A M	8:04 A M	Philo	Add units X-arm flux control	"
52	7–10	Normal patrol	"	1			"	None	"
52	7–10	Normal patrol	"	1			"		"
53	7–10	Normal patrol	Auto.	1	8:00 A M	8:03 A M	Yes	Add units X-arm ext. R.& H.	"
54	7–10	Normal patrol	"	1	"	"	"	None	"
55	7–25	Call employee	"	1	9:19 P M	7:20 P M	Philo	Add units X-arm ext. R.& H.	"
56	7–16	Normal patrol	"	1	1:04 P M	1:05 P M	Yes	Add units extend arm	"
57	7–25	Call E*	"	1	7:19 P M	7:20 P M	Philo	Add units extend arm	"
58	7–7	Normal patrol	"	1	2:54 P M	2:55 P M	Yes	Extend arm	"
59	7-16-25	Normal patrol	Auto	1	12:34 P M	12:35 P M	Yes		"
60	7–25	Call E*	"	1	7:10 P M	7:20 P M	Philo		"
61	7-16-25	Call E*	"	1	1:04 P M	1:05 P M	Yes	R.& H.* Add units extend arm	"
62	7-25-25	Call E* Hare	"	1	7:19 P M	7:20 P M	Philo	R.& H*	"
63	8–5	Call E* Hare	"	1	10:53 P M	10:55 P M	Yes	R.& H.*	"
64	"	Call E*	"	1	"	"	"	None to date	"
65	"	Call E*	"	1	"	11:01 P M	"	None to date	"
66	?	Call E*	Probably ca	used from				None to date	"
67	?	Call E*	Trouble of	8-5-25				None to date	"
68	8–10	Call E*	Auto	2	3:31 P M	7:43 P M	Canton	None to date	"
69	8–18	Special patrol	"	1	10:10 P M	10:11 P M	"	9-1-25 add 2-units	"
70	"	Special patrol	"	1	"	"	"	9-1-25 add 2-units	"
71	"	Special patrol	"	1	"	"	"	None to date	"
72	8–12	Special patrol	"	1	11:05 P M	11:06 P M	Yes	9-1-25 add 2 units to mid. cond.	"
73	"	Special patrol	"	1	"	"	"	9-1-25 add 2 units to mid. cond.	"
74	9–3	Call E* Sowell	"	1	4:03 A M	4:05 A M	Canton only	9-1-25 add 2 units to mid. cond.	"
75	"	Call E* Sowell	"	2	4:07 A M	4:46 A M	Yes	9-1-25 add 2 units to mid. cond.	"
76	9–3	Special patrol	Auto.	7	4:03 A M		Yes	9-1-25 add 2 units to mid. cond.	"
77	"	Special patrol	"	7		5:11 A M	"		"
78	"	Special patrol	"						"
79	"	Special patrol	"	Caused by	trouble				"
80	"	Special patrol	"	of	9–3				"
81	"	Special patrol	"						"
82	9–3	Special patrol	Auto.						"
83		Normal patrol							Unknown
84		Call E*							"
85		Normal patrol							"
86		Normal patrol							"
87		Normal patrol							"
88		Normal patrol							"

so-called flux control unit very definitely did not seem to do what the sponsors claimed it would do, it was decided to test out three other changes and these consisted of the following:

1. The top-arm was extended two and one-half feet in each direction, making it the same length as the middle arm and the hanger of the middle arm was lowered approximately 2 ft., 10 in. on the cage. This is shown in Fig. 6. This made it possible to increase the insulation on the top arm, where the trouble again seemed to be centered, from the original 10 units to 12 units, and this change was made on the entire line. This, of course, was based on the theory that the lightning voltages were not very much in excess of the flash-

over voltage of the top string and it was thought possible that the installation of two additional units would raise the flashover of the string to such a point that the

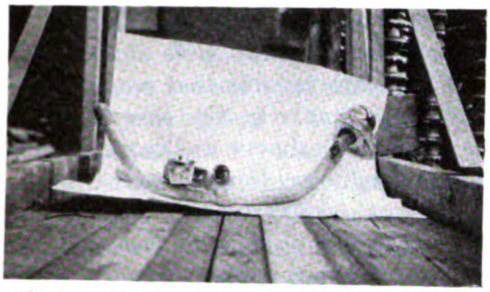

FIG. 4—TYPICAL BURNING OF "FLUX-CONTROL" HORNS AND INSULATORS PHILO-CANTON LINE (1925)

induced voltage would not exceed the flashover voltage of the string in at least, say, 90 per cent of the cases.

2. The moving out of the point of attachment of the top string of insulators resulted in a greater clearance between it and the second arm hanger. The object of this, of course, was to increase the flashover distance to the surrounding structure.

3. In addition to these changes which were carried through not only on the Philo-Canton line, but also on the Philo-Crooksville, Fostoria-Lima, and Lima-Twin Branch lines, there was installed on the Philo-Canton line the following equipment:

An 18 in. times 22 in. cast-iron arcing ring was em-

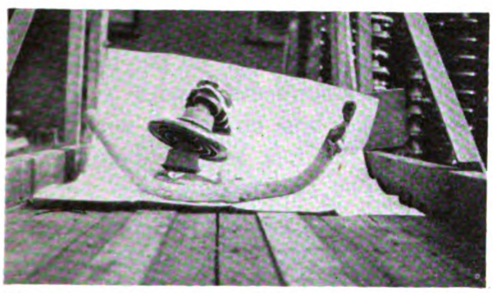

FIG. 5—TYPICAL BURNING OF "FLUX-CONTROL" HORNS AND INSULATORS PHILO-CANTON LINE (1925)

ployed on the lower end of the upper string and a 24-in. arcing horn mounted parallel to the conductor. This assembly was used on only one side of each tower and the flux control assembly was maintained on the opposite side, alternating the position of the two on successive towers so that for each circuit there were installed an equal number of arcing rings and "flux controls." There was no change made in the flux control assembly from what was originally employed with the exception of the fact that three-insulator units were added (making 12 in all); also where any damage had been done to the assembly the damage was repaired.

Fig. 7 shows a straight-arcing ring and horn-suspension assembly, and Fig. 8 is a drawing of this same assembly.

In the case of dead-end assembly a 33-in. diameter-pipe ring with a double horn was employed; Fig. 9 is a photographic view of such an assembly after the flashover described under case No. 78.

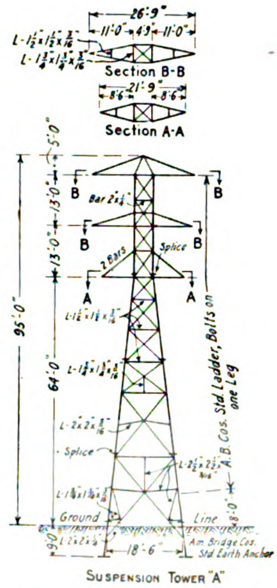

FIG. 6—CHANGES MADE IN UPPER AND MIDDLE ARMS PHILO-CANTON LINE (1925) TO OBTAIN LARGER CLEARANCE

While the troubles listed under cases 36 to 68 were taking place, the changes enumerated above were being made all at the same time, the changes being made on only one circuit at a time during the daytime and the circuit being put back into service at night. It will

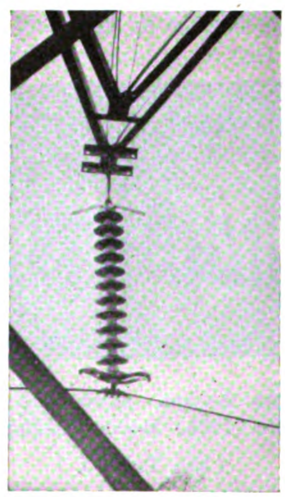

FIG. 7—ARCING RING AND HORN ASSEMBLY, PHILO-CANTON LINE (1925)

be noticed that in 24 of the 33 cases, the trouble was again on the top conductor and that in all but five of the cases the flux control was employed. In general the type of damage was the same as that in group two, consisting of considerable damage to the string, to the conductor, and to the flux control unit. Where no

arcing protection of any kind was employed, that is on the middle and bottom conductors, the damage in some cases was more severe and in other cases less than in the two upper conductors. It is to be noted that among this group, while there were some units in service with the arcing ring protection, there were no cases where any damage was sustained to units with such protection.

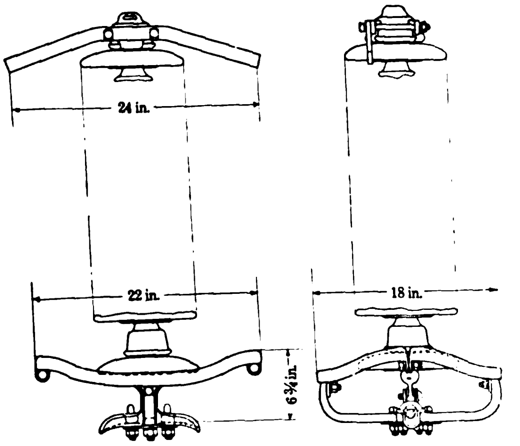

FIG. 8—ARCING RING AND HORN ASSEMBLY FOR SUSPENSION TOWER PHILO-CANTON LINE (1925)

The last group, namely cases 69 to 88 inclusive, extended over a period of time of well over two months and during the course of this period no changes of any kind except those described previously, were made. It will be seen that of the 20 cases, 13 occurred on the top conductor, five on the middle conductor, and two on the bottom conductor. Of the 13 top-conductor failures, seven were cases in which flux control had been employed and six in which rings and horns had been employed, but with this difference: in five of the seven cases employing flux control one or more insulator units were shattered, but only in three of the six cases employing rings and horns were any insulators damaged. Again, while in four of the seven flux-control cases there was damage done to the conductor, and in the case of the rings and horn combination three of the six cases resulted in damage of conductor, the extent of the damage in the case of the horn combination seems to have been less than in the case where the flux control has been employed.

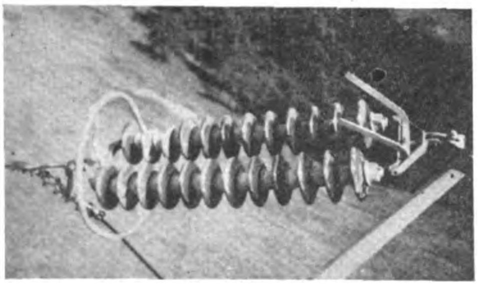

FIG. 9—DEAD END ARCING RING AND HORN ASSEMBLY PHILO-CANTON LINE (1925) AFTER FLASHOVER CASE NO. 78

(See Table I.)

The troubles encountered on the Twin Branch-Lima and the Fostoria-Lima lines were almost negligible in comparison with the trouble that was encountered on the Philo-Canton line. In the case of the Fostoria-Lima line only one flashover was experienced and that was on a top conductor during a period when the line was operated at 66,000 volts. The conductor was slightly damaged but no damage was sustained to the insulators. In the case of the Twin Branch-Lima line only three cases of flashovers due to lightning were experienced in 1925, two being on the top conductor and one on the middle conductor. In each of these cases at least two insulators were shattered but no damage was done to the conductor. On the Philo-Crooksville line in a period of considerably over a year, there were two cases of flashover but neither case caused trouble of serious consequence.

RELAY PROTECTION

At the beginning of 1925 the following scheme of protection was employed on the Philo-Canton line. At the Philo end current-balance relays were employed, operating only in case both lines were in circuit, and separate overload relays were employed on each of the two lines. The balance relays were operating on a so-called cross-connection and the lines were interlocked with a locking-out relay to render the second line non-automatic for a period of five sec. in case of the functioning of the switch on the first line. At the Canton end, cross-connection with a duo-directional reverse power relay was employed with fast and slow overload relays, the fast relays operating only with both lines in. The two feeders here were also interlocked with a five sec. locking-out relay. As the lines continued to be damaged some changes were made in the direction of speeding up the interlocking time and also in the direction of speeding up the relays at the Canton end. In October, there were installed at the Canton end of the line a set of current-balance relays similar to those at the Philo end but the duo-directional reverse power relay was maintained to select between the Windsor-Canton and Philo-Canton lines in case of one-line operation throughout. In general, the relays functioned entirely satisfactorily and it is not believed that the severe burning which took place was caused in any way by the failure of the relays to clear the circuits quickly enough, the relay settings being as fast as could possibly be obtained without endangering normal operation.

A MORE DETAILED ANALYSIS OF TROUBLES

While these troubles were occurring it was impossible to get any accurate data as to what was happening. Lines were flashing-over; insulators were being shattered; the conductor was being burned; and the field

forces were too busy trying to place the line in an operating condition with a minimum delay to be able to give very much attention to the details of what was happening. Things were happening so thick and fast that there was no opportunity to stop and consider the matter calmly. With the approach of the end of the lightning season a little more time could be taken to determine what had actually happened and to make an intelligent analysis.

First, toward that end, was the gathering together of data with regard to the trouble shown in the tabulation under Table I. This tabulation was very carefully gone over and a survey was made in the field to supplement, if possible ,the information given therein. In the course of this investigation it was found how very little knowledge as to what actually happened was obtainable and the smallness of the amount was really surprising. It was found, as a careful review of the troubles tabulated in Table I will show, that there existed a good deal of conflicting data and that a good many of the reports which were supposed to have been based on observation at the time the repairs were made, were entirely unreliable. However, this much stood out with bold clearness. The Philo-Canton line had been subjected to an unusual amount of punishment from lightning. That it was due to the fact that the area which it traversed was a particularly stormy area there was very little doubt. There also did not seem to be any doubt that the measures that had been taken up till then were none of them completely effective and some of them were almost negligibly so. Further, a calm review of what had been done and the lines that had been followed brought home clearly the fact that designing a line merely to withstand lightning voltages was certainly not a proper procedure since it resulted in placing insulation on the lines of such a value that it could not possibly be matched economically by that of the transformers, oil switches, and other apparatus connected to the system.

Simultaneous with the gathering of the field data a very thorough review was made of the work in connection with this subject done by Steinmetz, Creighton, Austin, Peek and others, and particularly their work in connection with the ground wire.

Viewing the troubles encountered on the Philo-Canton line, after an analysis had been made of all the available field data, and in the light of the work of the other investigators mentioned, the explanation that seemed to stand up best came down to the following:

1. The Philo-Canton line traverses an unusually stormy country and the year 1925 seems to have been an unusually severe year from the standpoint of lightning.

2. The height of the particular tower was considerably higher than any that had been previously constructed on the system and this resulted in potentials being induced in the upper two conductors during lightning higher than those that were encountered on the Windsor-Canton line by at least 300,000 to 400,000 volts.

3. The omission of the ground wire subjected the insulator strings to this full voltage and this value was sufficient often enough during 1925 to give the large number of cases of trouble that are tabulated.

4. The fact that the Twin Branch-Lima and the Fostoria-Lima lines were not subject to these flashovers can be explained by the following:

   a. The first of these two lines did not operate for a sufficiently long period during the lightning season.

   b. The Fostoria-Lima line was in for a whole year but most of the time it was operating at 66,000 volts and its performance when insulated for 132,000 volts with a follow-up voltage of 66,000 volts would, of course, be expected to be considerably different from what it would be with a follow-up voltage of 132,000 volts.

   c. From general observations taken, it appeared indisputable that the lightning in the territory traversed by these two lines was not anywhere near the same severity as that encountered along the Philo-Canton line.

Viewed thus a satisfactory solution seemed attainable by adopting the following methods:

1. Preventive. Installation of ground wire to reduce the lightning voltages.

2. Remedial. Where, either because of the severity of the lightning or because of the great importance of the load, no *chances* could be taken, the installation of arcing rings and horn devices to clear the insulator string and the conductor in case of spill-over.

Before definitely embarking on this course, it seemed advisable to check this proposed solution and consequently a series of tests was carried out with the lightning generator of Peek to determine the effectiveness of the ground wire on the tower shown in Fig. 2. These tests showed definitely that a reduction amounting on the average to about 50 per cent in the value of the induced voltage could be obtained by the installation of one ground wire at the peak of the towers. This is shown in Fig. 10, which shows the induced potential in A, suspension, B, moderate angle, and C, dead-end towers—the height of the crossarms is the

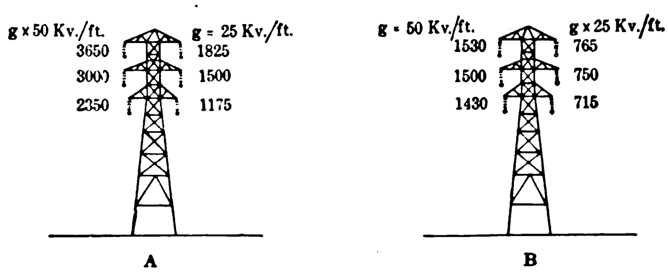

FIG. 10—GROUND WIRE TESTS ON PHILO-CANTON 132 K. W. TOWER

A. No ground wire B. With ground wire

same in each case and is shown in Fig. 2—with and without ground wires, under conditions of a potential gradient of 50-kv. per foot of height, and of 25-kv. per foot of height.

Another phase of the investigation was a series of tests in connection with the arcing rings and horns which it was thought advisable to employ on the towers traversing territory particularly susceptible to lightning. Before working out the designs, a series of tests was

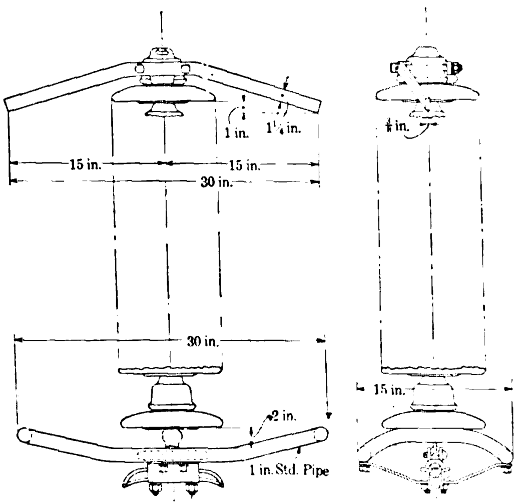

Fig. 11—Arcing Ring and Horn Assembly (1926 Installation) for Single Suspension String—Philo-Canton Line

carried out in the high-voltage engineering laboratory at Pittsfield, to determine the specific shapes and sizes of horns and rings and their placement on the string to clear a power arc from the insulator string and from the

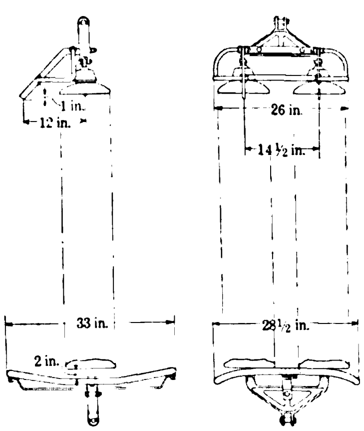

Fig. 12—Arcing Ring and Horn Assembly (1926 Installation) for Dead End String Philo-Canton Line

conductor if flashover should take place and should be followed by a power arc. The rings and horns that were worked out as well as their relations to the string and to the conductors are shown in Figs. 11 and 12 which show the designs for a straight suspension string and for a straight dead-end string. A similar design was worked out for the double suspension string.

As a result of all these studies and investigations, ground-wire installation was decided upon on all 132-kv. steel tower lines that had been erected since the beginning of the Philo-Canton line, or that were in process of erection by the end of 1925, all of which were erected without ground wire. In addition, arcing rings and horns were laid out for the Philo-Canton line and for a number of other lines where either, as in the case of Philo-Canton, it was known that lightning conditions were very bad, or where, because of the existence of but a single circuit between stations, it was imperative to keep the outage time in that circuit as near zero as possible.

Design of Ground Wire and Connections

It is conceded among engineers that the disrepute into which the ground wire had fallen was due primarily to the fact that it had been put up more or less on the basis that it was merely an appendix to the line, and since it was not carrying any energy, and therefore not earning its way, that it ought therefore to be put in with as little expense as possible; this resulted in almost every case in the installation being as poor a one as possible. The conductors employed were very seldom anything but galvanized steel wire, and that was generally of a very much smaller diameter than the main conductor and of a lesser number of strands. The attachment was generally of some clamp type; the sagging of the ground wire was given very little consideration; and all in all the thing was put in in a most non-engineering manner. As a consequence troubles of all sorts were encountered with the ground wire. Three or four years after the installation the wire as a rule would begin to rust and a short time after that breakages would crop out in various sections of the line, resulting in grounds and short circuits being placed on the system. In many cases, too, the main line would swing into the ground wire or the ground wire into the line due to their unequal sags or due to their unequal swings.

It has always been known that if a ground wire similar to the main conductor were employed and the same attention given to its installation as given to the main conductor, these troubles could be avoided, but with the exception of a very few cases the authors do not know of any installations that were put in on that basis. In view of the fact that the decision to install the ground wire was reached after considerable trouble without it, and after a conviction that the ground wire would remedy a considerable portion of this trouble, it was deemed advisable not to repeat the mistakes of handicapping the ground wire through poor installation. On the other hand, it was felt that if there were any ways that the installation could be made cheaper than that which would obtain by the use of a straight line conductor, advantage should be taken of these means. Accordingly, there was worked out in conjunction with the conductor manufacturer, a special 159,000 cir. mil. A. C. S. R. conductor con-

sisting of twelve 0.1151 in. diameter aluminum strands and seven 0.1151 in. steel strands, and this conductor was found to have mechanical characteristics so closely similar to that of either 336,400 or 397,500-cir. mil that under most conditions it could be used interchangeably with them.

More attention than is usual was given to the hardware and to the method of attachment of the ground wire.

APPLICATION OF EXPERIENCE TO TOWER LINE DESIGN

The authors believe that theoretical analysis and their experience in operation applied to tower-line design with a view particularly of designing the lines for continuous service can be summed up as follows:

1. It is essential that a balance be maintained between the height of tower, the length of span, and the lightning voltage that may be expected in the conductor span. As a general rule the cost of the line can be decreased by increasing the length of span, but carried beyond a certain point the continuity of service to be expected from the line is bound to be decreased materially in the raising of the height of the conductors. The standard suspension insulator has been developed to such a point at the present time that the increased number of points of attachment on the line will have materially less effect on lowering the continuity of service than will the raising of the height of the conductor.

2. A proper balance should be maintained between the number of insulators employed per string, the insulating values employed on other apparatus on the system, and the clearance to ground. Insulating a line sufficiently high to prevent flashover in a great majority of cases, will result as a general rule (except perhaps in certain types of lines operating at 220 kv. or higher voltages) in overinsulating the lines at the expense of the rest of the equipment and will result in failures at station and substation points.

3. Unless the line is very low, it is believed that steel-tower structures carrying power conductors of 44,000 volts and over should in general be designed and installed with a ground wire. It is fully realized that there may be locations and conditions under which this is not practicable, for example, in territory where the soil conditions are such that the ground resistance is very high, and where consequently the effectiveness of the ground conductor is minimized to an almost negligible value; but these are special cases. There may also be cases in territory that is particularly lightning-free where no ground wire would be justified. In no case, the authors believe, should the use of a ground wire be dismissed without giving full consideration to the known lightning conditions of the territory over which the line has to traverse, to the height of the tower, to the insulation proposed for the tower, and to their relations to the lightning voltages that might be expected on the power conductors.

4. If a ground wire is installed it should be accepted as an essential part of the line and its installation treated the same as that of the main conductors, full attention being given to the material of the conductor itself and to its method of attachment and stringing. There is no reason why the main power conductor should be designed for a possible 50 years of life and the ground conductor designed for a life equal to 10 per cent of that.

5. It is possible that a line will have to be built of so great a height, because of the contour of the country or for some other reason, that even with the use of a ground wire, sufficient protection will not be obtained to keep the number of flashovers down to a low enough point. In these cases, the authors believe it would be well to install remedial devices in the form of arcing rings and horns or their equivalents to prevent conductor burning and insulator shattering in case of a flashover.

6. The line must be designed so that its switching arrangement is correct; that is, the line must be so designed that it can be relayed properly and disconnected from the rest of the system quickly in case of trouble.

Acknowledgment is hereby made to Mr. F. W. Peek, Jr., and Mr. W. L. Lloyd, Jr., of the General Electric Company, and to Mr. A. O. Austin of the Ohio Brass Company for their assistance in carrying out some of the investigations, and to Mr. Frank Howard, of the Ohio Power Company, for his assistance in carrying through some of the developments and in obtaining the field data.

The complete paper gave a complete record of the relay settings on the Philo-Canton line during 1925, a discussion of the action in regard to the design of new towers taken during the period of trouble, a discussion of the research work on the subject of the ground wire done by various investigators, the results of an investigation of the relationship between the length of the insulator string and clearance of the string to ground to obtain a balance between the two, and an outline of plans for obtaining complete information on the future behavior of these lines.

NEW ELECTRIC CODE FOR MEXICO

Demand for electrical supplies in Mexico have been stimulated by the issuance of a new electric code, which raises the standard of permitted equipment. Existing installations shall be made to conform to the new code by July 11, 1926, but the Department of Industry, Commerce, and Labor is authorized to extend the period if necessary.

The code is an adaptation to Mexican conditions of codes of the United States. The National Electrical Code and the National Safety Code are drawn on extensively. A number of changes from American practises are introduced, such as longer spans between poles and more lenient wiring regulations, as there is considerable use of stone and concrete in the construction of Mexican homes.

Zero Method of Measuring Power with the Quadrant Electrometer

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Member, A. I. E. E.

and

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Student Member, A. I. E. E.

Synopsis.—*This paper describes a zero method of measuring power by means of the quadrant electrometer developed by the authors, and which we believe to be new. Zero deflection of the electrometer is obtained by opposing the torque produced by the a-c. load by means of a counter torque set up by continuous potentials introduced into the electrometer circuit. The continuous potentials required are small in value and easily handled.*

We have derived the equations that apply to the method and checked their correctness by experimental observations on resistance, capacity, and inductive circuits.

THE importance of the quadrant electrometer as an instrument for measuring the power factor and loss in dielectrics and cables is well recognized. The quadrant electrometer wattmeter has also prove valuable in measuring iron losses in small specimens.

The usual connections for using the quadrant electrometer as a wattmeter are shown in Fig. 1. In Fig. 1, N is the needle; Nos. 1 and 2 are the respective quadrant pairs which are enclosed in the case of the electrometer. The deflection of the electrometer is proportional to the vector product of the load voltage V and the voltage drop across the quadrants, 1 and 2, caused by the load current I flowing through the non-inductive resistance R_1. If it is impossible to apply full voltage to the

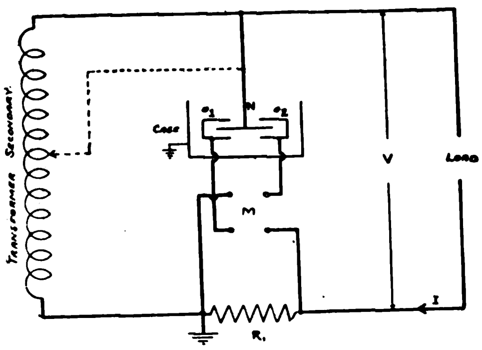

FIG. 1—QUADRANT ELECTROMETER WATTMETER

needle of the electrometer, a fractional part of the supply voltage may be applied to the needle as indicated by the dotted line in Fig. 1. Right and left deflections are taken at each load by means of the reversing switch or commutator, M, and the power consumed by the load is given by equation (1)[1].

$$I\,V\cos\varphi = \frac{1 + R\left(\frac{V}{n}\right)^2}{2\,b_1\,R_1}\,n\,(\beta - \alpha) - \frac{2-n}{2}\,I^2\,R_1 \qquad (1)$$

Where

I = Load current in amperes
V = Load voltage in volts
$\cos\varphi$ = Power factor of the load
R_1 = Value of the non-inductive resistance in ohms
n = The factor by which the voltage applied to the needle must be multiplied to give the load voltage V
α = Deflection of the electrometer with the commutator vertical
β = Deflection of the electrometer with the commutator horizontal
R = An electrometer constant called the needle constant
b_1 = An electrometer constant

The quadrant electrometer wattmeter may be used as a deflection instrument as described above, or it may be used as a zero instrument by a method developed by Simons and Brown[2]. Simons and Brown showed that the deflection may be reduced to zero by the insertion of a resistance in the needle circuit of the instrument. The insertion of the proper value of resistance enables one to bring the voltage applied to the needle in quadrature with the voltage drop across the resistance R_1 and thereby reduce the deflection to zero. The power factor of the load may then be calculated from equation (2)[2].

$$r_2\,c_2\,\omega = \cos\varphi + \frac{2-n}{2}\,\frac{I\,R_1}{V} \qquad (2)$$

Where

r_2 = The resistance inserted in the needle circuit
c_2 = The capacity of the needle circuit
f = Frequency
$\omega = 2\pi f$

and the other symbols have the same meanings as those used in equation (1).

The zero method of Simons and Brown possesses certain limitations, as pointed out by them,[3] on capacity loads of low power factor where n is large. This method is difficult to use on loads of high power factor because of the large value of resistance required for insertion in the needle circuit, and is not applicable to inductive

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1. For references see bibliography appended.

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circuits unless the needle voltage is reduced to a small fraction of the load voltage.

I. Theoretical

Zero or balance methods are in general more accurate than deflection methods, and their advantages are too well known to require discussion here. This paper describes a new zero method of measuring power and power factor with the quadrant electrometer. The method is applicable to inductive, resistance, and capacity loads and is independent of the value of the fractional part $(1/n)$ of the load voltage applied to the needle.

The zero method described here depends upon the use of continuous potentials to reduce the deflection of the electrometer to zero. A continuous potential is applied to the needle in addition to the a-c. load voltage and a second continuous potential is introduced into the quadrant circuit in addition to the drop across the resistance R_1, caused by the alternating-load current. The polarity of these two continuous potentials is arranged so that their effect opposes the deflection caused by the alternating potentials applied to the needle and quadrants respectively. The deflection is reduced to zero by adjusting the value of the continuous potentials to the proper value. The advantage of the method lies in its simplicity.

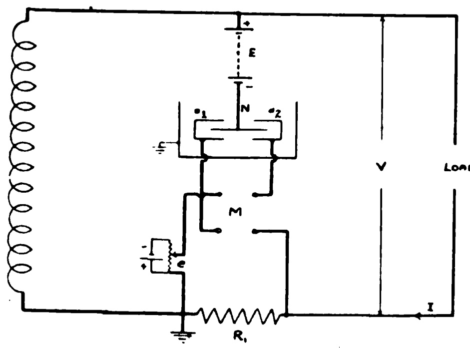

Fig. 2—Connections for Zero Method *A*

A number of arrangements of the connections for introducing the continuous potentials into the circuits of the electrometer have been investigated. Three of these arrangements, called, *A*, *B*, and *C*, respectively, are described in the paper.

Zero Method A. The diagram of connections for zero method *A* is given in Fig. 2, where E equals the continuous potential introduced into the needle circuit of the electrometer and e is the continuous potential introduced into the quadrant circuit; V and I represent the a-c. voltage and current, respectively, and R_1 is the non-inductive resistance.

Three methods of reducing the deflection caused by the a-c. load present themselves; (1) vary both E and e; (2) vary E, e constant; (3) vary e, E constant. Theoretically it makes no difference by which of these methods zero deflection is obtained, but from practical considerations it is simplest to vary e, which is on the grounded side of the instrument, keeping E in the high potential side constant. The variation in e is obtained by using a potentiometer rheostat as shown in Fig. 2.

In making a measurement, two readings are taken in order to eliminate certain electrometer constants. The operation is as follows: Assume that the commutator M is in a vertical position, and that the a-c. circuit is closed. As the instrument begins to deflect, the value of the continuous potential e is adjusted by means of the potentiometer until the deflection equals zero. The value of the potential E and of e_1 are noted. Then the commutator is placed in a horizontal position and the torque due to the a-c. power is again balanced by adjusting the continuous voltage applied to the quadrants. Let e_2 equal the value of the continuous quadrant voltage under these conditions. The experimental results show that the two values of the quadrant continuous potentials, e_1 and e_2, are very nearly equal and, in the equations, the average value e is used without introducing any appreciable error.

Before shifting the commutator from a vertical to a horizontal position, the a-c. circuit and the battery circuit of quadrant voltage, e are opened. This prevents the electrometer needle from deflecting excessively and reduces the time between readings.

Equation (3) gives the general equation of the electrometer which was derived by Kouwenhoven in a previous paper.

$$(1 + R\,V_0^2)\,\theta = -\frac{b_1}{2}V_1^2 + \frac{b_1}{2}V_2^2 + b_1 V_0 V_1 - b_1 V_0 V_2 + c_0 V_0 + c_1 (V_1 - V_2) \quad (3)$$

Here

V_0 = The instantaneous value of the voltage applied to the needle.

V_1 = The instantaneous value of the voltage applied to the quadrant pair No. 1

V_2 = The instantaneous value of the voltage applied to quadrant pair No. 2.

θ = Resulting deflection $(\alpha - \beta)$

α = Deflection with the commutator vertical

β = Deflection with the commutator horizontal

R = Needle constant of the electrometer

b_1, c_0 and c_1 = Electrometer constants

Let v equal the instantaneous value of the load voltage V, and i equal the instantaneous value of the load current I; then with the commutator vertical, we have

$$V_0 = v + i R_1 - E$$
$$V_1 = -e_1$$
$$V_2 = i R_1$$

With the commutator horizontal, the values of V_0, V_1 and V_2 are

$$V_0 = v + i R_1 - E$$
$$V_1 = i R_1$$
$$V_2 = -e_2$$

Substituting these values of V_0, V_1 and V_2 in the general electrometer equation (3) and solving, we obtain

equation (**8**), the derivation of which is given in the mathematical part of the paper.

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} - k\,.\,\frac{e}{R_1} \qquad (\mathbf{8})$$

where k is an electrometer constant with a value of $\dfrac{c_1}{b_1}$ as shown in the mathematical part of the paper.

The term, $\dfrac{I^2 R_1}{2}$, of equation (**8**) is a correction term and equals half the loss in the resistance, R_1, which is measured by the electrometer.

If the polarities of the batteries E and e are reversed with respect to those shown in Fig. 2, we find that the power consumed by the load is given by equation (**9**).

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} + k\,\frac{e}{R_1} \qquad (\mathbf{9})$$

Equations (**8**) and (**9**) involve only the single electrometer constant, k. The other electrometer constants, that must be determined if the instrument is to be used as a deflection wattmeter, are eliminated.

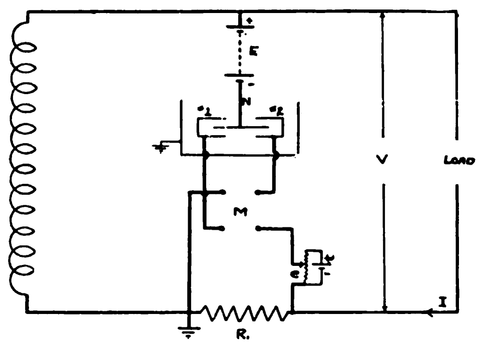

FIG. 3—CONNECTIONS FOR ZERO METHOD *B*

A study of equations (**8**) and (**9**) show that this constant k may be eliminated if we take the mean of two sets of readings. The first set being taken with the connections as shown in Fig. 2, and the second set with the batteries E and e reversed. The constant k, however, can be evaluated very easily as shown in the experimental part of the paper, and the value of the term $k\,\dfrac{e}{R_1}$ determined in each case.

Equations (**8**) and (**9**) were checked experimentally and the results are given in the experimental part of the paper.

Zero Method B. The diagram of connections for zero method B is given in Fig. 3. Two readings are taken for this connection also, in the first the commutator is vertical, and in the second horizontal. When the commutator is vertical

$$V_0 = v + i\,R_1 - E$$
$$V_1 = 0$$

and

$$V_2 = i\,R_1 + e_1$$

With the commutator horizontal, V_0 has the same value as before, but now

$$V_1 = i\,R_1 + e_2$$

and

$$V_2 = 0$$

Proceeding as in connection A, we find that the power consumed by the load is given by equation (**12**) which is derived in the mathematical part of the paper.

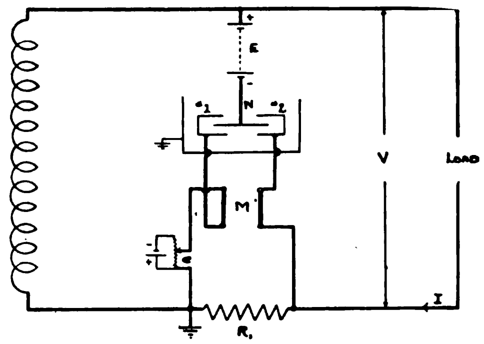

FIG. 4—CONNECTIONS FOR ZERO METHOD *C* COMMUTATOR VERTICAL

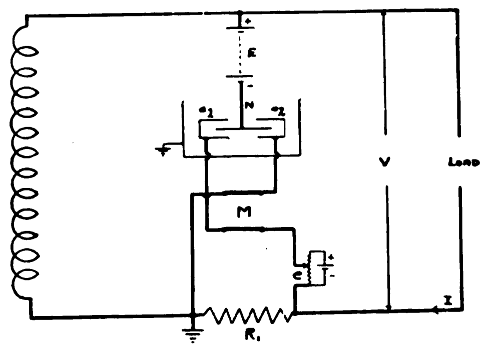

FIG. 5—CONNECTIONS FOR ZERO METHOD *C* COMMUTATOR HORIZONTAL

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e + \dfrac{e^2}{2}}{R_1} - k\,\frac{e}{R_1} \qquad (\mathbf{12})$$

Reversing the batteries E and e, we obtain

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e + \dfrac{e^2}{2}}{R_1} + k\,\frac{e}{R_1} \qquad (\mathbf{13})$$

Experimental proof of the correctness of equations (**12**) and (**13**) is given in the experimental part of the paper.

Zero Method C. The diagrams of connections for zero-method C are given in Fig. 4 and Fig. 5, in which the potentiometers for varying e are not shown.

Zero method C, as may be seen from Fig. 4 and Fig. 5,

is a combination of the two previous zero methods, A and B. A study of equations (**8**) and (**12**) shows that the $\frac{e^2}{2}$ terms are of opposite signs; therefore, this term may be eliminated from the final result by combining the two methods.

In taking a measurement the operation is as follows; with the commutator vertical and the quadrant d-c. voltage in the grounded side of the quadrant circuit,

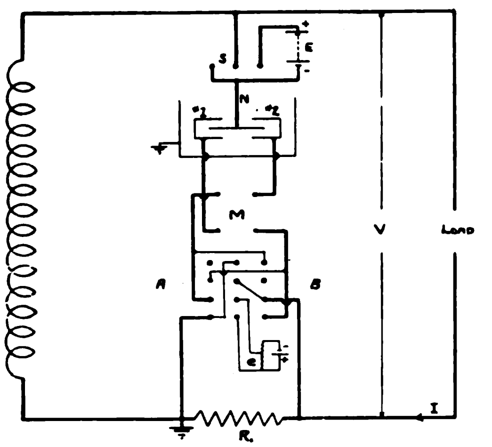

Fig. 6—Switching Arrangement for Zero Methods

as shown in Fig. 4, a balance is obtained between the torque due to the alternating and continuous voltages. Then the commutator is placed horizontally and the quadrant d-c. voltage is thrown to the high side of resistance, R_1, as shown in Fig. 5. and a balance again obtained by adjusting the quadrant continuous voltage.

With the commutator vertical as in Fig. 4, we have

$$V_0 = v + i\,R_1 - E$$
$$V_1 = -\,e$$
$$V_2 = i\,R_1$$

and for Fig. 5

$$V_0 = v + i\,R_1 - E$$
$$V_1 = i\,R_1 + e$$
$$V_2 = 0$$

Substituting these values in the general electrometer equation (**3**) and solving, we obtain (**15**) the derivation of which is given in the mathematical part of the paper

$$I\,V\cos\varphi + \frac{I^2\,R_1}{2} = \frac{E\,e}{R_1} - k\,\frac{e}{R_1} \qquad (\mathbf{15})$$

If the polarities of the two batteries E and e are reversed, we get the relation (**16**):

$$I\,V\cos\varphi + \frac{I^2\,R_1}{2} = \frac{E\,e}{R_1} + k\,\frac{e}{R_1} \qquad (\mathbf{16})$$

Test data are given in the experimental part of the paper to prove the correctness of equations (**15**) and (**16**).

The battery e may be thrown from one side to the other side of the circuit by means of two double-pole, double-throw switches, or a single, four-pole, double-throw switch, and the connections shown in Fig. 4 and Fig. 5 are combined in a single switching arrangement shown in Fig. 6. It is possible to use zero methods A, B, or C by means of the connections shown in Fig. 6.

A single-pole, double-throw switch, S, is shown in Fig. 6 in the needle circuit. This switch when thrown to the left connects the needle directly to the line and permits bringing the mechanical and electrical zeros into coincidence. When the switch S is thrown to the right the battery E is connected in the needle circuit.

When the four-pole, double-throw switch shown in Fig. 6 is closed on the side marked A, the connections are such as to give zero method A. When closed on the opposite side, B, connections are made for zero method B. For zero method C the four-pole, double-throw switch is closed on side A when the commutator M is vertical and on side B when the commutator is placed horizontal.

Method C eliminates the term $\frac{e^2}{2}$ from the equation and is therefore simpler to use from the standpoint of calculation. We can determine k by taking several electrometer readings in a circuit the loss of which is known. The constant k, is evaluated by this method in the experimental part of this paper, for the quadrant electrometer used in the tests.

It is also evident from equations (**15**) and (**16**) that k may be eliminated if we take the means of two sets of

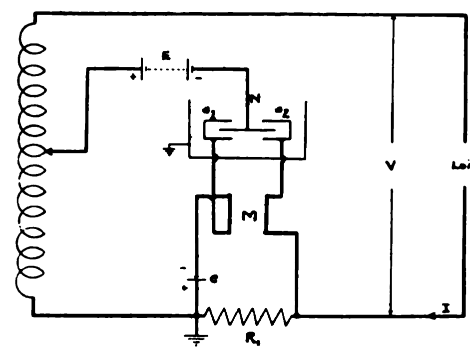

Fig. 7—Fractional Voltage on Needle for Zero Method C Commutator Vertical

readings as described under method A, the first being taken with the polarities of the batteries as shown in Fig. 6, and the second with the batteries reversed.

We can simplify the equations for the purpose of calculation by writing them in a slightly different form. For example we can write equation (**15**) in the form of equation (**17**).

$$I\,V\cos\varphi + \frac{I^2\,R_1}{2} = \frac{(E-k)\,e}{R_1} \qquad (\mathbf{17})$$

Zero Method—Fractional Voltage on the Needle. Any one of the three methods described may be used with fractional voltage applied to the needle. Method C requires the least amount of calculation and is probably

the simplest method to use, therefore, it will be the only method discussed with fractional needle voltage. The connections are shown in Figs. 7 and 8.

With the commutator vertical as in Fig. 7, we have

$$V_0 = \frac{v + i R_1}{n} - E$$

$$V_1 = - e$$

$$V_2 = i R_1$$

and for Fig. 8

$$V_0 = \frac{v + i R_1}{n} - E$$

$$V_1 = i R_1 + e$$

$$V_2 = 0$$

where n equals the factor by which the a-c. voltage applied to the needle must be multiplied to give the total alternating voltage of the circuit.

Substituting these values in the general equation (**3**) of the electrometer, and solving, we obtain (**18**) the derivation of which is similar to that of equations (**15**) and (**16**)

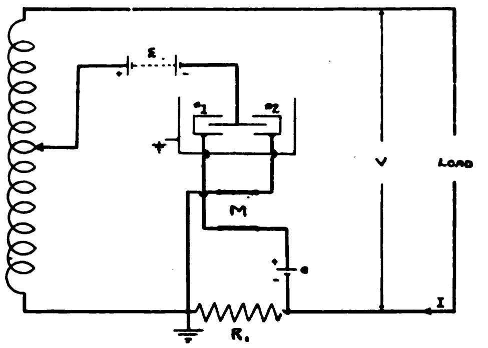

FIG. 8—FRACTIONAL VOLTAGE ON NEEDLE—ZERO METHOD C COMMUTATOR HORIZONTAL

which are derived in the mathematical part of the paper

$$I\, V \cos \varphi + \frac{2 - n}{2} I^2 R_1 = n \frac{(E - k)\, e}{R_1} \qquad (18)$$

It is evident from a study of equation (**18**) that if n equals 1, it reduces to equation (**17**).

The correctness of equation (**18**) was also verified experimentally.

II. EXPERIMENTAL

The electrometer used in these tests was a Dolezalek quadrant electrometer.

Determination of the Constant, k. The constant, $k = \frac{c_1}{b_1}$, was determined by using a resistance load in the circuit of Fig. 6. The load consisted of a non-inductive resistance, R_0, whose value was 260916 ohms. Method C was used in determining the constant. The applied a-c. voltage was 201 volts at 60 cycles. The continuous voltage, E, that is inserted in the needle lead, was made up of three 22.5-volt Radio B batteries. Its value was measured with a 150-volt d-c. voltmeter. The continuous voltage that is inserted in the quadrant circuit, was taken from a six-volt storage battery connected to a potentiometer rheostat. The value of the continuous quadrant voltage, e, that is actually used in the circuit was measured by a 3/15/150-volt Weston Laboratory Standard d-c. voltmeter. The voltmeters used in the experimental work were checked against a Weston Standard Cell.

The quadrant electrometer was set up and adjusted until its electrical and mechanical zeros coincided. Then the load was applied and readings were taken at different values of R_1, the non-inductive resistance across which the quadrants are connected. Two readings of e were made at each setting of R_1; e_1 with the commutator in a vertical position and e_2 with the commutator in the horizontal position. The value of e was adjusted each time until the deflection was reduced to zero, and e_1 is the value of the quadrant voltage for zero deflection and the commutator vertical, and e_2 for zero deflection and the commutator horizontal.

The readings are given in Table I below:

TABLE I
ZERO METHOD C—RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0-ohms	R_1 ohms	E volts	Commutator $\|\|$ e_1-volts	$=$ e_2-volts	Average e volts
201	260916	500	69.4	1.128	1.121	1.1245
		1000	69.45	2.284	2.208	2.246
		2000	69.45	4.63	4.31	4.47
		1000	69.4	2.29	2.20	2.245
		500	69.4	1.127	1.120	1.1235
		1000	69.35	2.284	2.205	2.245
		2000	69.4	4.62	4.32	4.47

The value of the alternating current in the circuit and the total loss measured by the electrometer, which in this case is the loss in the load R_0 plus one-half the loss in R_1, were calculated for each set of readings. From these results the constant, k, was determined from equation (**15**) as shown in Table II. Its value was found to equal 0.8154.

TABLE II
DETERMINATION OF CONSTANT k

Zero-Method C R_1 ohms	$I^2\left(R_0 + \frac{R_1}{2}\right)$ Watts calculated	$\frac{E\,e}{R_1}$	Resistance Load R_0 $\frac{Ee}{R_1} - I^2\left(R_0 + \frac{R_1}{2}\right) = k\frac{e}{R_1}$	k
500	0.1544	0.1561	0.0017	0.7559
1000	0.1540	0.1560	0.0020	0.8905
2000	0.1531	0.1552	0.0021	0.9395
1000	0.1540	0.1558	0.0018	0.8020
500	0.1544	0.1559	0.0015	0.6673
1000	0.1540	0.1556	0.0016	0.7130
2000	0.1531	0.1552	0.0021	0.9395
			Average,	0.8154

Experimental Proof of Zero Method A. Experimental proof of the correctness of the theory involved in zero method A and of equations (**8**) and (**9**) that apply to

this method was obtained by using a resistance load as described in the determination of the electrometer constant k. The connections shown in Fig. 2 were used in this test, except that the polarity of the two batteries are opposite to that shown in the figure. Therefore, equation (9) applies to this test.

The results of the test are given in Table III. The watts consumed by the load R_0 and the loss in the resistance R_1 were calculated from the values used in the circuit as was the case in Table II.

A comparison of the results given in the last two columns of Table III shows good agreement between the calculated watts and the watts as measured by the electrometer.

As stated in the theoretical part of the paper, the constant k need not be determined if two sets of readings are taken, one with the battery polarities as shown in Fig. 2, and the other with the polarities reversed. In order to check this conclusion from the theory a number of sets of readings were taken at different values of R_1, using the resistance load, R_0, of 260916 ohms. The results for two sets of these readings are given in Table IV.

A comparison of the average watts as measured by the electrometer with the calculated watts shows an excellent agreement, and proves that this method may be used if desired to determine watts consumed by a load. A disadvantage of this method lies in the fact that four readings are needed.

In most cases, it is better to determine the electrometer constant k and calculate the power consumed by the load from a single set of readings.

The experimental results prove that Method A and the equations that apply are correct.

Experimental Proof of Zero Method B. The experimental proof of the correctness of the theory of zero Method B and of equations (12) and (13) was also

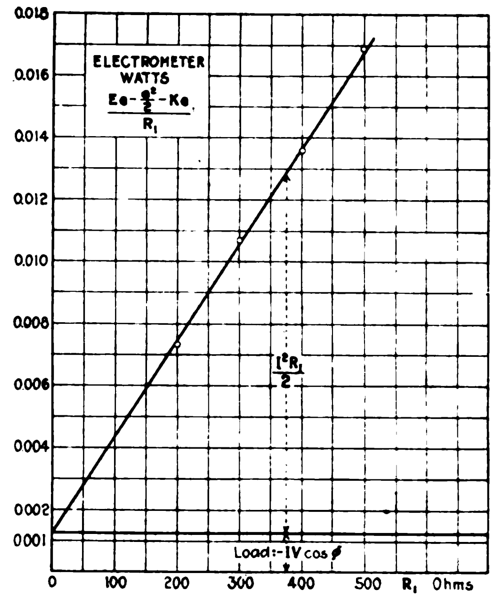

FIG. 9—CAPACITY LOAD (ZERO B METHOD)

obtained using a resistance load, R_0. The connections used are those given in Fig. 3, and equation (12) applies to this test.

The results of this test are given in Table V and a study of the last two columns show that there is a good

TABLE III

ZERO-METHOD A—RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0 ohms	R_1 ohms	E volts	Commutator || e_1 volts	Commutator = e_2 volts	Average e volts	$I^2\left(R_0+\frac{R_1}{2}\right)$ Watts calculated	Electrometer watts $\frac{Ee-\frac{e^2}{2}+ke}{R_1}$
202	260916	100	69.1	0.23	0.216	0.223	0.1563	0.1556
202		500	69.0	1.148	1.112	1.13	0.1559	0.1565
202		1000	69.1	2.318	2.254	2.236	0.1552	0.1538
203		2000	69.0	4.72	4.6	4.66	0.1562	0.1572
203		4000	69.0	9.68	9.42	9.55	0.1544	0.1553

TABLE IV

A-C. SUPPLY VOLTAGE = 203 VOLTS

Remarks Batteries	R_1 ohms	E volts	Commutator || e_1 volts	Commutator = e_2 volts	Average e volts	Electrometer Reading $\frac{Ee-\frac{e^2}{2}}{R_1}$	Electrometer Reading Average watts	Calculated watts $I^2\left(R_0+\frac{R_1}{2}\right)$
As in Fig. 2	100	69.1	0.298	0.16	0.229	0.1582	0.1575	0.1578
Reversed	100	69.1	0.31	0.144	0.227	0.1568		
As in Fig. 2	2000	69.0	4.81	4.64	4.725	0.1574	0.1564	0.1562
Reversed	2000	69.0	4.72	4.6	4.66	0.1554		

agreement between the calculated watts and the watts as measured by the electrometer.

The experimental results prove the correctness of the theory involved in Method B.

Experimental Proof of Zero Method C. Experimental proof of zero method C follows from the results of the tests of methods A and B and also from the measurements made to determine the value of the constant k which are given in Tables I and II. Therefore, no further readings will be given for the measurement by method C of the power consumed in a resistance load.

Capacity Load. Tests were made to determine the loss in a condenser using zero methods A, B and C. The condenser used in these tests was a 1/10 microfarad standard mica condenser. The results obtained by the three methods checked closely, and are given here for methods B and C only.

Data taken by method B, using the connections of Fig. 2, are given in Table VI.

TABLE V
ZERO METHOD B, RESISTANCE LOAD R_0

A-C. Supply voltage	Load R_0 ohms	R_1 ohms	E volts	Commutator $\parallel$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Calculated watts $I^2\left(R_0+\frac{R_1}{2}\right)$	Electrometer watts $\frac{Ee+\frac{e^2}{2}-ke}{R_1}$
201	260916	500	69.35	1.12	1.111	1.115	0.1544	0.1541
		1000		2.208	2.20	2.204	0.1540	0.1535
		2000		4.33	4.31	4.32	0.1531	0.1527
		1000		2.214	2.192	2.203	0.1540	0.1535

In order to eliminate the correction term $\frac{I^2 R_1}{2}$ the electrometer[4] watts are plotted against the values of R_1 as abscissas. These points lie on a straight line as shown in Fig. 9. If this line is extended to the ordinate axis it will cut the axis at a value equal to the watts lost in the load.[5] From Fig. 9 we see that the loss in the condenser is 0.00125 watts.

A test was made with the same condenser using method C. In this test the loss in the condenser was calculated from the formula

$$I\,V\cos\varphi = \frac{(E-k)\,e}{R_1} - \frac{I^2 R_1}{2}$$

The current I equaled 0.00754 amperes as calculated from the constants of the circuit. The readings are given in Table VII and the average loss was found to equal 0.00127 watts and the power factor was 0.085 per cent. The results of the tests by the two methods are in close agreement.

TABLE VI
CAPACITY LOAD, ZERO-METHOD B
A-C. Applied Voltage = 199 Volts at 61 cycles

R_1 ohms	E volts	Commutator $\parallel$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Electrometer reading $\frac{Ee+\frac{e^2}{2}-ke}{R_1}$ = watts
200	69.0	0.016	0.027	0.0215	0.00733
300		0.044	0.05	0.047	0.01069
400		0.079	0.08	0.0795	0.01356
500		0.13	0.118	0.124	0.01692

TABLE VII
CAPACITY LOAD, ZERO-METHOD C
A-C. Applied Voltage = 200 Volts at 60 Cycles

R_1 ohms	E volts	Commutator $\parallel$ e_1 volts	Commutator $=$ e_2 volts	Average e volts	Electrometer watts $\frac{(E-k)\,e}{R_1}$	$\frac{I^2 R_1}{2}$ watts	Watts loss in condenser
200	69.0	0.023	0.018	0.0205	0.00698	0.00569	0.00129
300		0.05	0.036	0.043	0.00977	0.00853	0.00124

TABLE VIII
A-C. Applied Voltage = 62 Volts at 60 Cycles

Method	R_1 ohms	E volts	Average e volts	$E\,e$	$\frac{e^2}{2}$	$k\,e$	Electrometer reading. (Loss in Inductance plus $\frac{I^2 R_1}{2}$)
A	200	69	1.707	117.8	−1.456	−1.392	0.575
B	200		1.6695	115.2	+1.393	−1.361	0.576
C	200		1.6955	117.0	0	−1.382	0.578

Inductive Load. Readings were taken with an inductive load using all three zero methods. The load consisted of an inductance of about 8. henrys and 1650 ohms resistance.

In this test the polarity of the batteries was such that equation (**8**) applies to the results of method A; equation (**12**) to method B; and equation (**15**) to method C.

The results are given in Table VIII and the loss as calculated includes half the loss in the shunt resistance R_1, which was the same for each method.

A comparison of the results of the three methods given in the last column of Table VIII shows that they give the same loss for the circuit within $\pm$ 0.3 per cent.

The experimental results prove conclusively the correctness of the equations as derived, and that the methods may be employed to measure the loss at any value of the power factor leading or lagging.

III. Mathmetical

Derivation of Equation (**8**) *Method A.* Equation (**8**) is obtained by substituting the instantaneous values of the potentials applied to the needle and quadrants in the general equation (**3**) of the electrometer. The electrometer reads the integral of these voltages over a complete period T.

With the commutator vertical in Fig. 2 we have

$$V_0 = v + i R_1 - E$$
$$V_1 = - e_1$$
$$V_2 = i R_1$$

where $v = \sqrt{2} V \sin \omega t$

and $i = \sqrt{2} I \sin (\omega t \pm \varphi)$

Substituting these values and integrating over a complete period, we get the values of the terms in equation (**3**) as follows:

$$- \frac{b_1}{2} V_1^2 = - \frac{b_1}{2} e_1^2$$

$$+ \frac{b_1}{2} V_2^2 = + \frac{b_1}{2} \frac{1}{T} \int_0^T R_1^2 . 2 I^2 \sin^2 (\omega t \pm \varphi)\, dt = + \frac{b_1}{2} I^2 R_1^2$$

$$+ b_1 V_0 V_1 = + b_1 \frac{1}{T} \int_0^T [\sqrt{2} V \sin \omega t + R_1 \sqrt{2} I \sin (\omega t \pm \varphi) - E][- e_1]\, dt = + b_1 E e_1$$

$$- b_1 V_0 V_2 = - b_1 \frac{1}{T} \int_0^T [\sqrt{2} V \sin \omega t + R_1 \sqrt{2} I \sin (\omega t \pm \varphi) - E][R_1 \sqrt{2} I \sin (\omega t \pm \varphi)]\, dt = - b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$$

$$+ c_0 V_0 = c_2 \frac{1}{T} \int_0^T [\sqrt{2} V \sin \omega t + R_1 \sqrt{2} I \sin (\omega t \pm \varphi) - E]\, dt = - c_0 E$$

$$+ c_1 V_1 = - c_1 e_1$$

$$- c_1 V_2 = - c_2 \frac{1}{T} \int_0^T \sqrt{2} V \sin \omega t\, dt = 0$$

With the commutator horizontal the values of V_1 and V_2 change as stated under zero method A, and by substituting these new values of V_1 and V_2 in the terms of equation (**3**) and integrating we may determine the values of these terms for the commutator horizontal.

The signs and the values of the terms in equation (**3**) for the two positions of the commutator are given below in (**4**) and (**5**).

Pos of Comm.	Equa. No.	VALUE OF TERMS				
	(3)	$-\frac{b_1}{2} V_1^2 + \frac{b_1}{2} V_2^2$	$+ b_1 V_0 V_1$	$- b_1 V_0 V_2$	$+ c_0 V_0 + c_1 V_1 - c_1 V_2$	$= (1 + R V_0^2)\, \theta$
$\vert\vert$	(4)	$-\frac{b_1}{2} e_1^2 + \frac{b_1}{2} I^2 R_1^2$	$+ b_1 E e_1$	$- b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$	$- c_0 E - c_1 e_1 - 0$	$= (1 + R V_0^2)\, \alpha$
$=$	(5)	$-\frac{b_1}{2} I^2 R_1^2 + \frac{b_1}{2} e_2^2$	$+ b_1 (R_1 I V \cos \varphi + I^2 R_1^2)$	$- b_1 E e_2$	$- c_0 E - 0 + c_1 e_2$	$= (1 + R V_0^2)\, \beta$

Taking the algebraic sum of equations (**4**) and (**5**) we get equation (**6**).

$$(1 + R V_0^2)(\beta - \alpha) = 2 b_1 R_1 I V \cos \varphi + b_1 I^2 R_1^2 - b_1 E (e_1 + e_2) + \frac{b_1}{2} (e_1^2 + e_2^2) + c_1 (e_1 + e_2) \qquad (6)$$

The experimental results show that e_1 and e_2 are nearly equal and that we may write $e = \frac{e_1 + e_2}{2}$ without introducing any appreciable error. Since the deflections α and β are each zero, we may write equation (**6**) equal to zero and solve for the power consumed by the load.

$$I V \cos \varphi + \frac{I^2 R_1}{2} = \frac{E e - \frac{e^2}{2}}{R_1} - \frac{c_1}{b_1} \frac{e}{R_1} \qquad (7)$$

Equation (**7**) contains two of the electrometer constants b_1 and c_1, which may be combined as previously described, in a single constant $k = \frac{c_1}{b_1}$. Under these

conditions we may write equation (**7**) in the form

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} - k\frac{e}{R_1} \qquad (8)$$

If we reverse the polarities of the two batteries, E and e, and proceed as in determining equation (**8**) we find that the power consumed by the load is given by equation (**9**).

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e - \dfrac{e^2}{2}}{R_1} + k\frac{e}{R_1} \qquad (9)$$

Derivation of Equation (**12**), *Method B.* The relations giving the power consumed by the load with the connections as in Fig. 3, method B, are derived from equation (**3**) in a manner similar to that used in finding (**8**).

Pos. of Comm.	Equa. No.	VALUE OF TERMS
	(3)	$-\frac{b_1}{2}V_1^2 + \frac{b_1}{2}V_2^2 + b_1 V_0 V_1 - b\ V_0 V_2 + c_0 V_0 + C_1 V_1 - c_2 V_2 \quad = (1 + R\,V_0^2)\,\theta$
||	(10)	$0 + \frac{b_1}{2}(I^2 R_1^2 + e_1^2) + 0 - b_1(R_1 I\,V\cos\varphi + I^2 R_1^2 - E\,e_1) - c_0 E - 0 - c_1 e_1 \quad = (1 + R\,V_0^2)\,\alpha$
=	(11)	$-\frac{b_1}{2}(I^2 R_1^2 + e_2^2) + 0 + b_1(R_1 I\,V\cos\varphi + I^2 R_1^2 - E\,e_2) - 0 - c_0 E + c_1 e_2 - 0 \quad = (1 + R\,V_0^2)\,\beta$

Taking the algebraic sum of equations (**10**) and (**11**) and solving for the power consumed by the load we obtain equation (**12**) for connection B.

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E + \dfrac{e^2}{2}}{R_1} - k\frac{e}{R_1} \qquad (12)$$

Derivation of Equation (**15**), *Method C.* Method C is a combination of methods A and B, as stated above. With the commutator vertical equation (**4**) of method A, holds and with the commutator horizontal we have equation (**10**) of method B. Taking the algebraic sum of equations (**10**) and (**4**) we obtain equation (**14**).

$$(1 + R\,V_0^2)(\beta - \alpha) = 2\,b_1 R_1 I\,V\cos\varphi$$

$$+ b_1 I^2 R_1^2 - b_1 E(e_1 + e_2) + \frac{b_1}{2}(e_1 - e_2) + c_1(e_1 + e_2) = 0 \qquad (14)$$

Assuming that e_1 is very nearly equal to e_2 the fourth term of the equation becomes negligible and we can write that the power consumed by the load is

$$I\,V\cos\varphi + \frac{I^2 R_1}{2} = \frac{E\,e}{R_1} - k\frac{e}{R_1} \qquad (15)$$

The Correction Term, $k\dfrac{e}{R_1}$. Several methods are possible for eliminating the correction term, $k\dfrac{e}{R_1}$ in addition to those mentioned in the paper. The elimination of this term may be accomplished in method C, for example, by reversing the polarity of the battery in the needle circuit, instead of reversing e as described under this method. This, however, introduces another correction term in the equation which involves E and is, therefore, not to be recommended.

The importance of the correction term, $k\dfrac{e}{R_1}$, can be reduced by use of larger values of the needle battery E. This reduces the value of e needed to balance the torque of the a-c. voltages.

IV. Errors

The sources of error present in any quadrant electrometer have already been ably discussed in an Institute paper[2]. The more important are:

1. A study of the diagram of connections of the quadrant electrometer shows that the electrostatic capacity formed by the two quadrant pairs and their leads is in parallel with the non-inductive resistance R_1. Therefore, the drop across R_1 and this condenser in parallel with it will not be in phase with the current. This error is naturally greater the higher the value of R_1. Taking this into account we find that the equation[6] for method C is as follows:

$$I\,V\cos\varphi + \frac{2 - n}{2} I^2 R_1 + I\,(\omega\,c_1 R_1)\,V\sin\varphi$$

$$= \frac{n\,(E - k)\,e}{R_1} \qquad (19)$$

where c_1 is the electrostatic capacity of the quadrant pair circuit in farads.

In measuring the loss in the 1/10 microfarad condenser by methods B and C it was found possible to work with a value of R_1 as low as 200 ohms and still obtain good accuracy. Tests of this same condenser by the deflection method require a value of R_1 of the order of 1000 ohms to obtain satisfactory deflections. It is evident that the error introduced by the capacity of the quadrants depends upon the value of R_1, and that it is reduced in amount by the use of this zero method.

2. Further study of the quadrant electrometer circuit shows that the charging current I_1 from the

needle to the high quadrant flows through R_1 in addition to the load current, I.

This source of error is very small in low voltage electrometers and may usually be neglected.

3. The theory of the electrometer is based upon the assumption that the resistance of the needle circuit is zero, and the needle charging current flows through a pure capacity.

The use of the battery, E, in the needle circuit introduces a resistance, but its value in our tests was so small compared to the capacitance of the needle circuit that its effect was negligible.

4. If fractional voltage is applied to the electrometer needle, the e. m. f. of the portion of the transformer winding to which the needle circuit is attached, may differ in phase from the total voltage in the circuit. This source of error may become very important at low values of the power factor of the load, and in such cases must be corrected for[2].

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General Theory of the Auto-Transformer

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Synopsis.—*The method of complex quantities lends itself admirably to the development of general theory of the auto-transformer. As worked out, in this instance, it is found desirable to maintain the actual voltage ratio instead of reducing values to an equivalent 1:1 basis. Examples are given of calculations by this method, and also comparison is made with calculated performance of the two-circuit transformer. Certain inherent peculiarities of the auto-transformer are pointed out, being due to the effects of internal resistance and reactance.*

Part II is an application of the theory to transformers without iron and a number of interesting conclusions are brought out.

* * * * *

An auto-transformer may be represented as a single winding on an iron core, as illustrated in Fig. 1. Primary voltage, E_1, is impressed on the winding, and secondary voltage, E_2, is obtained by suitable taps. The primary current, I_1, flows in a portion of the winding of t_1 turns. The rest of the winding carries current, I_2, which is the resultant of the current I_1 and the load current I_L, and it consists of t_2 turns. The total turns of the entire winding are $t = t_1 + t_2$. Ratio of transformation is given by

$$f = \frac{t}{t_2} = \frac{t_1 + t_2}{t_2} = \frac{E_1}{E_2}$$

at no load.

Resistances of windings t_1 and t_2 are r_1 and r_2 respectively, and reactances are x_1 and x_2. Fig. 2 illustrates the vector relations which exist. We may begin with the flux ϕ, drawn vertically upward. This is produced by magnetizing current i_m in phase with it. Ninety deg. ahead of the flux is the core-loss current i_c. i_m and i_c vectorially added give the exciting current I_x. Ninety deg. behind the flux is the e. m. f., e_i, induced in the turns t_2. The load current $I_L = i_L + j\, i_L'$ is drawn at any desired angle with reference to e_i.

So far, the vector relations are similar to those of the ordinary two-circuit, constant potential transformer. But in the case of the auto-transformer a departure from similarity occurs at this point. This departure is due to two causes; (1) the current in the turns t_2 is not the load current, and (2) the vectors are given actual values and are not reduced to a 1 : 1 equivalent

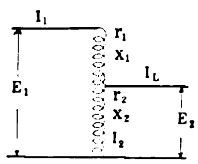

Fig. 1

ratio. This latter consideration is not awkward on account of the fact that auto-transformer ratios do not usually depart very far from 1 : 1, being in that respect quite different from two-circuit transformers.

We now draw $-f\,e_i$, 180 deg. ahead of e_i, and this is that portion of the impressed voltage required to produce e_i in t_2. Similarly, $-\dfrac{I_L}{f}$ is the load component of primary current, 180 deg. ahead of I_L.

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The entire primary current I_1 is the vector sum of I_x and $-\frac{I_L}{f}$. The secondary current, I_2 in t_2, is the vector sum of I_1 and I_L. Secondary voltage, E_2, is obtained by subtracting from e_i the $I_2 r_2$ and $I_2 X_2$ drops in turns t_2.

Primary voltage, E_1, is obtained by adding to $-f e_i$ the $I_1 r_1$, $I_1 x_1$, $I_2 r_2$, and $I_2 x_2$ drops, all operations being, of course, vectorial.

The method of complex quantities lends itself readily to this procedure. It is convenient to start with e_i as the zero vector, however, rather than with E_1 or E_2. This makes the use of the method very simple. Certain difficulties which are introduced may be readily provided for. The chief difficulty is in ascribing to the load current a definite, desired phase angle with respect to E_2, as the components of I_L are given with respect to the zero vector e_i. This and other points will appear in the case of examples cited.

The vector equations are as follows:

$$\dot{I}_1 = \dot{I}_x - \frac{\dot{I}_L}{f} = -\frac{i_L}{f} + i_c + j\left(i_m - \frac{i_L'}{f}\right)$$
$$= i_1 + j\, i_1'$$
$$\dot{I}_2 = \dot{I}_1 + \dot{I}_L = i_1 + i_L + j\,(i_1' + i_L') = i_2 + j\, i_2'$$
$$\dot{E}_2 = e_i - \dot{I}_2 z_2 = e_i - i_2 r_2 + i_2' x_2 - j\,(i_2 x_2 + i_2' r_2)$$
$$= e_2 + j\, e_2'$$

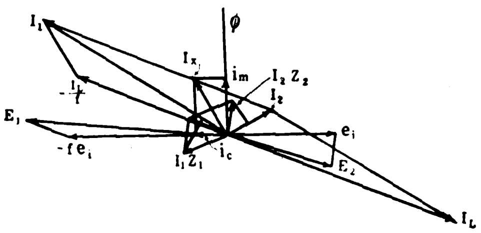

Fig. 2

$$\dot{E}_1 = -f e_i + \dot{I}_1 z_1 + \dot{I}_2 z_2$$
$$= -f e_i + i_1 r_1 - i_1 x_1' + i_2 r_2 - i_2' x_2$$
$$+ j\,(i_1 x_1 + i_1' r_1 + i_2 x_2 + i_2' r_2) = e_1 + j\, e_1'$$

Power input is $P_1 = e_1 i_1 + e_1' i_1'$

Power output is $P_2 = e_2 i_L + e_2' i_L'$

Efficiency is $\eta = \frac{P_2}{P_1}$

Primary power factor is $P f_1 = \frac{P_1}{E_1 I_1}$

Load power factor is $P f_2 = \frac{P_2}{E_2 I_L}$

Regulation is given by the equation

$$\text{Per cent regulation} = \frac{E_2 \text{ at no load} - E_2}{E_2}$$

when the primary impressed voltage is constant. All the above relations, however, are based on an assumed constant induced voltage, e_i, and consequently it would seem, judging by common experience with the two-circuit transformer, that the primary voltage will not be the same at load and no load. It is advisable, then, to determine both E_2 and E_1 for the condition of no load always keeping e_i constant.

The value of E_2 thus obtained should be multiplied by the ratio

$$\frac{E_1 \text{ at load}}{E_1 \text{ at no load}}$$

This reduces E_2 to the value it would have at constant impressed primary voltage. Carrying out this process, equations for the case of $\dot{I}_L = 0$ are as follows:

$$\dot{I}_1 = i_c + j\, i_m = \dot{I}_2$$
$$\dot{E}_2 = e_i - i_c z_2 - j\, i_m z_2 = e_i - i_c r_2 + i_m x_2$$
$$- j\,(i_c x_2 + i_m r_2)$$
$$= e_2 + j\, e_2'$$
$$\dot{E}_1 = -f e_i + i_c (z_1 + z_2) + j\, i_m (z_1 + z_2)$$
$$= -f e_i + i_c (r_1 + r_2) + j\, i_c (x_1 + x_2)$$
$$- i_m (x_1 + x_2) + j\, i_m (r_1 + r_2)$$
$$= -f e_i + i_c r_1 + i_c r_2 - i_m x_1 - i_m x_2$$
$$+ j\,(i_c x_1 + i_c x_2 + i_m r_1 + i_m r_2) = e_1 + j\, e_1'$$

$$\text{Per cent regulation} = \frac{K\, E_2 \text{ (at no load)} - E_2 \text{ (at load)}}{E_2 \text{ (at load)}}$$

where

$$K = \frac{E_1 \text{ at load}}{E_1 \text{ at no load}}$$

The value of this constant is either exactly unity or very near to it in practical cases. The difference in voltage between E_1 at load and E_1 at no load is given by the equation

$$\dot{E}_1 \text{ (at load)} - \dot{E}_1 \text{ (at no load)}$$
$$= i_L\left(-\frac{r}{f} + r_2\right) + i_L'\left(\frac{x}{f} - x_2\right)$$
$$+ j\left[i_L\left(-\frac{x}{f} + x_2\right) + i_L'\left(-\frac{r}{f} + r_2\right)\right]$$

where r and x are total resistance $r_1 + r_2$, and total leakage reactance $x_1 + x_2$, respectively.

This difference reduces to zero in many cases, for example, when $f = 2$, $r_1 = r_2$, and $x_1 = x_2$, which is the case with a uniformly wound coil tapped at its middle point.

Thus, in this case, per cent regulation is simply

$$\frac{E_2 \text{ (at no load)} - E_2 \text{ (at load)}}{E_2 \text{ (at load)}}$$

As an illustration of the whole method we will give

values for the calculation of a 50-kva., 60-cycle, 220/110-volt auto-transformer.

Constants, on percentage basis, are as follows:

Induced voltage $= e_i = 1$

$$r_1 = r_2 = 0.01$$
$$x_1 = x_2 = 0.02$$
$$i_m = 0.025$$
$$i_c = -0.01$$
$$f = 2 = \text{ratio of transformation}$$
$$\dot{I}_L = 1 + j\,0$$

Substituting these values into the above equations we get:

$$\dot{I}_1 = -0.51 + j\,0.025$$
$$\dot{I}_2 = 0.49 + j\,0.025$$
$$\dot{E}_2 = 0.9956 - j\,0.01005$$
$$\dot{E}_1 = -2.0012 + j\,0.0001$$
$$\dot{P}_1 = \text{power input} = 1.0206$$
$$\dot{P}_2 = \text{power output} = 0.9956$$

Efficiency $= 0.974$

Primary power factor $= 0.997$

$$\text{Power factor of load} = \frac{0.9956}{0.9956} = 1$$

To obtain regulation, we have the following values for the condition of zero loading:

$$\dot{I}_1 = \dot{I}_2 = -0.01 + j\,0.025$$
$$\dot{E}_2 = 1.0006 - j\,0.00005$$
$$\dot{E}_1 = -2.0012 + j\,0.0001$$

$$K = \frac{E_1 \text{ at load}}{E_1 \text{ at no load}} = \frac{2.0012}{2.0012} = 1$$

Therefore,

$$\text{Regulation} = \frac{1.0006 - 0.9956}{0.9956} = \frac{0.005}{0.9956} = 0.005$$

This transformer may be considered as a 1 : 1 two-circuit transformer according to the usual method of calculation. Table I gives comparative performance as auto-transformer and as two-circuit transformer. As transformer of the latter type the constants are:

$$e_i = 1, r_1 = r_2 = 0.01, x_1 = x_2 = 0.02, i_m = 0.05$$
$$i_c = 0.02, \dot{I}_L = 1 + j\,0$$

Values of the components of exciting current are seen to be twice those of the auto-transformer. In general, in order that flux and core-loss shall be the same in the two transformers, it is necessary to divide the values for exciting current of the two-circuit machine by the ratio of transformation of the auto-transformer.

TABLE I

	Two-Circuit Trans.	Auto-Trans.
Load Current	$1 + j\,0$	$1 + j\,0$
Efficiency	0.963	0.974
Regulation	0.022	0.005

Comparative efficiencies are as we should expect. Due to reduction in copper losses the auto-transformer shows superiority. In regulation, however, its superiority is far more marked, due largely to the fact that the impedance drop in the secondary winding has a negative effect and tends to raise the secondary voltage instead of lowering it.

Under short circuit, the exciting current ceases to flow in the secondary turns, and is diverted entirely into the short circuit. The short-circuit current may be considered as made up of three parts, (1) that supplied by the secondary turns, which is the induced voltage divided by secondary impedance, (2) the load component of the primary which is equal to (1) multiplied by $\frac{t_2}{t_1}$, and (3) the exciting current, which, at short circuit, is equal to $\frac{t}{t_1}$ times I_x at no load. In the case considered, in which $f = 2$, it is:

$$\dot{I}_2 = \frac{e_i}{r_2 + j\,x_2} = \frac{e_i\,r_2}{z_2^2} - j\,\frac{e_i\,x_2}{z_2^2} = 20 - j\,40$$

$$\dot{I}_{sh.\,cir} = 2\,\dot{I}_2 + 2\,\dot{I}_x = 40.02 - j\,80.05$$

where $\dot{I}_x$ is taken as flowing in the same direction as $\dot{I}_2$; that is, $\dot{I}_x = 0.01 - j\,0.025$.

Total short-circuit current is then 89, approximately.

When operated as a two-circuit transformer, the short-circuit current is 22.3, or one-fourth as much as that of the auto-transformer.

It is interesting to notice the conditions as relating to the exciting current with various loadings of the transformer. At no load, its value is the same in both parts of the winding, t_1 and t_2. Exciting ampere-turns are $I_x\,t$. As the load is increased the load impedance offers a path for the exciting current in parallel with t_2, thereby causing a slight increase in the exciting current which flows in t_1 and a slight decrease in that which flows in t_2. No account is taken of this variation for ordinary loading, as it is insignificant. The total exciting ampere-turns remain constant for all loads, producing constant mutual flux and constant induced voltage in the secondary. Voltage induced in t_1 must also be constant. At short circuit, we have maximum exciting current in t_1 and zero exciting current in t_2. In a 2 : 1 transformer the value of this current in t_1 is $2\,I_x$, where I_x is the no-load exciting current.

The total $I_1\,Z_1$ drop in t_1 is approximately equal to e_i, at short circuit, so that the impressed voltage $E_1 = 2\,e_i$. This relationship is similar to that which exists in a two-circuit transformer, where, at short-circuit, the voltage drop in the primary is approximately equal to the induced voltage. In this case, however, the equality is brought about by reduction in the value of the induced voltage, which, at short circuit, is only half its no-load value.

Part II

AUTO-TRANSFORMERS WITHOUT IRON[2]

Air-core transformers are in general at a disadvantage owing to the fact that their magnetic fields are produced in a medium of unit permeability. Absence of iron, however, offers some compensating advantages, namely, absence of core-loss and exciting current distortion, and saving in cost of iron and in cost of construction. At sixty cycles, these advantages are far out-weighed by the disadvantages in performance as compared with two-circuit transformers. At higher frequencies the situation becomes more and more favorable for the air-core transformers, until at radio frequencies the use of iron is inadmissible.

With auto-transformers the case is distinctly more favorable for the air-cores at lower frequencies. The same theory applies as with iron-core transformers except that the core-loss component of the exciting current drops out. The constants are, of course, very different and it will be of interest to give some values and results that may be expected in practise. An air-core auto-transformer should be wound for maximum self-inductance of the entire winding and maximum mutual inductance of the two parts, that is, of t_1 and t_2. This maximum mutual inductance will, of course, mean minimum leakage reactance.

An auto-transformer may be designed from either of two points of view as respects operation. It may be designed either to operate at a fixed ratio of transformation or as a compensator with taps to give different voltages over a considerable range of ratio.

Table II gives comparative results to be expected from an air-core compensator with three taps giving voltage ratios of 4 : 3, 4 : 2, and 4 : 1. The same voltage is impressed on the primary in each case, and the same load current is assumed. The constants for the three cases are given in the preceding table.

TABLE II

	A	B	C
Transformer ratio	4:3	4:2	4:1
Primary resistance, r_1	0.01	0.02	0.03
Secondary resistance, r_2	0.03	0.02	0.01
Primary reactance, x_1	0.1	0.2	0.3
Secondary reactance, x_2	0.3	0.2	0.1
Magnetizing current	0.3	0.3	0.3
Load current	$1-j\,.1$	$1-j\,.1$	$1-j\,.1$
Induced voltage, e_i	1.5	1	0.5
Primary voltage, E_1	2.12	2.12	2.12
Primary current, I_1	0.838	0.61	0.41
Power input	1.5945	1.0642	0.5349
Secondary voltage, E_2	1.575	1.047	0.52
Secondary current, I_2	0.372	0.559	0.783
Power output	1.5833	1.05	0.523
Efficiency	0.992	0.986	0.979
Primary power factor	0.896	0.822	0.614
Load power factor	1 approx	1.	1.
Secondary no-load voltage	1.59	1.06	0.53
Primary no-load voltage	2.12	2.12	2.12
Per cent regulation	0.0095	0.0124	0.0192

2. A paper on this subject was presented by the author before Section M of the American Association for the Advancement of Science, December 1916, but was preliminary in character and never has been published.

It is to be noted that for low ratio, the primary turns are relatively heavily loaded while the secondary turns are lightly loaded.

With high ratio, the opposite is true. Therefore, if the transformer is to be operated continuously at a fixed ratio, the cross section of wire for primary and secondary should be proportioned to the respective currents to be carried. For a 2 : 1 ratio, the wire should be the same in cross-section for both windings.

In the above table, we see, as we saw with the case of the iron-core transformer, that the impressed voltage is constant regardless of load. The effect of $r\,I$ drop in the primary is exactly neutralized by the $r\,I$ drop in the secondary except for the small and constant drop due to the exciting current. This balance of drops does not obtain if the resistances and reactances are not so proportioned as to accomplish it, but there is always a tendency in that direction. To illustrate this situation we will make comparison of two auto-transformers with the following constants: ratio of transformation, 5 : 4; exciting current, 0.3; load current, $I_L = 1 - j\,.2$; induced voltage, 1; total resistance, 0.04; total reactance, 0.4. The resistances and reactances of the two transformers are differently distributed between primary and secondary, as follows:

TABLE III

	D	E
Primary resistance, r_1	0.02	0.003
Primary reactance, x_1	0.2	0.03
Secondary resistance, r_2	0.02	0.037
Secondary reactance, x_2	0.2	0.37
Primary current, I_1	0.922	0.922
Secondary current, I_2	0.328	0.328
Primary voltage, E_1	1.41	1.358
Secondary voltage, E_2	1.05	1.093
No-load primary voltage	1.37	1.37
No-load secondary voltage	1.06	1.115
Regulation constant, K	1.03	0.99
Per cent regulation	0.038	0.011

Transformer E is seen to operate at nearly constant impressed voltage, and it is this one in which the wire has been proportioned to the currents to be carried.

Certain inherent features of the performance of air-core transformers are of interest. They are due to the fact that the magnetic field is in a medium of constant permeability and consequently all effects due to magnetic saturation are automatically eliminated.

1. Thus, if the characteristics of an air-core transformer are known for one value of impressed voltage, they may be obtained for any other value. For example, let $E_1 = 100$, and let maximum efficiency occur with a load of 10 amperes, and, let us say, 950

watts. If, now, the voltage is raised to 110, maximum efficiency will occur at $\frac{110}{100}$ times $10 = 11$ amperes, and $\left(\frac{110}{100}\right)^2$ times $950 = 1150$ watts. One efficiency curve applies to the transformer, whatever the impressed voltage, provided the scale of amperes and watts is changed in the proper ratio.

2. To obtain maximum capacity, it is only necessary to impress such a voltage on the primary as will correspond with maximum permissible current in the windings at full load, or, conversely, the windings of a transformer may be so chosen as to carry maximum permissible current at full load with any specified impressed voltage.

3. Regulation of an air-core auto-transformer is more affected by leakage reactance than by resistance, when operating at high power factor. This fact is quite apparent from a study of the vector diagram. The primary $I\,x$ drop is almost directly in phase with the impressed voltage, instead of being at right angles to it, giving nearly the worst condition for regulation. To offset this, however, the secondary $I\,x$ drop, while considerably out of phase with E_2, is generally so directed as to assist regulation, partially neutralizing the bad effects of primary reactance.

(4). Power factor of the air-core transformer is generally much poorer than that of the iron-core type because the magnetizing current is a comparatively large out-of-phase component of the primary current. This large magnetizing current is not altogether undesirable, however. It causes a greater lead of I_2 with respect to E_2 and reduces the amount of I_2 without proportionally increasing I_1.

In general, it may be said that the air-core auto-transformer offers possibilities at 60 cycles. At higher frequencies, such as 120 or 180 cycles, it becomes of decidedly more than theoretical interest.

Variable Armature Leakage Reactance in Salient-Pole Synchronous Machines

BY VLADIMIR KARAPETOFF[1]

Fellow, A. I. E. E.

Synopsis.—*The electrical performance characteristics of a polyphase synchronous machine, that is, its voltage-current relations under load, depend essentially upon the nature and the extent of the magnetomotive forces of the armature currents. Broadly speaking, the effect of these magnetomotive forces is two-fold; i. e., (a) they oppose and distort the field magnetomotive force and (b) they create leakage fields linked with the armature conductors. The first influence is known as the armature reaction, and the second as the armature reactance. More specifically, in a machine with salient poles, the armature reaction may be resolved for purposes of computation into the direct reaction (along the center lines of the poles) and the transverse reaction, midway between the poles. In polyphase machines of usual proportions, the armature leakage reactance, x, usually plays a secondary role, and for most purposes is assumed to be constant and independent of the power factor of the load. The vector of the reactive drop, Ix, is simply drawn in a leading time quadrature with the current I.*

However, in machines with considerable armature reactance, or where higher accuracy is required, the assumption of a constant x leads to noticeable discrepancies between the computed and observed data. This is of particular importance in problems which involve hunting, instability, etc., and in which the torque (or displacement) angle must be predicted. This angle depends to a considerable degree upon the leakage reactance of the machine. It has been previously proposed by others to use two distinct values of leakage reactance, one when the leakage paths around a group or belt of armature slots are closed through the center of a pole face (maximum reactance), and the other when such slots are midway between the poles (minimum reactance). However, no account has been taken apparently of a gradual change in the reactance between the two extreme positions, nor have the results been properly correlated with the rest of the factors which enter in the performance of the machine.

In the present paper, the leakage inductance is assumed to consist of two parts, one of which is constant (the average inductance), and the other varying harmonically at a double frequency, reaches a maximum opposite the centers of the poles. A magnetic linkage equation is written, and its derivative with respect to the time angle is taken to obtain the induced voltage. The result shows that the foregoing assumption leads to two reactive drops, one, the usual average Ix drop and another a supplementary drop, leading Ix by an angle 2 ψ, where ψ is the internal phase angle at which the machine is operating. These quantities are introduced in the usual Blondel diagrams for the generator and the motor, and the relationships among the various quantities are established both graphically and analytically.

IN the performance characteristics of synchronous machines with salient poles, there are certain discrepancies between the computed and the measured electrical quantities, even when the usual Blondel diagram is used which is supposed to take into consideration the influence of salient poles on the armature reaction[2]. These discrepancies may be accounted

1. Professor of Electrical Engineering, Cornell University, and Engineering General Department, General Electric Co.

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2. For a theory of Blondel's diagram, see V. Karapetoff, *The Magnetic Circuit*, Arts. 48 and 49. The subject of direct and transverse armature reaction is also treated in detail in Chaps. 47 and 48 of the author's *Experimental Electrical Engineering*, Vol. II, 3rd ed., now going through the press. Extensive literature references will be found there.

for, at least in part, by taking into consideration the variations in the value of the permeance of the armature leakage flux during a cycle.

At zero power factor of the load, the armature leakage flux reaches a lower maximum value than with the same armature current at unity power factor, because in the latter case the armature slots, in which the current reaches its maximum, are almost opposite the centers of the poles, and the permeance of the leakage paths is greater. Hence, at high values of power factor, the machine should be expected to behave as if its leakage reactance were greater than that obtained from a short-circuit test. Often such is actually the case. Moreover, the torque (or displacement) angle[3] often comes out from test larger than from computation. This also indicates an actual increase in the equivalent reactive drop ix, as would be expected theoretically at higher values of power factor.

Several authors have pointed out the fact that the armature leakage reactance varies during the cycle, and some have used *two values of reactance*, one opposite the poles, the other midway between the poles[4]. However, to the writer's knowledge, *gradual changes* in the reactance have not as yet been considered quantitatively in their effect upon the Blondel diagram, and the latter is usually drawn with a constant ix drop. An attempt is made below to develop a method whereby such cyclic variations in the reactance can be taken into consideration in Blondel's theory of two armature reactions. Of course, a similar correction could be applied to the less accurate Potier diagram, but it would seem hardly logical to correct for the effect of salient poles upon the leakage reactance in a diagram in which the effect of salient poles on the armature reaction is disregarded altogether.

I. Average Reactance and Supplementary Reactance

In Fig. 1, the curve $A\ B\ C\ D\ E$ represents values of the armature leakage inductance plotted with reference to the axis of abscissas $X\ X$. The time angle is denoted by α, where

$$\alpha = 2\,\pi\,f\,t = \omega\,t \qquad (1)$$

t being time and f the frequency. When $\alpha = 0$, let the group of armature conductors under consideration be opposite the center of a pole. The tooth-tip leakage is then at a maximum, and hence the leakage inductance reaches its maximum value. When $\alpha = 90$ deg., the same group of conductors is midway between the poles and the leakage inductance is a minimum.

Thus, the leakage inductance varies at twice the frequency of the main induced voltage of the machine, and, as a first approximation, the inductance curve in this discussion will be assumed to be a sine wave of double frequency. Even when an actual test gives a curve departing from a sine wave, this experimental curve can be replaced by an equivalent sine wave, because higher harmonics in the inductance can produce only higher harmonics in the terminal voltage or in the current of the machine, and in this paper only the quantities of fundamental frequency are considered. The variable value of inductance, L_α, at an instant of time corresponding to the electrical angle α, shall therefore be expressed as

$$L_\alpha = L + \Delta\,L \cos 2\,\alpha \qquad (2)$$

Here L is the *average* value of the inductance over a cycle, and $\Delta\,L$ is the greatest departure from the average, that is, the amplitude of the sine wave with respect to the axis $X'\,X'$.

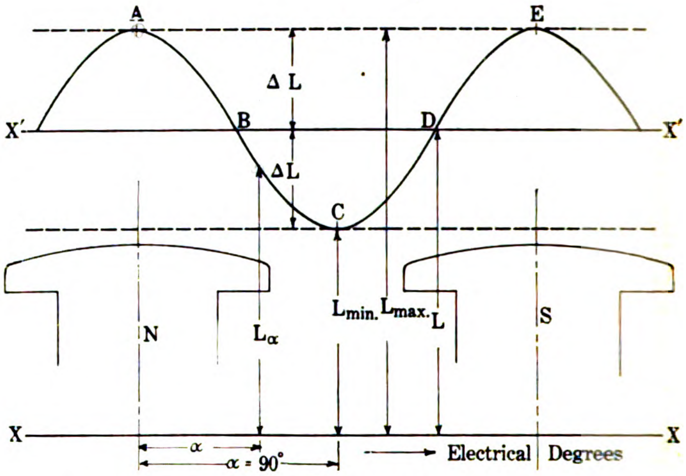

Fig. 1—Variable Armature Leakage Inductance L_α and Its Average Value L

Assuming the armature current to be sinusoidal, it can be written in the form

$$i_\alpha = I \cos(\alpha - \psi) \qquad (3)$$

where I is the amplitude of the current, and $\psi = Q\,O\,G$, Fig. 2, is the internal phase angle at which the machine is operating. The angle ψ characterizes the interval of time between the instant when a group of armature conductors is opposite the center of a pole and the instant when the current in the same group of conductors reaches a maximum[5]. For a generator, ψ is assumed to be positive when the current reaches a maximum *after* the corresponding group of conductors has passed by the center of a pole (although the current may be leading with respect to the terminal voltage). In a motor, ψ is greater than 90 deg., and may even be greater than 180 deg. when the motor is under-excited. Thus, in equation (3), the case of $\psi = 0$ corresponds to the generator working at such a power factor that the current I reaches its maximum when that group of

3. Mag. Cir., the angle $\beta + \phi_2$ in Fig. 40; this angle is denoted by θ in Fig. 2 of this paper.

4. See, for example, C. P. Steinmetz, *A-C. Phenomena*, Chapter on Armature Reactions in Alternators.

5. *The Magnetic Circuit*, pp. 154 and 155; the angle ψ is marked in the diagrams there.

conductors, through which I is flowing, is directly opposite the center of a pole. It can be shown that under these conditions the current is slightly leading with respect to the terminal voltage, but this fact is of no particular importance in this discussion.

Multiplying equations (**2**) and (**3**) term by term, in order to obtain the instantaneous magnetic linkages, gives,

$$i_\alpha L_\alpha = L\,I \operatorname{Cos}(\alpha - \psi) + \Delta L\,I \operatorname{Cos} 2\,\alpha \operatorname{Cos}(\alpha - \psi) \quad \textbf{(4)}$$

In the last term, the product of the cosines can be replaced by their sum and difference. Namely

$$\operatorname{Cos} 2\,\alpha \operatorname{Cos}(2\,\alpha - \psi) = 0.5 \operatorname{Cos}(\alpha + \psi) + 0.5 \operatorname{Cos}(3\,\alpha - \psi)$$

Leaving only the fundamental term containing α, and

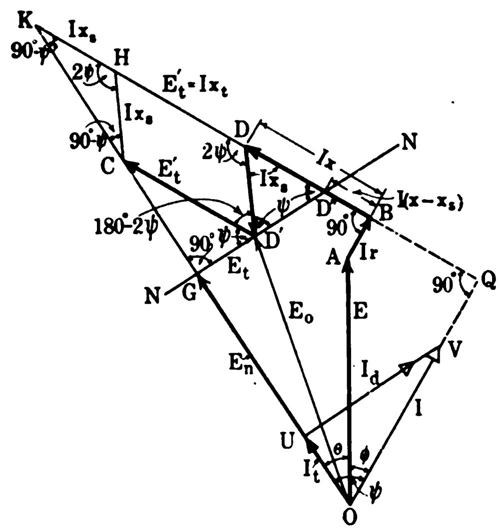

FIG. 2—A MODIFIED BLONDEL DIAGRAM OF A SYNCHRONOUS GENERATOR WITH THE AVERAGE REACTIVE DROP, Ix, AND SUPPLEMENTARY REACTIVE DROP, Ix_s

disregarding the term with $3\,\alpha$ (the third harmonic), *approximately*,

$$i_\alpha L_\alpha = L\,I \operatorname{Cos}(\alpha - \psi) + 0.5\,\Delta L\,I \operatorname{Cos}(\alpha + \psi) \quad \textbf{(5)}$$

The voltage drop due to these linkages is

$$e_x = d\,(i_\alpha L_\alpha)/d\,t = \omega\,d\,(i_\alpha L_\alpha)/d\,\alpha \quad \textbf{(6)}$$

Hence, taking a derivative of equation (**5**),

$$e_x = -\,\omega\,L\,I \operatorname{Sin}(\alpha - \psi) - 0.5\,\omega\,\Delta L\,I \operatorname{Sin}(\alpha + \psi) \quad \textbf{(7)}$$

The term $-\,\omega\,L\,I \operatorname{Sin}(\alpha - \psi)$ represents a sine voltage which leads the current wave by 90 deg. and corresponds to the average constant reactance

$$x = \omega\,L \quad \textbf{(8)}$$

such as ordinarily used in the theory of synchronous machines. The last term in equation (**7**) corresponds to a *supplementary reactance*

$$x_s = 0.5\,\omega\,\Delta L \quad \textbf{(9)}$$

The corresponding voltage drop, $x_s\,I \operatorname{Sin}(\alpha + \psi)$, *leads* the main reactance drop $I\,x$ by the angle $2\,\psi$, because

$$(\alpha + \psi) = (\alpha - \psi) + 2\,\psi \quad \textbf{(10)}$$

Thus, the following expression is reached for the vector of total reactive voltage drop in the armature:

$$\text{Reactive drop} = I\,x\,\underline{/90°} + I\,x_s\,\underline{/90° + 2\,\psi} \quad \textbf{(11)}$$

The quantities x and x_s are expressed by equations (**8**) and (**9**); the values of L and ΔL are shown in Fig. 1. The angle notation in equation (**11**) means that $I\,x$ leads the vector I by 90 deg. and $I\,x_s$ leads I by 90 deg. $+ 2\,\psi$. In other words, $I\,x_s$ leads $I\,x$ by $2\,\psi$.

II. A MODIFIED BLONDEL DIAGRAM

An application of these results to the Blondel diagram is shown in Figs. 2 and 3 which are generalized Figs. 40 and 41 in the "Magnetic Circuit." Fig. 2 represents a generator at a lagging current and Fig. 3 a motor at a leading current[6]. The current I is shown in both cases from the point of view of the machine itself (and not of the line) so that the phase angle ϕ, when the machine is operating as a motor, is greater than 90 deg. This method of representation is of advantage in that the same diagram and the same set of formulas cover operation both as a generator and as a motor.

Beginning with the line voltage E, Fig. 2, the ohmic drop $A\,B = I\,r$ is added in phase with the current, and the average reactive drop $B\,D = I\,x$ in leading quadrature with it. The supplementary reactive drop, $I\,x_s = D\,D'$, is added at an angle $2\,\psi$ to $B\,D$, in the positive (counter-clockwise) direction. In the case of the motor, ψ is greater than 90 deg., and $2\,\psi$ is greater than 180 deg. $E_0 = O\,D'$ is the total induced electromotive force. The direction $O\,C$ is that of the induced electromotive force at no load, or the center line of the pole. Hence, by constructing a right-angle triangle $D'\,G\,O$, with $O\,D'$ as hypotenuse, the net voltage $O\,G = E_n$ induced by the real poles is obtained, and the voltage $G\,D' = E_t$ induced by the fictitious (transverse) poles.

From equations (**83**) to (**85**) on p. 156 of the "*Magnetic Circuit,*" it will be seen that instead of drawing E_t normal to $O\,C$, a vector $D'\,C = E_t'$ can be drawn parallel to $I\,x$. This procedure is necessary when the angle ψ is not known, and in fact can be used to determine this angle, namely, by completing the parallelogram $D\,D'\,C\,H$ and extending $D\,H$ to its intersection with $O\,C$ at K[7]. In the triangle $K\,H\,C$ the angle at H is equal to $2\,\psi$ by construction; the angle at K is equal to 90 deg. $-\,\psi$, because $O\,Q\,K$ is a right triangle, and the angle at 0 is equal to ψ. Thus, in the triangle $K\,H\,C$ the remaining angle, at C, is also equal to 90 deg. $-\,\psi$.

6. The current and voltage notation has been changed from i and e to I and E; the induced voltage is denoted by E_0 in place of E. I has been defined above as the amplitude of the current. There is no objection, however, to considering I and E in the diagram as vectors of the effective values.

7. The point K is of considerable importance in diagrams of synchronous machines, and Blondel uses the term Joubertian e. m. f. for the value of $O\,K$. It is convenient to call K the Joubertian point.

The triangle is isosceles and consequently $H K = i x_s$. This gives the following construction for the angles ψ and θ:

Lay off $O A$ and $A B$, and draw the direction $B K$, normal to the current. Lay off $B K = I x + E_t' + I x_s$, and connect point K to 0. This will give both the internal phase angle ψ and the displacement of torque angle θ. The latter is the electrical angle by which the pole structure of the loaded machine is advanced (or retarded) with respect to an identical unloaded machine connected to the same bus bars.

If it is required to compute the required excitation, complete the diagram by laying off $B D'' = I$

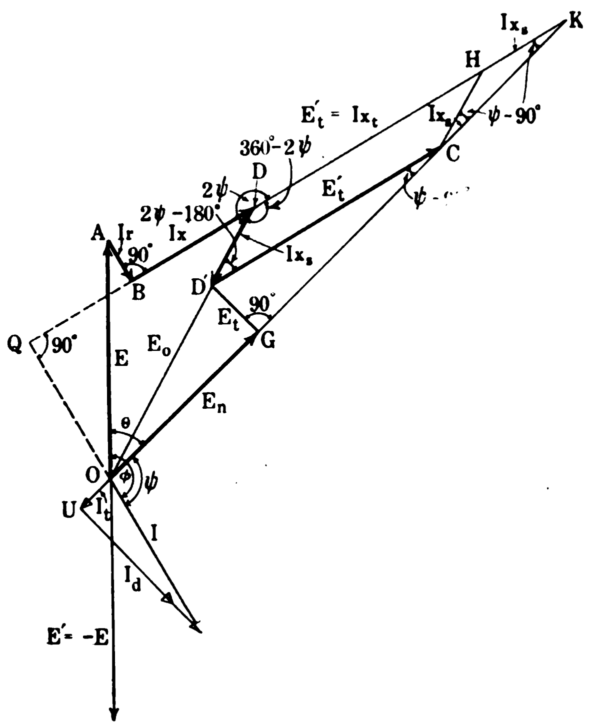

Fig. 3—A Modified Blondel Diagram, Similar to Fig. 2, for Synchronous Motor

($x - x_s$), and through D'' draw the straight line $N N$ normal to $O K$. This will determine the net induced electromotive force $O G = E_n$; from the no-load saturation curve, the corresponding net excitation, M_n, can be found. To this excitation, the direct armature reaction, M_d, is added [or subtracted, if sin ψ is negative, *ibid.*, equation (**79**)]. This will give the required field excitation, M_f, at that particular load.

Most of the construction lines and angles indicated in Fig. 2 are also shown in Fig. 3, and the description given above, with slight modifications, may also be followed in Fig. 3.

III. Analytical Solution

The heavily drawn polygon in Fig. 2 can be represented in the cissoidal complex form by the equation

$$E \operatorname{Cis} \phi + I r \operatorname{Cis} 0 + I x \operatorname{Cis} 90 \text{ deg.} + I x_s \operatorname{Cis} (90 \text{ deg.} + 2\psi) + I x_t \operatorname{Cis} 90 \text{ deg.} = (E_n + I x_t \operatorname{Sin} \psi) \operatorname{Cis} \psi \quad (\mathbf{12})$$

where

$$\operatorname{Cis} \phi = \operatorname{Cos} \phi + j \operatorname{Sin} \phi = \epsilon^{j\phi} \quad (\mathbf{12a})$$

and also

$$I x_t = E_t' = I k_t k_b m n v \quad (\mathbf{13})$$

[*Magnetic Circuit*, p. 156, equation (**84**)], so that the *transverse reactance*, corresponding to the transverse armature reaction, is

$$x_t = k_t k_b m n v \quad (\mathbf{13a})$$

Equation (**12**) expresses the fact that the geometric sum of $O A, A B, B D, D D'$ and $D' C$ is equal to $O G + G C$. To solve this equation for ψ, multiply both sides by Cis (90 deg. $- \psi$)[8]. The real part of the resultant expression is

$$E \operatorname{Sin} (\psi - \phi) + I r \operatorname{Sin} \psi - I x \operatorname{Cos} \psi - I x_s \operatorname{Cos} \psi - I x_t \operatorname{Cos} \psi = 0 \quad (\mathbf{14})$$

Dividing throughout by Cos ψ and solving for tan ψ,

$$\tan \psi = (E \operatorname{Sin} \phi + x_0 I) / (E \operatorname{Cos} \phi + I r) \quad (\mathbf{15})$$

where x_0 is the total equivalent reactance:

$$x_0 = x + x_t + x_s \quad (\mathbf{15a})$$

A reference to Fig. 2 will show that equation (**15**) could be written directly from the triangle $O Q K$, since in this triangle

$$\tan \psi = Q K / O Q \quad (\mathbf{16})$$

However, a derivation from equation (**12**) has been deemed to be of sufficient interest to be included in this paper for the sake of illustrating the general method of solution of such problems. This method is entirely automatic, while the particular geometric relations in a given problem may or may not be evident. The displacement angle θ is determined from the relationship

$$\theta = \psi - \phi \quad (\mathbf{16a})$$

for a motor θ is negative.

Equating separately the real and the imaginary parts on the two sides of equation (**12**), and solving each for the term with E_n, we obtain:

$$E_n \operatorname{Cos} \psi = E \operatorname{Cos} \phi + I r - I (x_s + 0.5 x_t) \operatorname{Sin} 2\psi \quad (\mathbf{17})$$

$$E_n \operatorname{Sin} \psi = E \operatorname{Sin} \phi + I (x + 0.5 x_t) + I (x_s + 0.5 x_t) \operatorname{Cos} 2\psi \quad (\mathbf{18})$$

Knowing the angle ψ from equation (**15**), E_n can be computed from either equation (**17**) or (**18**). When ψ is near zero, it is preferable to use equation (**17**); when ψ is nearly 90 deg., equation (**18**) will give more accurate results.

A graphical interpretation of equations (**17**) and (**18**) is shown in Fig. 4. This diagram is identical with Fig. 2, except that a line, $G W$, is drawn perpendicular to $O Q$. The lengths $D' R$ and $R G$ are each equal to $0.5 E_t'$. Equation (**17**) then simply means that

$$O W = O Q - W Q \quad (\mathbf{19})$$

while equation (**18**) states that

$$W G = R G + W R \quad (\mathbf{20})$$

8. Two Cis operators are multiplied by simply adding the angles; that is, Cis a. Cis b = Cis ($a + b$). This follows directly from the exponential expression in equation (**12a**); see also V. Karapetoff, *The Electric Circuit*, p. 93, equation (**154**).

Whether or not this graphical relationship will prove to be of further practical interest, remains to be seen. It has been deemed advisable to note it here, as a check on the formulas.

The theory deduced above has been checked on a machine with an exceptionally high leakage reactance. The assumption of a constant leakage reactance, deduced from the short-circuit test and from the design data of the machine, led to a wide discrepancy between the observed and computed performance characteristics.

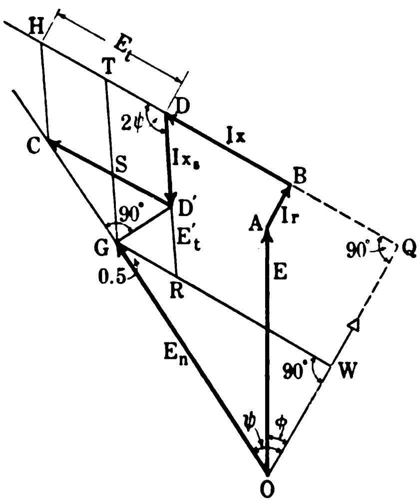

FIG. 4—A GRAPHICAL INTERPRETATION OF EQUATIONS (17) AND (18)

On the other hand, by assuming reasonable values of the average and supplementary leakage reactances, the current and voltage relations, as well as the torque angle θ, were found to agree quite closely with the test data[9].

In conclusion, the author wishes to express his appreciation to Mr. R. E. Doherty, Consulting Engineer of the General Electric Company, for suggesting this investigation and for encouragement while it was in progress.

CORRESPONDENCE

DISCUSSION ON ALTERNATING-CURRENT ANALYSIS ALTERNATING-CURRENT ANALYSIS (MERSHON)

To the Editor:

The statement which appeared in the May 1926 JOURNAL concerning the use in several text-books of the method presented by Mr. Mershon was hastily written on the basis of impression rather than fact. Since then I have attempted, but failed, to find the method in any of the usual texts. I take this opportunity to correct my error and apologize to Mr. Mershon.

HUBERT H. RACE

9. For a different treatment of the subject see R. Bruderlin, *Drehfeldmaschinen mit veränderlicher Reaktanz, Arch. f. Elekt.*, 1924, Vol. 13, p. 12.

PREDETERMINATION OF SELF COOLED, OIL IMMERSED TRANSFORMER TEMPERATURES BEFORE CONDITIONS ARE CONSTANT

The predetermination of temperature rise-time-curves for transformers is of the utmost importance for the calculation of permissible durations of overloading.

In the paper of *Mr. Cooney* in the JOURNAL of December 1925 methods are given to obtain a more accurate calculation of these curves. The special methods pointed out by the author are, first, the separation of the temperature rise of the winding above the ambiant air in the temperature rise of the winding above the oil and the temperature rise of the oil above the ambient air and, second, in taking into account the fact that the heat dissipation increases more rapidly than according to the first power of the temperature difference.

My note refers to this last point. The fact that the coefficient of cooling of a transformer increases with increase of temperature difference is expressed by the author in the formula:

$$\theta = k\,P^{0.8} \qquad \textbf{(a)}$$

This formula is used to calculate the final temperature rise at different losses (loads).

For the tracing of the temperature rise-time-curve the general known ϵ relation is used.

It seems to me that a temperature rise-time-curve still more in accordance with test curves may be obtained by taking into account the formula (**a**) also for the calculation of this curve. We shall give below a method by which this can be done.

The formula (**a**)

$$\theta = k\,P^{0.8}$$

can be written

$$\theta = \left(\frac{k^{1.25}}{\theta^{0.25}} \right) P \qquad \textbf{(b)}$$

By this formula it can be seen that the coefficient between brackets diminishes by increased values of θ. According to formula (*b*) the coefficient of dissipation will vary with the value $\theta^{0.25}$.

Thus, the value for the loss dissipated can be written:

$$K_f \frac{\theta^{0.25}}{\theta_f^{0.25}}\,\theta \qquad \textbf{(c)}$$

In this formula $K_f \,.\, \theta_f$ is the loss dissipated at the temperature difference θ_f, for the generated loss can be written

$$W = W_0\,(1 + \beta\,\theta)$$

W_0 is the loss for $\theta = 0$.

β is indifferent from α and takes into account the fact that the loss consists of iron and copper losses. Taking $\alpha = 0.004$ and the ratio between the iron and copper losses to be 1 : 3 the coefficient β will be 0.003.

The formula (3) of the paper can be written now as follows:

$$W_0 (1 + \beta\,\theta) = C \frac{d\,\theta}{d\,t} + K_f \frac{\theta^{0.25}}{\theta_f{}^{0.25}} \,.\, \theta$$

Taking the time constant:

$$T_\epsilon = \frac{C\,\theta_f}{W_0}$$

the following equation is obtained

$$\frac{d\,t}{d\,\theta} = T_\epsilon \frac{\theta_f{}^{0.25}}{\theta_f{}^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f{}^{0.25} - \theta^{0.25})} \quad \textbf{(d)}$$

The integration of this formula is difficult. The curve can be easily computed, however, by taking small

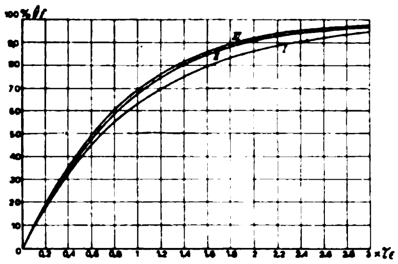

Fig. 1

intervals $\Delta\,\theta$ and calculating for the mean value of ||| θ of this interval the value of $\frac{\Delta\,t}{\Delta\,\theta}$. The time intervals can be obtained then by multiplying $\frac{\Delta\,t}{\Delta\,\theta}$ by $\Delta\ \theta$.

In this way the curve III of Fig. 1 is obtained. For θ_f is taken 100, for $T_\epsilon = 1$ and for $\beta = 0.003$.

Curve II is obtained by taking $\beta = 0.$, *i.e.*, by assuming the losses to be constant at all temperatures.

Curve I shows the well known ϵ curve.

In the middle part of the curves, III and II show a stronger curvature (radius of curvature smaller) than the curve I.

The fact that test values show generally the same deviation from the simple ϵ curve proves that the curve III is the more correct one.

Appendix

Derivation of formula (**d**).

$$W_0 (1 + \beta\,\theta) = C \frac{d\,\theta}{d\,t} + K_f \frac{\theta^{0.25}}{\theta_f{}^{0.25}}\,\theta$$

For $\theta = \theta_f$

$$W_0 (1 + \beta\,\theta_f) = K_f\,\theta_f \text{ or } K_f = \frac{W_0\,(1 + \beta\,\theta_f)}{\theta_f}$$

Thus

$W_0(1 + \beta\,\theta) = C\ \ d\,\theta - \ + W_0\,1 + \beta\,\theta_f$

$$W_0(1 + \beta\,\theta) = C \frac{d\,\theta}{d\,t} + W_0 \frac{1 + \beta\,\theta_f}{\theta_f} \frac{\theta^{0.25}}{\theta_f{}^{0.25}}\,\theta$$

$$W_0 \left[1 + \beta\,\theta - \frac{\theta^{1.25}}{\theta_f{}^{1.25}} - \beta \frac{\theta^{1.25}}{\theta_f{}^{0.25}} \right] = C \frac{d\,\theta}{d\,t}$$

$$W_0 \left[1 - \frac{\theta^{1.25}}{\theta_f{}^{1.25}} + \beta\,\theta \left(1 - \frac{\theta^{0.25}}{\theta_f{}^{0.25}} \right) \right] = C \frac{d\,\theta}{d\,t}$$

$$\frac{d\,t}{d\,\theta} = \frac{C\,.\,\theta_f}{W_0} \frac{\theta^{0.25}}{\theta_f{}^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f{}^{0.25} - \theta^{0.25})}$$

$$= T_\epsilon \frac{\theta^{0.25}}{\theta_f{}^{1.25} - \theta^{1.25} + \beta\,\theta\,\theta_f\,(\theta_f{}^{0.25} - \theta^{0.25})}$$

Thomas Rosskopf—Member I. E. C.,
Nijmegen, Holland

POSSIBLE DISCONTINUANCE OF RADIO STANDARD FREQUENCY TRANSMISSIONS

BY BUREAU OF STANDARDS

Since March, 1923, the Bureau of Standards has been transmitting, twice a month, radio signals of definitely announced frequencies for use by the public in standardizing frequency meters (wave meters) and transmitting and receiving apparatus. The signals are transmitted from the Bureau station, W W V, Washington, D. C., and from station 6XBM, Stanford University, California.

Since other means of freely disseminating the Bureau's standards of frequency are becoming increasingly available, the Bureau has considered the termination of the standard-frequency transmissions. The other means referred to are the lists of standard-frequency stations regularly given in the Radio Service Bulletin, published by the Bureau of Navigation, the use of piezo oscillators, and the wide availability of reliable standards and test service from a number of laboratories that do commercial testing of frequency meters. None of these means were available when the standard-frequency transmissions were inaugurated.

The standard-frequency transmission schedules already announced to extend through June and perhaps to October will be carried out as published, but the Bureau of Standards is announcing the possible termination of the service after that date in order that persons who depend upon the service in any special way may inform the Bureau of any objection to its termination, especially persons in the western part of the United States, who have been utilizing the signals from Stanford University, until the listing of standard-frequency stations on the west coast should have been begun. Letters on this subject may be addressed to Bureau of Standards, Department of Commerce, Washington, D. C.

Discussion at Midwinter Convention

SUPERVISORY SYSTEMS FOR ELECTRIC POWER APPARATUS[1]

(LICHTENBERG)

NEW YORK, N. Y., FEBRUARY, 9, 1926

C. E. Stewart: I should like, briefly, to call attention to one or two things of interest. In the first place, supervisory systems have passed the experimental stage. We have had actual service out of the systems so that we know that they are successful in the field for which they are intended. By the end of this year, systems put out by the General Electric Company alone will have supervision over some 2500 oil circuit breakers or their equivalent. We shall have in service a distributor type whereby a dispatcher at a central point will have supervision over breakers located in twenty-two out-lying stations.

Another very interesting application of supervisory systems will be made on an electrified railroad division sixty miles long between Chicago and South Bend, whereby a load dispatcher in Chicago will control eight automatic stations by means of a carrier selector system operating over one wire and ground-rail return. He will be able to start and stop any station, open and close the feeders going out from the station, and also control incoming lines in some cases.

R. J. Wensley: Mr. Lichtenberg says that telephone relays are not suited for supervisory control service. With this statement I do not agree. I would like to call attention to several installations in the New York area which depend entirely on telephone relays for reliability in operation. The equipments in actual operation seem to be the best refutation of Mr. Lichtenberg's condemnation of telephone relays.

The Long Island Railroad has one of the simple audible types in service controlling a remote 600-volt switch house. It is controlled by a dial and a howler gives an audible answer. It works over two wires and is the least expensive type of control.

This same company has a more elaborate equipment of the code-visual type in service at Amityville controlling one 2000-kw. converter in 600-volt railway service.

The New York Edison Company has a remote selective metering equipment in service at their Forty-First Street substation which transmits readings of volts and amperes over standard telephone cable.

The New York and Queens Electric Light and Power Company has a very comprehensive set of relay-visual equipment in the Woodhaven substation. With it they can control oil breakers, adjust induction regulators, bring in spare regulator and transformer when needed, and make necessary simultaneous readings of a-c. volts and amperes. These functions are all accomplished over telephone cable with a relatively few wires.

The most extensive equipment in this area is that on Staten Island. The equipment is used jointly by the Staten Island Rapid Transit Company and the Staten Island Edison Company. It is of the all-relay visual type. Five railway substations and one power-distribution substation are controlled from one dispatching point. Two separate-control desks use the same relay equipment to handle the business of the two operating companies.

H. C. Don Carlos (communicated after adjournment): In the operation of two generating stations under supervisory control, the Hydro-Electric Power Commission has encountered, among others, some very interesting protective problems. Although the final step in remedying certain troubles has not yet been taken, the following comments on them may be of interest to the profession.

The stations in question are near Campbellford, Ontario, on the Trent river, a navigable stream on which they form three successive developments with navigable reaches intervening. Ranney Falls or No. 10, the upstream station, is the point of control for Nos. 9 and 8, the total distance between plants 10 and 8 being three and a half miles. In No. 9 there are three vertical generators, each of 1400-kv-a. capacity, and in No. 8, three vertical generators of 2000-kv-a. capacity each. In common with a number of other stations, they supply power to a 44,000-volt, 60-cycle network, complicated by a large number of loops.

Since the navigation regulations limit the permissible variation of the level of the small reaches between the plants to about two inches, there is practically no storage available, and consequently very exact information is required at the control point on reach levels, plant output, gate openings (in tenths) of all turbines, as well as switch positions and various other control data. For each of the stations, something over fifty supervisory operations are performed in addition to the transmission of three graphic records. A twenty-pair standard, lead-covered telephone cable, located on a separate pole line, 25 ft. from a 44,000-volt power line, connects No. 10 to No. 9, and a ten-pair cable continues on to No. 8.

The No. 8 generating station went into operation under manual control, using automatic equipment, September 11, 1924, and under remote supervisory control, January 13, 1925. A great deal of trouble was at first experienced, which required patient study and careful analysis to eliminate. With few exceptions the equipment itself is now performing very well and gives promise of ultimate success if the disturbing effects of power short-circuits and lightning trouble can be overcome.

Soon after the supervisory cable went into operation, trouble began to develop in it, affecting one or more conductors each time, and occasionally actual burn-outs occurred. The more serious faults were traced down and eliminated, but after a time all spare conductors had been used, and finally we were left without sufficient clear wires to operate.

Induced disturbances due, to the proximity of the 44,000-volt power line, were at first suspected as the cause of our trouble, but theoretical considerations showed that since the sheath was grounded at all three stations, inductive effects could not be responsible. The use of insulating joints in the cable sheath, splitting it into numerous sections grounded at each end, was one of the proposals most frequently advanced by those who were not thoroughly familiar with the problem.

For various reasons, the sheath must be grounded to the apparatus ground of all three stations. The main trouble is caused by differences in potential between the so-called grounds (*i. e.*, the prevailing potential of the ground leads and steel work within the building) of any two of the three stations due to our inability to obtain a sufficiently high-capacity and low-resistance "ground."

This potential difference is uniformly distributed over the cable sheath (which carried a portion of the fault current) between the two stations. The conductors, however, are normally at uniform potential from end to end, and their insulation is quite unable to withstand the stresses due to the potential drop along the sheath, which may be upwards of 8000 volts.

This surprising figure has a simple explanation. The ground resistance at each of the three stations is in the order of two ohms each, and the cable-sheath resistance is nearly 10 ohms. The possible fault current is in the order of 3000 amperes. Duly considering the return distribution of fault current, calculations and tests indicate a probable maximum potential difference of 8000 volts.

It should be remarked that the frequency of our troubles is attributed to the use at No. 10 of a common ground for the power neutral and the station apparatus (the neutrals at Nos. 9 and 8 are not grounded), so that a 44,000-volt fault anywhere on the system causes a difference in potential between the station

1. A. I. E. E. JOURNAL, February, 1926, p. 116.

ground at No. 10 and those at Nos. 9 and 8. This, of course, occurs despite the fact that the power neutral is grounded at two other locations. To remedy this condition, a separate ground for the power neutral has recently been installed at a considerable distance from the station ground, as a result of which the station ground, in large measure, is freed from variations in potential due to fault currents in the neutral. When again in operation, the supervisory cable will thus be undisturbed by faults other than those at one of the three stations in question.

Among the numerous remedies considered may be mentioned:

a. The adoption of a-c. supervisory operation with transformers at each end of the cable completely isolating the conductors from the station ground, or from any apparatus connected thereto.

b. The use of a stabilizing ground conductor of sufficient admittance to limit the possible voltage difference between the three station grounds to an amount which would not prove injurious to the cable.

c. The use of transformers, the primary of which would be connected between the cable sheath and the station ground, and the secondary of which would consist of all the other conductors of the cable wound in close coupling and of such ratio (approximately 1:1) as to cause the conductors to follow approximately the same potential gradient as the sheath.

In addition to the foregoing, the idea of installing a highly insulated cable has been advanced, but this would not help matters since the supervisory equipment, which, in itself, will not withstand high potentials, would be still subjected to the severe stresses and cannot, according to the manufacturer, be protected against trouble of the nature described without blowing fuses which render it inoperative until an attendant makes replacements.

Of the three schemes mentioned, (a), which was developed independently by the Commission and the manufacturer, appears to have merit, but it is expensive and involves the use of additional equipment in the automatic train, and the consequent additional care and maintenance and risk of failure is objectionable. Plan (b) is also expensive, and lacking in some of the merits of (a), although free from its shortcomings. On the whole, (c), proposed by R. W. Osborne, telephone engineer of the Commission, seems to offer the greatest return for the investment, and the greatest promise of satisfactory ultimate operation. Preliminary tests of its behavior under transient disturbances are now pending.

It is interesting to note the manufacturer's contention that conditions exist in this installation which have not been encountered before, yet we are all agreed that the trouble is due to differences in potential between the ground conductors of any two of the stations. So far as I am aware, our ground resistances are not high for isolated plants and are not capable of any considerable improvement consistent with a reasonable outlay which can be relied upon the year round. In fact, the expensive proposition of ground stabilization by means of an interconnecting cable (scheme b) would be cheaper, and, if feasible, far more positive than an attempt to overcome the trouble by further improving the station grounds.

The question of how usual or unusual the conditions are can be decided by any interested engineer who has a general knowledge of the dependable minimum resistances of ground connections, and if he has any particular case in mind and knows the ohmic resistance of the grounds and the maximum fault current, he can calculate the probable resulting potentials in a supervisory installation from causes such as I have described.

In his remarks under the heading "Protection," Mr. Lichtenberg has shown a very open mind and has stated his interest in the experience of operating companies. Some of his views seem to be at variance with the conclusions drawn in the foregoing, and in support of these conclusions I can only add that practical operating experience as well as theory seem to be in agreement—a circumstance which always carries weight.

F. R. McBerty (communicated after adjournment): Mr. Lichtenberg's contribution on the subject of the maintenance of supervisory systems composed of telephone relays (which is in substance a repetition of his remarks before the meeting reported in the JOURNAL of August, 1925, page 879) demands some qualification in the records of the Institute. Mr. Lichtenberg's experience with such relays must have been both limited and unfortunate. Having participated in the design of the telephone relays most extensively used throughout the world and being now the manufacturer of an "all-relay" supervisory system for power equipments, I can perhaps offer definite and accurate information on these matters.

Mr. Lichtenberg is in error in his statement as to the fundamental ideas and assumptions present in the minds of the designers of telephone relays. The designers as a matter of fact did not work under the idea that the relays would be or could be inspected frequently or that some person would be present at one end or the other of a line equipped with them to note their failures and ensure their operation. On the contrary they had in mind that such relays would be used in great numbers, would be operated by persons intent on telephonic communication, would be operated in constantly shifting combinations which would make discovery of individual failure difficult, and would largely determine the reliability of telephone service. The designing and making of relays which should be both sufficiently cheap in cost and sufficiently reliable in service was so well done that there are now scores of millions of them in service throughout the world, of which a large part have been in operation for a quarter century performing thousands of millions of operations per day with a percentage of failure so slight that of all common causes of defect in the operation of telephone systems, the failures of telephone relays form a negligible factor.

Among manual-exchange systems composed of such relays there is no daily inspection, and in most cases not even an annual nor a decennial inspection or test; in machine-switching systems the faults due to relays are a trifling factor in comparison with the faults caused by step-by-step or power-driven moving switch mechanism.

The supervisory system illustrated in Fig. 12 of Mr. Lichtenberg's paper is composed of telephone relays of a type used for performing selection in the automanual city telephone exchange systems and in automatic or dial-controlled private exchanges. As an example, a single unit has performed on test more than fifty million circuit closings without failure or significant change in contact resistance. There are large city exchanges in operation in which the initial selections for all originating telephone calls are made by such relays comprising a total of about sixty thousand relays, some of which have been in continual operation for fifteen years, which are never inspected or tested and which collectively show failures or defects in operation numbering no more than two hundred cases per year in the performance of about five hundred million selective operations. In a particular large exchange the ratio of failures to selections is about one in five million. These relays have never been given routine tests and have had only occasional and in some cases, no inspection since installation.

Reference was made by Mr. Lichtenberg, in his paper dealing with the same subject matter reported in the JOURNAL of last August, to the wide range of temperature under which supervisory systems must operate. Relay selection gear fulfills these requirements far better than any other form of selecting mechanism in existence. As an example, there is an unattended remote-controlled all-relay telephone exchange in Ohio, which gives continual local and long-distance service to about 140 subscribers, situated at a distance of sixteen miles from a city and operated over a pair of control wires from the city, housed in a small building without any means of controlling temperature or hu-

midity. The relay selection equipment has developed only one fault in fourteen months, has had only casual inspection without any adjustment or repair whatever in seven months, and has been without even a visit from an inspector for ten weeks during the winter. During this time there have been no cases of interruption of service or of failures in selection traceable to the relay switching equipment.

The conspicuous merits of the relay selection systems composed of telephone relays, as compared with step-by-step, ratchet-driven and with rotary power-driven selective gear, are as follows:

The moving parts of the relays are pivoted armatures and long flexing flat springs only, with small and fixed ranges of movement with ample factor of safety in power working against relatively unchanging frictional resistance. The contacts themselves, when multiplied, are for all practical purposes free from failure. When properly constructed the relays never afterwards require adjustment or cleaning. The complications of the selective gear lie in the circuits, which being in the form of soldered and cabled wire net works are unchanging and permanent.

Such relays could readily be made much heavier and even more ornamental, but so far as I am aware there are no reasons other than personal taste to warrant the added expense. After all the function of a relay is to move a bit of bronze or platinum against another bit, and telephone relays do that very well.

On the contrary step-by-step or constantly moving selective mechanism is in all cases dependent upon the operation of relays, subject to whatever failures may characterize relays, with the additional handicap of being itself composed of numerous small moving parts—ratchets, pawls, retractile springs and brushes—among which accurate, minute, mechanical adjustments must be closely maintained under driving forces varying widely and against frictional resistance and inertia also varying widely. Its complications lie largely in nice relations of moving parts and forces. In order to be operative such mechanism universally requires rather closely regulated voltage, must be adjusted, lubricated, and kept free from dust and oxidized metal—conditions which change with use, atmospheric conditions and time.

Chester Lichtenberg: Supervisory systems, as mentioned in the paper, are new. Only a few of them have been in service sufficiently long to obtain experience with them. The discussion presented by Mr. Don Carlos is, therefore, exceedingly valuable since it presents in most thorough fashion an operating problem together with three suggested solutions of it.

The discussions of Messrs. Stewart, Wensley and McBerty present data which supplement that given in the paper and express opinions relative to operation. These opinions are indeed very valuable, since designers of supervisory systems will no doubt examine and take from them such suggestions as will prove of material benefit to the art.

A discussion of supervisory systems cannot be concluded without again making clear the fact that these systems are quite different from remote-control systems and, therefore, their application must be carefully made if they are to be successful.

THE CROSS-FIELD THEORY OF ALTERNATING-CURRENT MACHINES[1]

(West)

New York, N. Y., February 11, 1926

P. L. Alger: Mr. West has presented in his paper a business-like and accurate way of obtaining the characteristics of an a-c. motor. The method is particularly adapted, and, in fact, was especially intended, for use by engineers having to do with large numbers of motors. Probably we all agree that the circle diagram, or some similar graphical method, is most suitable for college instruction, and for use by persons only dealing with motors occasionally. When large quantities of motors are to be designed, however, it is necessary to take into account many of the minor features of the theory, and, at the same time, to make the method extremely systematic. Thus, I am heartily in sympathy with the point of view which Mr. West expounds so thoroughly.

While the title of the paper emphasizes the cross-field theory, the same method could be used equally well with the rotating-field theory, for most machines. It is my opinion that both the rotating-field and the cross-field theories have advantages in particular cases, and that a complete understanding of design can be obtained only by a mastery of both theories. So far as I know, there is only one respect in which the two theories give different results.

This one exception occurs when the secondary winding of a single-phase machine has sufficient skin effect to make its effective resistance and reactance at line frequency appreciably different from their values with direct current. Since the actual current in any one secondary conductor consists of components of two different frequencies, the two components encounter different impedances, and so the effective voltage across the conductor is not equal to the product of the total current by any definite value of impedance. The cross-field theory treats the entire current in one axis as being of line frequency, and so does not take into account the variation of impedance with frequency. On this account, the rotating-field theory gives more accurate results for machines of this type.

I believe that the obvious objection to Mr. West's method, that it is very complicated, can be largely overcome by a study of the formulas, and their rearrangement into a form consisting of a principal term and various corrective terms. For example, if the magnetizing reactance is large by comparison with the leakage reactance, many of the formulas can be simplified by expressing them in power series in terms of $\frac{x}{X_m}$, and then neglecting higher powers than the first of this ratio. In some cases, the most complicated formulas can be put into a simple and usable form by assuming average values for certain of the less important constants, and preparing charts showing the effects of variations in the major constants. Then, correction formulas can be made up, showing the effects upon the result of changes in the minor variables made independently, and these auxiliary formulas can be used whenever especial accuracy is desired.

I believe that the ultimate design method is one which takes into account all of the variables, but only carries the result to the desired accuracy, and no further.

K. L. Hansen: In his analysis of the single-phase, induction motor, Mr. West has followed the usual and much discussed method of the cross-field theory. He has, apparently, introduced a slight modification by adding the secondary leakage flux to the mutual flux in the expressions for some of the induced voltages. The introduction of this refinement is, however, incidental and is obviously not the main object of the paper.

In the opening paragraph the author states that some phenomena are more easily understood by a study following the revolving-field theory, and other phenomena are made more clear by use of the cross-field theory. This statement, in connection with the title of the paper, would naturally lead one to believe that some distinct advantage of the cross-field theory over the revolving-field theory would be pointed out, at least in the specific instances which the author has chosen for illustration. The paper does not fulfill this expectation.

According to the author, the choice of methods should depend on what is most desired, *e. g.*, speed, accuracy, or aid to visualization. From the standpoint of speed and accuracy the cross-field theory obviously offers no advantage over the rotating-field theory. From the standpoint of visualization or physical conception the cross-field theory appears to be rather inferior to the rotating-field theory. Indeed, at the very outset an artifice

1. A. I. E. E. Journal, February, 1926, p. 160.

is resorted to of considering the squirrel cage as the equivalent to a commutated winding with brushes bearing on the commutator short-circuited on themselves in the transformer and field axes.

There can be no objection to replacing the actual circuits we are dealing with by artificial equivalent ones when something is gained from the standpoint of clearness or shortening of the analytical work; but in this instance nothing is apparently gained thereby. In the revolving-field theory the squirrel cage is considered to be exactly what it is—a system of polyphase circuits. It seems that the currents flowing in the artificial secondary circuits employed by the author are of constant frequency and that therefore the secondary reactance x_2 is a constant quantity independent of the slip. Have the calculations in the paper been made on that assumption, and if so, do they lead to correct results?

A few years ago a writer in the JOURNAL argued that when several theories are advanced to explain the same phenomena, economy of thought demands that all but one of these theories be abandoned, unless each of the several theories possesses distinct advantages not possessed by the others. He then proceeded to make a misapplication of the revolving-field theory, and as his deductions naturally were in error he concluded that the revolving field theory is more liable than the cross-field theory to lead to erroneous results. He also was laboring under the delusion that the revolving-field theory is not applicable to commutator motors, and therefore advocated that this theory be abandoned in favor of the cross-field theory.

The present writer's opinion is that the point of retaining, in the interest of economy of thought, only one theory to explain a certain set of phenomena, is well taken; but I can not agree that in this case the revolving-field theory should be abandoned. My preference for the revolving-field theory is that is appears to be the more general one of the two. If the two components of the revolving field are equal, we have a single-phase system; if they are unequal, we have an unbalanced polyphase system. If one component vanishes, we have a balanced polyphase system, and if the angular velocity of the rotating field is equal to zero, we have a direct-current system. In other words, all phenomena of rotating electrical machines can be explained as special cases of the general theory based on two oppositely rotating magnetic fields.

H. R. West: I agree with Mr. Alger that the best method of calculation is that which gives results of the necessary accuracy, and no more, with the least amount of labor. On the other hand, I cannot accept the statement that the methods of calculation that I have given are very complicated. The greater part of the work of calculating a motor is contained in the tabulated part. Examination of this tabulated part of the calculation will show that nearly all of the rows of numbers are obtained with only one setting of the slide rule, or merely by addition. With a very little practise, one will find that the calculation can be carried through very easily and quickly. The method given for the single-phase induction motor has been compared in actual trial with the most up-to-date methods of accurately calculating the polyphase induction-motor characteristics, and although it has been found to be somewhat more laborious, as obviously it must, since the operation of the single-phase, induction motor is very complicated in comparison to that of the polyphase motor—still it is found to be comparable in the amount of work and time required. Furthermore, anyone who can use a slide rule can carry out the calculation completely. It is not necessary for him to know anything about motors or electric circuits in order to carry out a complete calculation.

There are some very obvious approximations that can be made in the calculations, particularly in calculating the constants F_n and G_n. These approximations would result in very little more than an apparent reduction in the labor of calculating, and therefore the expressions were given in full for the sake of completeness.

As Mr. Alger suggests, a systematically arranged calculation form would probably be found equally helpful in calculating the characteristics of a motor from equations that might be derived by the revolving-field method. However, I do not believe that the revolving-field method of analysis will lead as directly to equations or formulas that are most useful for calculation purposes.

Mr. Hansen calls attention to the terms in my equations that represent the speed voltages corresponding to the rotor leakage fluxes. The inclusion of these terms is not new[2] with the author, although they have been neglected by some writers, generally with only very slight effect on the accuracy of the results.

The correctness of the results that have been obtained by the cross-field method of analysis has been questioned by Mr. Hansen. The exact equivalence of the results obtained by the revolving-field and cross-field methods was demonstrated several years ago[3]. Furthermore, examination of the analytical expression which Mr. Hansen derived for the line current taken by the single-phase induction motor in his very instructive paper[4] on the rotating-field theory will show that his equation is exactly equivalent to the corresponding one of my paper.

Reply to the remaining portions of Mr. Hansen's discussion must consist largely of repetition of the ideas expressed in the opening paragraphs of my paper. Both methods have their own advantages, depending partly on the types of motors. For instance, it is obvious that the revolving-field method should be used for the balanced polyphase induction motor, and the cross-field method should be used for the a-c. series motor. At the same time, I believe that a study of both of these motors from both points of view will often be found worth while. In the case of the single-phase induction motor, which seems to offer the most debatable ground in regard to the cross-field and revolving-field methods, it seems that the revolving-field method is much superior for the purpose of giving a mental picture of how the motor works. At the same time, I have found that the cross-field theory adds to and clarifies that picture. On the other hand, I am convinced that the cross-field method of analysis is more useful for exact analysis, since it leads directly to results that are immediately useful for exact numerical calculation without the necessity of making two separate calculations for a polyphase motor and then combining them.

As Mr. Alger has pointed out, there seems to be only one case in which the revolving-field method can be used and where the cross-field method cannot be used, *i. e.*, where the rotor inductances depend upon the frequencies. Otherwise, one method seems to be as general as the other.

The paper was not intended as an attempt to prove the general superiority of one method over another for any particular motor, but to demonstrate the possibility of using the cross-field method of analysis to obtain readily usable, accurate, numerical methods of calculation of motor characteristics. My experience leads me to believe that such methods of calculation can be most readily derived by the use of the cross-field method, in the case of many kinds of motors, particularly single-phase motors.

DEVELOPMENT AND APPLICATION OF LOADING FOR TELEPHONE CIRCUITS[5]

(SHAW AND FONDILLER)

NEW YORK, N. Y., FEBRUARY 9, 1926

Bancroft Gherardi: The invention of loading and the development of telephone repeaters have, together, revolution-

2. See, for instance, Arnold, Wechselstromtechnik. V 1.
3. Arnold, Wechselstromtechnik, and Karapetoff, JOURNAL A. I. E. E., Aug. 1921.
4. JOURNAL A. I. E. E., February, 1925.
5. A. I. E. E. JOURNAL, March, 1926, p. 253.

ized the engineering of toll-line plants in the United States. For the invention of loading we are indebted to Dr. Pupin.

Before loading was invented, cable was to toll-telephone transmission much the same as strychnine is to the human system. Any great amount of cable produced definitely unfavorable reactions. The advent and application of loading produced a substantial change in this situation. Whereas, before loading was available, a toll-line cable of even twenty or thirty miles in length presented a serious problem which could only be solved by the generous use of copper, loading very much extended the range of cable so that practical toll cables of even 200 mi. length were available. With the advent of telephone repeaters and their use in combination with loading, toll cables 1000 mi. in length or even longer became practical and economical.

Today we are giving commercial telephone service regularly through cable between Boston and New York on the one hand and Chicago on the other. Before the end of 1926 New York and Boston will be connected by an all-cable route to St. Louis. From Boston to St. Louis it will be about 1400 mi. following the route of the cable.

Many other important cable routes are completed or now under way so that within a few years the principal toll routes in the northeastern section of the United States will be cable.

There are several advantages in this type of construction. On the more congested routes right-of-way problems would have been formidable without cable. Between New York and Philadelphia, by the end of this year we would have required twenty 60-wire pole lines to take care in overhead construction of the circuits that we shall have in cable. The maintenance of these lines under unfavorable conditions would have been a formidable problem.

To some, it might appear that the loading coils and repeaters would necessarily be a somewhat incidental factor in the total amount of construction involved in the toll-line cable. This is not the case. Considering a cable between New York and Chicago, it is found that only about 50 per cent of the total cost of the cable is in the cable itself and the structure supporting it.

F. B. Jewett: In looking over the paper and in casting my mind back over the history of my connection with the telephone business (which is in point of time almost coincident with the span of time in which loading has been a factor) I was interested to recall the several steps through which this whole art of loading has gone from the days when it was first presented through Dr. Pupin's work. My mental review included the early stages of our attempts to use loading up to the present time when it is recognized as a factor of very great importance.

I chuckled to myself as I thought of a time, nearly twenty years ago, when we thought our development work as applied to loading was nearing completion. The word went out that we ought to hustle up the work we then had in hand and button up this loading development so that it would be standard for all time and we could take our forces off and go to other things. Well, just as in the case of all things of an engineering nature which have real continuing merit, so it is in the case of loading. Being a real thing, there is no end to the development work and the field of application continues to grow. As the paper states, there are more men engaged in loading development problems today than there ever were in the history of the work; also the problems which open up before us as possible of solution through loading and the combination of loading with repeaters, are more extensive now than they ever have been in the past.

As a result of the work to date, which has resulted not only in improvements in kind but in cheapening the forms of loading, we are continuing to reduce the size and length of circuits on which it is economical to apply loading. At any given stage of the development of a thing like the loading coil, there comes a time when although physically possible of use on certain kinds of circuits, it is economically not feasible to use it because it is cheaper to get the desired result in some other way. But, with the cheapening of loading coils and their improvement, the gage and length of circuits on which loading is commercially applicable and advantageous have been reduced until we are approaching the point where it would appear to be economical to use loading on wires as fine as it is mechanically possible for us to employ them.

As the paper indicates, the development work started by the requirements of loading per se, has ramified in all sorts of unexpected nooks and crannies. It has expanded to include electrochemical processes, matters of tool design for the utilization of those enormously powerful presses for forming the core material, special machinery for winding coils, the kinds of insulating material, a thousand and one things which you wouldn't ordinarily think of as being connected with loading-coil developments. Loading-coil developments have also had profound effect on the methods of line construction. The precision with which we have to space these coils, the accuracy with which we have to maintain the balances between the parts of a circuit and the circuits themselves—all of these things indicate what a vast engineering field has grown up as a result of this thing which appeared relatively so simple.

Just one point in closing: I have no statistics to give but will mention one interesting calculation to indicate what the traffic possibilities are in a group of circuits of modern structure, equipped with loading coils and with modern repeaters. Mention has been made of the New York-Chicago cable. That cable in the main, as far as I know, is a cable of standard size. That means it is a cable which has an outside diameter of 2⅝ in. The lead sheath is ⅛ in. thick and inside there is a core of paper-insulated wires. It is primarily a telephone cable. Just as an illustration, let us consider what the communication-carrying capacity of this telephone cable would be if it were used just as it stands for telegraph purposes instead of telephone. With the voice-frequency multiplex system, it is possible to obtain about ten telegraph channels per telephone pair. If each of these telegraph channels were equipped with multiplex printing telegraph apparatus commonly used by the Western Union Telegraph Company, we could operate about ten thousand printer circuits in each direction. Working simultaneously at their normal speeds, it would be possible with this set-up to transmit between New York and Chicago the whole contents of a New York daily newspaper, exclusive of advertising material, in less than two minutes.

M. I. Pupin: The authors mentioned that it is convenient to discuss the coil-loaded line in terms of its corresponding smooth line. I should like to add one word to that statement —that it is still convenient—because I discussed it that way twenty-six years ago, in my first paper before the American Institute of Electrical Engineers. They also say that "Professor Pupin gave his famous solution in a paper presented before the Institute in May, 1900." That is a very complimentary statement but I should like to see that compliment completed. I should add that in that paper was also given the fundamental mathematical method of treating networks, filters and balancing networks. Before that time no one knew anything about it. They call them filters in West and Bethune Streets. At Columbia University we call them pilot conductors. But they are more persistent than we are, and so they have their own way. But the theory of the filters was first given at Columbia University and not at West Street.

Now, having said all the disagreeable things that I can think of, I am going to add another one which is not so very disagreeable perhaps, or perhaps more so. They talk of the loading coil, the toroidal loading coil. There is a very, very important bit of history attached to that. When I came out with the toroidal form of the loading coil, the engineers of the American Telephone & Telegraph Company couldn't see any virtue in it at all. It took them some time to recognize its virtues but when they did, they recognized them very clearly. Since that time they have been eliminating all other forms of coils that they

employed by the hundreds of thousands in their business.

Now I won't be disagreeable any more. The work that that company has done upon the development of the toroidal coil (invented at Columbia University and not in Bethune St.) is most remarkable. The development went on with a steady progress until today they have a coil that represents scientific research efforts perhaps unequalled by anything else that has happened in the telephone art during the last twenty-five years, since I made the invention.

It is a remarkable result and I think by next year they may have another announcement to make which will be even more remarkable than anything else they have announced so far, but I am not at liberty to talk about that.

It goes without saying that, in the course of the development of an invention, other things are brought in to supplement the invention and it speaks very highly for the loaded telephone cable that it is supplemented so beautifully by the telephone repeater of the vacuum-tube type. A fellow who can't associate with anybody else is not a very good fellow as a rule. An invention that can't stand the companionship of other inventions is probably a poor invention. The loaded-conductor invention takes the repeater invention into its arms and they hug each other and make a beautiful pair of congenial companions. That to me is more encouraging and more complimentary to the loaded-conductor invention than anything else that has happened. Attempts have been made to supplant the loading coil, to get along with repeaters only by adding attenuation equalizers, but they didn't prove practicable. This created the impression in places that the loaded-conductor invention was dead and a friend of mine came to me one day and repeated a sentence which I published in a book some time ago: "Inventions grow old and are superseded by other inventions."

Some one once said to me, "Isn't that a sad expression, Professor? Doesn't that indicate that your invention is dead?"

That doesn't refer to my invention at all. If it did I wouldn't have put it there. It would betray too much disappointment and I dislike exhibitions of disappointment. No, the invention is not dead; it is still alive and quite vigorous.

It is very true, as Mr. Shaw has said, that not even a very small fraction of the hundred million dollars is in my pocket. Anybody can see that; and it isn't in the pockets of the Telephone Company either, which is not quite as obvious. It is in the pockets of the people of the United States, where it belongs, and they will get a great deal more in their pockets in the course of time, because every year the combination of loading and telephone repeaters is saving an enormous amount of money to the people of the United States. And what is it producing? It is producing an effect for which Washington and Lincoln longed. Washington thought of nothing so much as of the consolidation of the American Union. Lincoln, much against his will, even went to war for the purpose of saving that Union and consolidating it.

Now when you hear of that beautiful telephone system, from Boston to New York, to St. Louis and to all the big centers in the United States, tell me of something else that has that power of consolidating the American Union! There is nothing else unless it be the radio broadcasting. That is another electrical art but that is not a part of the paper.

Who has produced this wonderful art which is producing this wonderful effect? I read another passage from my book: "It is not so much the occasional inventor who nurses a great art like telephony and makes it grow beyond all our expectations as it is the intelligence of a well organized and liberally supported research laboratory," like the Bell Telephone Laboratories at West and Bethune Streets, which I have been abusing so much.

The industries of this country have finally discovered the correct method of doing things. Their great research laboratories take the more or less crude ideas of individuals and develop them and put them together as the American Telephone and Telegraph Co. has put together the loaded conductor and the telephone repeater. This is creating one of the finest telephonic systems that the world has ever known, and has gone far beyond our expectations.

The paper testifies to that better than anything I have seen.

William Fondiller and Thomas Shaw: Dr. Jewett has referred to the early stages of loading development work, and recollected that it was thought at that time that loading was to be standardized for all time so that the engineers might give their attention to other problems. While such a consummation may have appeared very desirable to some at that time, new developments in materials and processes and in methods of operation continually open up new fields of investigation and design. Our paper has attempted to chronicle the major steps in this development.

In considering Professor Pupin's discussion, the authors very much regret that he appears to feel that they have not fully recognized his contributions to this art, and that as a result of this has made several remarks which he designates as "disagreeable things."

The paper refers to Professor Pupin's famous solution of the coil-loaded transmission line. It is so generally known that it hardly requires repetition that Professor Pupin obtained the fundamental patents on the coil-loaded line and the toroidal form of loading coil.

As stated at the beginning of the paper, this does not attempt to cover the origin of loading or the early developments of the art, as these have been treated quite fully in earlier papers, particularly Mr. Gherardi's 1911 paper before the Institute. The loading-coil invention, as was true of Bell's original invention and as is true of nearly all important advances ,was not without its controversies. This is similarly true of the developments in filters and balancing networks which Professor Pupin also mentions. Any reference to these past controversies is entirely aside from the purpose of the paper.

Now, about that part of Dr. Pupin's discussion relating to the beautiful companionship of the loading invention and the repeater invention, a casual reading of the paper may lead one to infer that the application of repeaters to loaded circuits was easily accomplished. Be it understood, however, that the paper is a statement of end results, rather than a detailed account of the difficulties which had to be overcome to reach these results; in fact a great deal of investigation was required, extending over a number of years, before it was commercially possible to combine phantoming, loading, and repeatering telephone circuits. A study of the line characteristics indicated that the failure of the early types of loading coil to maintain the necessary stability was principally responsible for the inability of the repeaters to get along with the loading coils. Development of new magnetic materials and improved construction methods were required before these obstacles were overcome.

METHODS OF HIGH QUALITY RECORDING AND REPRODUCING OF MUSIC AND SPEECH BASED ON TELEPHONE RESEARCH[1]

(Maxfield and Harrison)

New York, N. Y., February 9, 1926

C. R. Hanna: The following discussion applies particularly to that part of the paper dealing with the reproducing mechanism. The relative merits of the several improvements that were made are not clearly brought out in the paper and it is the purpose of the writer to compare the importance of the various developments.

In listening to reproduction from one of the new-type phonographs, the average person is impressed with just two things; first, the apparent greater volume of sound, and second, the great improvement in the response at low frequencies. The greater volume of sound is due partly to the fact that there are more low frequencies present, and perhaps, in a measure,

1. A. I. E. E. Journal, March, 1926, p. 243.

to the fact that the diaphragm is one which acts like a piston, causing a greater volumetric rate of displacement of air into the horn for a given needle velocity than with the old type of flat diaphragm.

The improvement in the low-frequency characteristic of the reproducer, as described, could not have been obtained without the use of the slowly expanding logarithmic or exponential horn. The authors refer to the work of Arthur Gordon Webster in this connection: the general properties of the exponential horn were given in his National Academy of Science paper of 1919. Webster did not, however, carry his work sufficiently far to show the properties which the authors have stated in their paper; namely, that the exponential horn is a uniform radiator of sound down to a certain frequency, known as the cut-off frequency, which is determined by the rate of increase of section and the area of the large end of the horn.

The authors cite some work (as yet unpublished), by Messrs. Flanders and Thuras, in which these properties are shown both theoretically and experimentally. I desire to call attention to the fact that the paper by Hanna and Slepian on "The Function and Design of Horns for Loud Speakers"[2] showed these same properties for the exponential horn. The equation for such a horn is

$$A = A_0 \epsilon^{Bx}$$

where

A = Area at any point

A_0 = Initial area

x = Distance from initial area, cm.

B = Constant which determines the rate of increase. It was demonstrated that the cut-off frequency is determined by the relation

$$\frac{2\pi f}{B} = \frac{a}{2}$$

where a = velocity of sound. From this it is seen that the smaller B is, the lower will be the cut-off.

The radiation characteristic of the infinite exponential horn

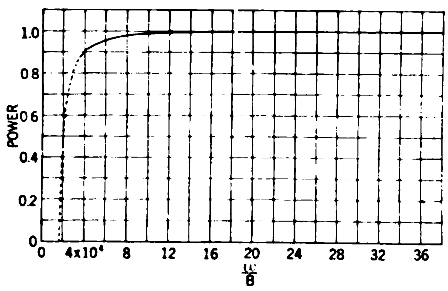

Fig. 1

for a fixed velocity of air in its throat was also shown in the paper by Hanna and Slepian. Fig. 1, herewith, shows this curve. The abscissas are $\frac{\omega}{B}$ and the ordinates give the comparison between the exponential horn and the infinite straight pipe which is a uniform radiator down to zero frequency. The cut-off point is seem to be as stated above.

It was clearly brought out in this paper that an exponential horn could be made with much smaller dimensions than any other shape of horn giving equal performance. A comparison was also shown between a particular exponential horn and a conical horn of equal length and terminal dimensions. This is given in Fig. 2, the superiority of the exponential horn being quite pronounced. Up to this time many persons had advocated the conical horn. It is believed that this paper was the first to show the superiority of the exponential horn.

2. A. I. E. E. Transactions, 1924, page 393.

Now, taking up the matter of the final or large area of the horn, as is pointed out by Maxfield and Harrison, if this area is large enough to prevent end reflections in the range of frequencies where the horn is a good radiator along its length, a horn will be secured which has very little resonance. The curves of Fig. 3 were presented by Hanna and Slepian to show the variation of reflection with frequency and area. The curves indicate that the smaller the area and the lower the frequency, the greater will be the reflection. It is seen, however, from the curve for

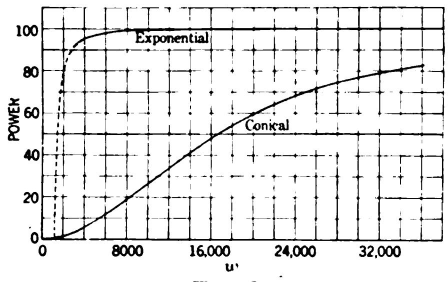

Fig. 2

the largest area, that the reflection becomes appreciable only in the range of frequencies where the horn ceases to be a good radiator along its length. Hence it follows that a horn of this shape can be designed with no marked fundamental resonance.

The degree of horn resonance and the position of the cut-off frequency as indicated by Fig. 20 of the Maxfield and Harrison paper agree very closely with values that can be predicted from the curves of Figs. 1 and 3 in this discussion.

The very careful proportioning of masses and compliances in the mechanical system of the reproducer has played only a minor part in the securing of a more uniform frequency-response characteristic than in the older types of phonographs. The slight extension of the upper frequency range may be attributed to the accurate design of mechanical parts. It should be pointed out, however, that since the phonograph record is a constant-current (or velocity) generator, the impedance of the mechanical system does not have to be uniform over a wide band of frequencies for it to be forced to vibrate in accordance with the vibrational velocity of the record. A departure from this fact, not apparent from the electrical analogy given by the authors in their paper, is the ability of the whole arm of the reproducer to vibrate in the low-frequency ranges instead of just the diaphragm mechanism. This may be overcome either by increasing the mass of the arm or, as the authors have done, by reducing the stiffness of the diaphragm.

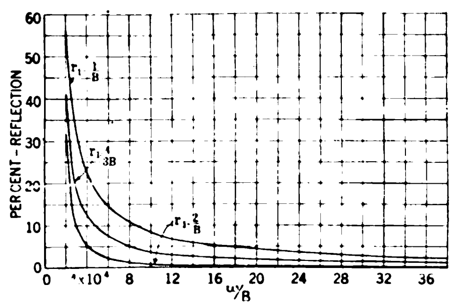

Fig. 3

Great credit is due the authors for the design of a mechanical system which is light and resilient, enabling the needle to track the record with small reaction force (and consequent decrease in wear) at the high frequencies where the accelerations are great, and at low frequencies where the deflections are great. The big improvement in the quality of reproduction, however, is due to the use of an exponential horn whose rate of increase

of section is very small and whose final section is quite large.

E. W. Kellogg: I think most of us have thought of the rocking arm, which connects the needle with the diaphragm in a phonograph, as a simple lever, rigid enough so that when the needle moves one way, the diaphragm moves the opposite direction by a corresponding amount. If we could see what is really going on during a high-frequency vibration, we should probably find that the motion was more nearly like that of a snake. Messrs. Maxfield and Harrison and their associates have accepted the wave-motion picture and based their design upon it. The most striking resultant change in design is the interposition of a flexible link, or spring, between the end of the lever and the diaphragm. On first thought, it seems like deliberately throwing away some of the available motion, but the result is quite the opposite. I refer to the spider through which the diaphragm is driven.

If telephonic currents are to be transmitted without distortion over a high-efficiency line of length exceeding a sixth of a wavelength for the highest frequencies, the line must end in a non-inductive resistance of a definite value. A corresponding resistance is required in a mechanical system. In the case of the reproducing system the required resistance is obtained from the sound radiation of the diaphragm. But for the cutting tool, some other resistance must be found. In an electrical circuit nothing is easier to get than resistance, yet its mechanical counterpart is by no means easy to obtain. Sliding friction is not at all suitable. Motion in viscous fluids and electromagnetic drag, such as used in wattmeters, are true analogs. I wish to draw an illustration from the case of electromagnetic drag. An aluminum ring, weighing about four grams, surrounds a magnet pole, so that it is in a radial field of about 10,000 gausses. If one pushes it up and down, it feels as if it were in thick molasses. Under its own weight it settles about one millimeter per second. Yet if this ring is vibrated in an axial direction at 4000 cycles, its mass so predominates over the resistance that the power factor is only about 40 per cent. Mechanical hysteresis is another means for absorbing energy from vibrations. Rubber has long been used for such purposes. But rubber, so far from being pure in mechanical resistance, is a spring with a power factor of only about 10 per cent. I think the authors of the paper are to be complimented upon the ingenious device by which they obtain with the use of rubber a practically pure resistance with which to load the cutting tool. It should be borne in mind that the damping required for the cutting tool is of an altogether different order of magnitude from that which many of us have employed to take out the resonance peaks from loud-speaker diaphragms and similar applications.

The paper mentions methods of measuring mechanical impedances. I should be much interested to hear something further of the means used, for the problem presents many difficulties, and the results of such measurements would find many applications.

One statement in the paper causes considerable surprise. The knife edge was discarded because it has too great an elastic yield, and because it brings in too much rotational friction. The knife edge, of course, must work with an initial pressure exceeding the maximum force on the bearing, due to the vibrations, and is not well adapted to stand forces in more than one direction, but, in the case of the pivot for the reproducing lever, one would expect a well designed knife edge to work very satisfactorily.

L. T. Robinson: I am in agreement with the statement of the authors that, "There is therefore no distortion in the record whose purpose is to compensate for errors in the reproducing equipment." In employing so many elements, some of which can be so readily modified in performance the temptation is very strong to look only at the final result and not be too critical as to where any corrective treatment is to be administered. I hope the stand taken by the authors will be firmly adhered by them and others who are working along similar lines. In this way, any progress that has been made, or will be made, becomes permanent.

Speaking of the electrically-cut record in general, we need not, for the moment, be concerned with minor details of the process. The results already obtained are so good that we may feel sure that the electrically cut record has come to stay and will place the phonographic art on an entirely new plane of excellence.

The mechanical reproducing system described by the authors is a distinct advance over former phonographs. However, I feel that full realization of the advantage of the electrically cut record will come through electrical reproduction.

One great advantage of the electrical method of reproducing is that the control of the sound volume is obtainable quite independent of the cut on the record and the cut on the record is controllable with consideration for the best conditions for the record alone. The advantages of such separation can be learned from the paper if it is read with this point in mind.

Volume of the sound reproduced is quite important and reproduction to be quite satisfactory must be about equal to the volume of the original sounds. A loud tone produced on a given musical instrument is quite different from a soft tone produced on the same instrument and reproduced with larger volume.

A. E. Kennelly: We have here presented to us the wonderful analogy which underlies mechanical and electrical phenomena, with mechanical phenomena interpreted in electrical terms.

We have long known that mechanical inertia was really electrical, and now we are finding that all these mechanical phenomena are primarily electrical quantities.

J. P. Maxfield: There are one or two technical questions brought out in Mr. Hanna's discussion which are of interest: The first deals with the statement that the new reproducing mechanism has a greater apparent volume of sound. In this connection, it is interesting to note that the response curves of the new and the old machines shown in Fig. 20 indicate that in the frequency region from around 800 to 2000 cycles per second, the old machine produced a louder sound for a given needle velocity. It will be seen, therefore, that this apparent increase in volume has been obtained by the widening of the band reproduced rather than by increasing the amount of energy radiated in that frequency band in which the old machine was most efficient.

The other point of interest refers to his statement that "The very careful proportioning of the masses and compliances in the mechanical system of the reproducer has played only a minor part in the securing of the more uniform frequency response characteristic than in the older type of phonograph." In view of the high quality which is obtained and of the commercial requirement that the wear on the record shall not be excessive, the authors do not agree with this statement. It is not necessarily true that because the record is a constant-current generator and, therefore, delivers constant current to the sound-box mechanism, that the diaphragm necessarily delivers constant current to the air. If a relatively stiff, heavy, vibrating system is used, it becomes exceedingly difficult with the constant-current type of generator to obtain good quality and if it is possible to obtain it, the wear on the record becomes excessive. A reference to Fig. 16 indicates that the first part of the system reached is the needle point which has a definite compliance. At the higher frequencies, if the impedance of the reproducing system is too high, the needle will bend instead of moving the rest of the system and the response will be reduced thereby. Similarly, at the low-frequency end, if the diaphragm-edge compliance is too small, that is, if the diaphragm is too stiff, the whole tone arm will vibrate and thereby reduce the motion of the diaphragm relative to its case. It is true that, so far as response is concerned, this effect can be corrected by increasing the moment of inertia of the tone arm—a method which is equivalent to increasing the mutual inductance of the transformer, T_1, (Fig. 16); but if the solution is thus obtained, the wear on the record becomes excessive and in some cases the force becomes so great that the needle will not track in the groove.

The solution presented in the paper is one in which the mechanical impedance has been made as nearly as possible independent of frequency and is of the nature of a pure mechanical resistance. The result of this type of solution is that a maximum of sound energy at all frequencies within the band is radiated with a minimum of wear on the record.

MECHANICAL FORCE BETWEEN ELECTRIC CIRCUITS[1]

(Doherty and Park)

New York, February 9, 1926

J. Slepian: The relation which is perhaps most frequently used by electrical engineers for calculating mechanical forces between circuits is that due to Maxwell, which states that in any displacement in which currents are kept constant, the mechanical work received during the displacement is equal to the increase in magnetic energy of the system. This relation is readily derived from the principle of conservation of energy by taking into account the electrical input during the displacement. As Professor Karapetoff puts it, there is a "fifty-fifty" rule here; half the electrical input goes to increasing the magnetic energy and half is given up to mechanical work.

However, this fifty-fifty rule does not apply when there is iron in the neighborhood, subject to saturation, and Messrs. Doherty and Park do well to bring out this fact strongly. In my own experience I have seen several cases where this rule led to completely erroneous results when applied to practical machines. In one instance, a complete change in sign of the force was involved, a repulsion was predicted, whereas actually an attraction was found. The magnetic circuit shown in Doherty and Park's Fig. 1 is one for which application of the fifty-fifty rule would give the wrong sign if the iron is saturated. With constant current, motion of the armature upward *decreases* the magnetic energy, and yet, the armature is attracted and not repelled.

The great contribution of Doherty and Park in this paper lies in showing that application of the principle of conservation of energy in another way leads to a relation which is universally applicable, saturation or no saturation. Namely, if the mechanical displacement is effected, not with constant currents but with constant flux linkages, then the mechanical work received is equal to the *decrease* in magnetic energy. The authors further add to the value of this result by showing how the calculation on this basis may be carried out, when the curves connecting flux linkages with currents for various positions of the moving parts are known.

I have a suggestion to make as to the formulas *(9)* and *(11)* which the authors give, and the corresponding expression for magnetic energy. While it is principally a matter of notation, I think it is important because it makes such a difference in the clarity of ideas. For simplicity, considering only two circuits, the authors would write the magnetic energy,

$$E = \int_0^{\Omega_1} i_1 \, d\,\omega_1 + \int_0^{\Omega_1} i_2 \, d\,\omega_2$$

To bring out more definitely that i_1 and i_2 are functions of both variables, w_1 and w_2 I shall write this as

$$E = \int_0^{\Omega_1} i_1 (\omega_1 \, \omega_2) \, d\,\omega_1 + \int_0^{\Omega_2} i_2 (\omega_1 \, \omega_2) \, d\,\omega_2$$

Now ω_2 is not a constant in the first integral, but may be varied as ω_1 varies, and ω_1 is not a constant in the second integral. However, whatever relation is adopted between ω_2 and ω_1 in the first integral, the same relation must be used in the second if the correct value for magnetic energy is to be obtained.

Now integrals of this kind are of frequent occurrence in mathematical physics, and they are usually denoted by line integrals written thus:

$$E = \int_{\substack{\omega_1 = 0 \\ \omega_2 = 0}}^{\substack{\omega_1 = \Omega_1 \\ \omega_2 = \Omega_2}} i_1 \, d\,\omega_1 + i_2 \, d\,\omega_2$$

This single integration is to be carried out over a curve in the $\omega_1 \, \omega_2$ plane, joining the point $\begin{pmatrix} \omega_1 = 0 \\ \omega_2 = 0 \end{pmatrix}$ to point $\begin{pmatrix} \omega_1 = \Omega_1 \\ \omega_2 = \Omega_2 \end{pmatrix}$.

In general, the value of such a line integral depends upon the path chosen in going from the initial point to the final point, but in this case since the magnetic energy is the same, however the state $\begin{pmatrix} \omega_1 = \Omega_1 \\ \omega_2 = \Omega_2 \end{pmatrix}$ is reached, the integral is independent of the path. Mathematicians have shown that in this case it follows that

$$\frac{\partial\, i_1}{\partial\, \omega_2} = \frac{\partial\, i_2}{\partial\, \omega_1}.$$

This may be looked upon as a generalization for the case of saturation, of the well-known fact for the linear case, that the mutual inductance of circuit No. 1 upon circuit No. 2 is equal to the mutual inductance of circuit No. 2 upon circuit No. 1.

On the fourth page first column of their paper, the authors give a number of formulas applying to their Fig. 1, and state that the quantity L_0, which appears there, is the inductance corresponding to no saturation. However, in their derivation of these formulas, if I understand their derivation correctly, L_0 is taken as the inductance corresponding to the air gap alone. That is, L_0 is the inductance corresponding to infinite permeability, and not to no saturation. There thus seems to be an omission in the authors' proof, which might be rectified as follows.

Let

L_0 = inductance corresponding to air-gap alone: *i. e.* inductance corresponding to infinite permeability.

Let

L_0' = inductance corresponding to no saturation,

Let

L_1 = inductance corresponding to iron alone with no saturation, *i. e.*, inductance with zero air-gap and no saturation.

Then,

$$\frac{1}{L_0'} = \frac{1}{L_0} + \frac{1}{L_1}$$

Hence, since L_1 is constant.

$$\frac{\partial}{\partial\, x}\left(\frac{1}{L_0'}\right) = \frac{\partial}{\partial\, x}\left(\frac{1}{L_0}\right)$$

Hence, since L_0 appears in the authors' formulas only in the factor

$$\frac{\partial}{\partial\, x}\left(\frac{1}{L_0}\right)$$

Therefore L_0' may replace L_0 throughout.

R. H. Park: In order to test the ease of applicability of the formulas developed and the agreement of calculated and observed results, a calculation and test was made in a particular case.

The circuit employed (see Fig. 1 herewith) consisted of two magnetic yokes separated by a brass strip and excited by direct current in two coils connected in series.

In order to determine the attractive force of the yokes, a weight was attached to the lower yoke and the exciting current was reduced until the yokes separated.

In order to calculate the force, the flux linkages ω were measured with a ballistic galvanometer for different air-gap and excitation. This data are shown in Fig. 2.

From the saturation curves, the curves of $\frac{\partial\, i}{\partial\, x}$ at constant ω were computed (see Fig. 3) as outlined in the paper. The forces were then calculated from the areas under these curves.

1. A. I. E. E. Journal, March, 1926, p. 231.

The agreement of observed and calculated results is shown in Fig. 4. The smooth lines in the figure represent the calculated, and the small circles, the observed results.

The difference between observed and calculated results is about 4 or 5 per cent, the observed results being, in general less than the calculated. The tendency for the observed results

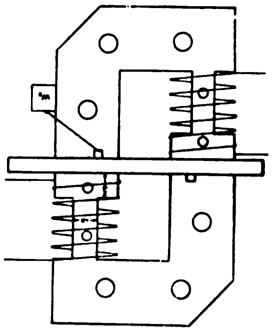

Fig. 1

to be low may be accounted for by unavoidable disagreement in the positions of the center of moment of the load and of the attractive force resulting in less effective magnetic pull, or by the effect of vibration.

From a theoretical point of view, we know that, until the satura-

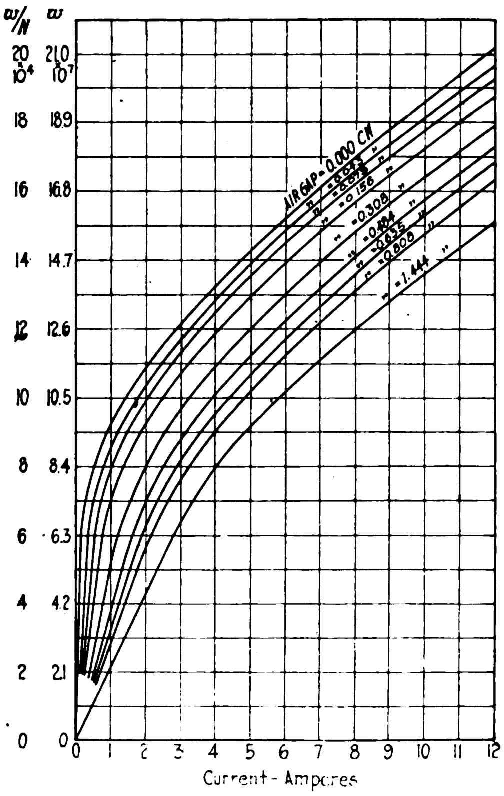

Fig. 2

tion of the core is sufficient to change appreciably, the distribution of the field in air, the curves of $\frac{\partial i}{\partial x}$ should be linear.

It may be observed that the experimental results agree with this requirement, the curves of $\frac{\partial i}{\partial x}$ being linear except at very high saturation.

This fact indicates that the approximate expression for force [equation (65) of the paper] holds good in this case until extremely high values of saturation are encountered.

Thus, the experimental results obtained agree with those theoretically deduced in the paper.

R. E. Doherty: The authors wish to thank Dr. Slepian for his

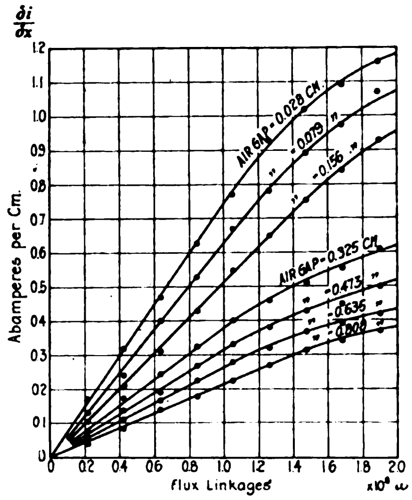

Fig. 3

suggestion regarding notation. It is undoubtedly a somewhat clearer representation of quantities than that used by them.

With respect to his other suggestion, however, the authors have not made the omission in logic which he alleges.

They have treated two different *special cases* where saturation

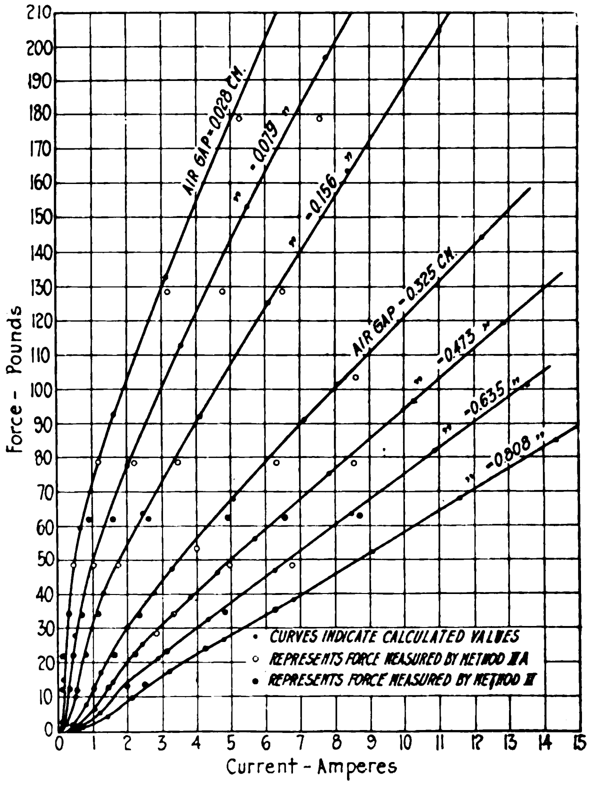

Fig. 4

is taken into account, and in the results of both cases, the term L_0 appears. The symbol L_0 is defined in the list of notations as "the self-inductance in henrys of a single circuit without satura-

tion," and it therefore, in general, includes the effect of the reluctance of the iron as well as of the air. Dr. Slepian's point is that the effect of the reluctance in the iron, when saturation is absent, is not taken into account.

The two cases treated are,

a. "Special Case," in connection with Fig. 3 of the paper. Here it is specifically stated that, so far *as* L_0 is concerned, the magnetic reluctance of the iron is neglected. Therefore L_0 in this special case in the industance corresponding to zero reluctance in the iron. Hence Dr. Slepian's discussion, referring to the equations based on this assumption, is not pertinent.

b. Another case, Appendix D, in which no qualifying assumption is made with respect to L_0 except those given in the definition, quoted above, from the list of symbols. And, therefore, if it is desired to consider the case which Dr. Slepian has in mind, he should use the equations for this case given in Appendix D.

PARAMETERS OF HEATING CURVES OF ELECTRICAL MACHINERY[1]

(KARAPETOFF)

NEW YORK, N. Y., FEBRUARY 10, 1926

G. E. Luke: As mentioned in this paper, Professor Kennelly derived the heating characteristics of an electric machine by considering it as one "chunk" of metal[2]. This paper gives the thermal equations on the basis of two "chunks" of metal (core and windings). An approximate solution of this problem based on three "chunks" of metal (core, windings, and frame) was given in another previous Institute paper[3]. As a matter of fact, a correct solution of this problem would have to be based upon an infinite number of "chunks."

Professor Karapetoff assumed two thermally connected masses of metal (core and windings), each having a uniform temperature and loss throughout. In practise, the losses and temperatures are usually much higher in the teeth than in the main part of the core; hence, there will be a heat flow in that direction. In the windings, there may be a considerable heat flow from the embedded part to the ventilated end portion. Thus, the heating curve of the "hot spot" on the copper will depend not only upon the thermal constants of the embedded copper and core but also upon the thermal conditions of the end windings. Again the large variation in the temperature of the cooling fluid in its passage through the machine will tend to cause all parts of the machine to vary with it.

The assumptions which must be made in order to derive the approximate thermal characteristics of a machine are more closely approached in small machines with relatively little forced cooling. On the other hand, in large machines, where long heat and fluid flow paths are found, together with a high velocity of the cooling fluid, the derivation of the heating characteristics on the assumption of uniform core and winding temperatures is likely to be erroneous.

The method of solution of the problem as simplified by Professor Karapetoff interested me, as several years ago I had occasion to solve the same problem. In my solution, θ_1 was evaluated from eq. (2) (also $d\ \theta_1$) and substituted in eq. (1). This also gave a linear differential equation having constant coefficients, but the second member, instead of being zero, as in eq. (8), was a function of p_1, p_2, k_1, k_2, s_1, and α, where α is the temperature coefficient of resistance. The solution of this was similar to eq. (10) with a constant term added. Although the method of solution given in this paper seems to be indirect, yet the equations representing the arbitrary constants are more systematic than the method I used.

1. A. I. E. E. JOURNAL, January, 1926, p. 40.
2. Temperature Rise of Electric Machines on Intermittent Duty, by G. E. Luke, *Electrical World*, May 27, 1922.
3. *Heating of Railway Motors in Service and Test-Flaor Runs*, by G. E. Luke, JOURNAL A. I. E. E., (1922), p. 165..

For the application of these equations, the author suggested that the many constants be calculated from experimentally obtained heating curves. The difficulty is to obtain accurate heating curves of the copper and iron temperatures especially on the rotating members.

I have applied these equations for predetermining the temperatures of machines on short-time overloads by calculating the constants from the known physical conditions. Thus, on such loads, most of the losses are stored and since the copper has such a high rate of loss, its temperature rises quickly. For example, the temperature rises of a 50-h. p., d-c. railway motor on a 150-per cent load, for one-half hour, as calculated (starting cold) were 51.5 deg. cent. armature core and 85.5 deg. armature copper, while the actual tested values were 48.0 and 87.5 deg. cent. respectively.

Another interesting application of these heating equations was to calculate the heating and cooling curve of a 600-volt, 31,000-cir. mil., rubber-insulated, stranded copper cable, with a

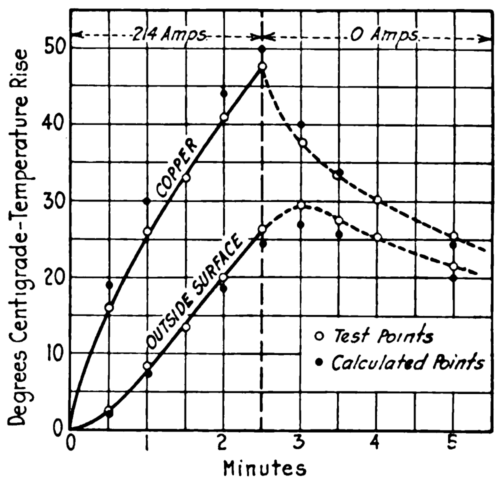

FIG. 1—HEATING AND COOLING CURVE OF A 600-VOLT, 32,000-CM. RUBBER-INSULATED, STRANDED COPPER CABLE

load of 214 amperes for 2½ min. The calculated points were based only on the weight of copper and insulation, the conductivity of heat of the rubber, and the surface heat transfer from the cable. The solution is necessarily approximate since the insulation and copper were assumed to have a uniform temperature θ_2 and θ_1, respectively. The results are given in Fig. 1 herewith. Since the loss in the rubber was zero, its slope was zero at the start of the cycle.

Although the assumption of two thermal masses simplifies the problem considerably, the final solution is still long and complicated and therefore will be used seldom by the average engineer. This solution should prove of value to the specialist, however, when considering problems such as I have mentioned. This solution also will indicate the limitations and errors of the less approximate solution based on a single uniform mass of metal.

W. F. Dawson: I want to show some curves (Fig. 2 herewith) that follow the curves given in Goldschmidt's paper[4] and also by Dr. Kennelly.

These curves are the heating curve of a mass of copper imbedded in insulation and other surrounding material. To simplify the problem, let us assume that it is not armature copper in an armature, but a field coil where the only loss is the copper loss. The initial rate of temperature rise depends upon the specific heat of the material, the specific gravity, (density), the specific resistance, and the current density. It so happens that, at 1100 amperes per sq. in., where there are no parasitic or extra losses, and the mean temperature is about 60 deg. cent., the rate

4. *Journal* I. E. E. (London) May 1905, Vol. 34, No. 172, p. 660.

of temperature rise is almost exactly one deg. cent. per min. This current density also gives approximately one watt per cu. in. (0.95 watt).

In practise, it is found that at 1100 amperes per sq. in., the initial rate of temperature increase is much less than one deg. cent per min., seldom more than one-half of a deg. cent. per min. and sometimes as low as one-third of a deg. cent. per min. The explanation lies in the fact that these windings are always surrounded with a considerable amount of insulation and frequently with masses of iron. Goldschmidt has suggested that the

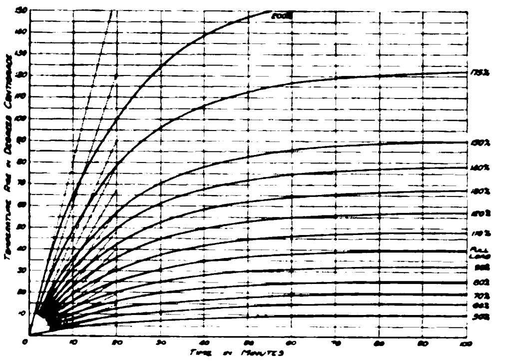

FIG. 2—TEMPERATURE GRADIENT CURVES BASED ON 2200 AMPERES PER SQ. IN., FULL LOAD AND TWO-DEG. RISE PER MIN.

specific heat of cotton insulation is approximately six times that of copper; hence it is easy to explain that the added thermal capacity of the surrounding insulation and iron is responsible for the lowered rate of temperature rise. A divisor of two is usually quite safe, hence with a current density of 2200 amperes per sq. in., one can safely assume that the initial rate of temperature rise will not exceed two deg. cent. per min.

I have made several tests with temperature rise plotted against time and found that, when a proper factor was used for the thermal capacity, the test results compared very closely with curves calculated according to Goldschmidt's formula. In one, a strange "hump" was shown in the observed heating curve and it was referred back to the testing department with the comment that "the phase currents in the armature became temporarily unbalanced." This was found to be the case. The extra heating was due to double-frequency currents induced in the field because currents in the armature phases became unbalanced. Fig. 2 will be found useful in the study of short-time ratings of windings, and the effect of fractional loads and overloads. It should be considered as a suggestion rather than something to be followed under all circumstances. It is plotted on the assumption that 2200 amperes per sq. in. gives an initial temperature rise of two deg. cent. per min. (this assumes that total thermal capacity equals twice that of the copper winding), that the final temperature rise will be 40 deg., and that the temperature rise varies as the square of the current load.

A little study will suggest many uses for curves of this sort; for example, a short-time overload is required on a machine that has been operating at fractional load until it has reached steady temperature. From the steady temperature indicated by the curve for that fractional load, follow the abscissa line to the left until it intersects the curve corresponding with the overload and note the corresponding time. Add the time for the required overload, and the intersection of the corresponding ordinate with the overload curve will indicate the total temperature rise.

C. J. Fechheimer: A few more words may be added in regard to the longitudinal heat flow in the copper. In machines which have, let us say, over 50-in. core length, the influence of the longitudinal flow upon the copper temperature at the middle of the core may be neglected. But in short machines, that flow plays an important part in the heat dissipation at the center. In some short machines, (say eight in. of core length or less), most of the heat generated in the copper is dissipated from the end windings, and there may even be flow of heat from the iron to the embedded copper whence it flows longitudinally to the ends. Frequently, then, there is not a great difference in temperature between the embedded copper and the ends.

It is well known that the time constant in a simple exponential equation is proportional to the ratio of the storage of heat to the dissipation of heat. In general, that time constant is considerably higher for the embedded part than for the ends, and, since there is so large an interchange of heat between the two in the short machine, the influence of the longitudinal flow cannot be ignored. About eight years ago I tried to obtain a solution of the problem, taking into account time and the distance along the conductors as independent variables. I obtained the partial differential equations and was able to integrate them. But the equations became so unwieldy when the terminal conditions were substituted that I abandoned the solution. I believe I still have the papers, and should be glad to send to Professor Karapetoff the results as far as I went, if he cares to go over them.

Suppose the time-temperature curves for a short machine are illustrated graphically as in Fig, 3 herewith. Curve I shows the rate of heating of the embedded part, and Curve II that of the

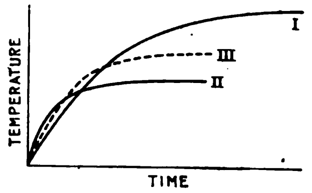

FIG. 3

ends, assuming that neither is influenced by the other. The actual time-temperature curve of the copper at the middle of the machine is about as in Curve III. The ends attain their maximum temperature in considerably less time than the embedded parts, each acting alone, and the maximums are quite different. If the equation of Curve III can be taken as of simple exponential form $[\theta = \theta_o (1 - \epsilon^{-\frac{T}{t}})]$, and if the final temperature rise θ_o and the initial slope $\left(\frac{d\theta}{dt}\right)_{t=o}$ be known, the entire curve can be plotted.

In Dr. Kennelly's paper of last year, and in this paper of Professor Karapetoff's mention is made of the similarity between the time equations of the heat circuit and the electric current containing inductance and resistance. In the discussion of a paper by Mr. Luke in 1922, that similarity was noted.[3] Perhaps that was brought to the attention of the electrical engineers long ago.

A. E. Kennelly: In the paper which I presented last year, I was not interested primarily in the determination of the conditions of heating, but in the presentation of the statistical factors concerning heating. As has been pointed out by several speakers, and as pointed out in the discussion last year, there are a number of instances in which the heating curves of parts of machines, or of parts of windings, or of core bodies, follow exponential curves,

and it is marvelous, I think, how common exponential curves, either of the rising type or of the falling type, are in natural phenomena.

We have been in the habit of referring the unit of time in which the exponential change occurs to a time constant in which the change is 63.2 per cent of the final ultimate change and in the next time constant 63.2 per cent of what again is left. That is a very awkward numerical calculation to present to practical men, so that, in order to avoid that unnecessary numerical and statistical combination, I ventured to point out that it is sufficient to take approximately 70 per cent of that exponential time constant (69.3 per cent theoretically) and to state that, as the binary time-constant or the time to come up to one-half; so that if in the first binary time constant of, let us say, twenty minutes, this element of the machine will come to half its final temperature elevation, then, in the next binary time constant of twenty minutes, it will come to half of what is left or three-quarters of the whole.

As has been pointed out by Professor Karapetoff and others, probably no machine develops a strictly exponential time curve of heating. As engineers, we try to find reasonable practical applications and we say, "Well, granted that it is never quite true, are there not cases which present themselves where the deviations for ordinary practical purposes can be neglected?" It is my opinion, after having gone over a considerable number of such heating curves, that many cases can be treated upon the basis of an experimental time constant.

So I think the procedure we can agree upon is this: Let us find the cases which present themselves in engineering practise where the actual curves are nearly constant, so that we may say, for practical purposes, that this machine, under such a load, will come up to one-half its final temperature elevation in so many minutes. Then one knows just how the heating will be beyond that point. Then, let us tabulate the exceptions.

I think we may look upon this as a valuable tool for the future, but I want first to see a tabulation of what can be done with existing machinery of various classes, using the simple, single time-constant. From what I have been able to ascertain from actual engineers,—men who are using this,—there will be a considerable number of cases where that does apply reasonably well.

F. Fabinger (in writing[5]): It may be of interest to call attention to my article entitled "A Contribution to the Theory of Heating of Electrical Machinery" published in the May 1923 issue of the *Elektrotechnicky Obzor* which is the official organ of the Association of Electrical Engineers of Czechoslovakia. In this article, I consider a body which is a source of constant quantity of heat per unit time to be completely surrounded by another body of infinite conductivity, in contact with a cooling medium of constant temperature. The differential equations in this case lead to a solution similar to Karapetoff's eq. (**10**); that is, the instantaneous temperature is expressed by a sum of two exponential terms.

Vladimir Karapetoff: As Dr. Kennelly has pointed out, the next step is to apply the proposed theory to a few machines to see how handy (or unhandy) it will be. I also hope that someone will be spurred to improve the two-chunk theory, but let us hope that this will be not in the direction of a three-chunk theory, but in the direction of distributed flow of heat.

To me, the next step is this: Assume the heat flow in the stator copper to be parallel to the shaft of the machine and the heat flow in the stator core to be radial. The temperature at a point will then not only be a function of time, but of the coordinates of that point as well, so that, as Mr. Fechheimer has pointed out, we shall have equations with partial derivatives. It would be of considerable interest to establish such equations. Even should they prove to be too complicated for a straightforward solution, some approximation methods may be applicable in numerical cases.

5. From Prague, Czechoslovakia.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

SMALL CORONA LAMPS

Gaseous conductor lamps have been produced by D. McFarlan Moore for service on 115-volt circuits and in sizes smaller than those heretofore developed. They are now available in two sizes, illustrated in the accompanying cut, for operation upon 115-volt circuits, a-c. and d-c.

The lamps are understood to be filled with neon, argon and helium in certain proportions. When excited by electric pressure, the gas becomes luminous at the cathode. On direct current, the gas around one electrode glows. On alternating current, the gas glows at both electrodes.

The round bulb lamp, which is little more than an inch in diameter, consumes approximately 1/10 watt with an efficiency of the order of ¼ lumen per watt. The small tubular bulb lamp consumes about 1/50 watt.

These lamps, because of their low illuminating power and low efficiency, are not employed for purposes of illumination but possess value as markers and signal lights. By reason of practically instantaneous lighting and extinction characteristics they possess peculiar value for stroboscopic use. This type of lamp is employed in successful experimental transmission of motion pictures.

At the Annual Convention of the Institute at White Sulphur Springs, in discussion of these lamps, it was suggested that one field of application for them lies in their use as signal lamps on motors for direct drive in industrial work where 220-volt supply circuits necessitate the use of 220-volt lamps which oftentimes are not easily available.

EYESIGHT CONSERVATION

The investigation of school architecture and construction showed that defective illumination of classrooms has an adverse influence on the activity of the intellectual processes of children.

The investigators, according to the report of the Eyesight Conservation Council, studied the relative value of daylighting and artificial lighting, concluding that "owing to the manner in which the human eye has developed during many ages under natural lighting conditions, the great changes in the intensity of daylight, varying as much as 1,000 foot-candles and more within a few minutes, are less trying to the eye than are the variations of relatively few foot-candles of artificial light."

The standards used in the U. S. investigation were those of the Code of Lighting School Buildings prepared jointly by the Illuminating Engineering Society and the American Institute of Architects and approved as an "American Standard" by the American Engineering Standards Committee, on which the Eye Sight Conservation Council was represented. This code makes definite provisions for natural as well as artificial lighting. (Eyesight Conservation Council of America.)

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Annual Convention, White Sulphur Springs

As we go to press, the Annual Convention of the A. I. E. E. is being held at White Sulphur Springs, W. Va., June 21-25 inclusive.

The program is comprehensive of many interesting and progressive aspects of the Institute's activities furnishing many attractions for the 350 engineers in attendance.

The various committees of the Institute have surveyed the advancement of the profession in their respective fields; President Pupin, President-elect Chesney and other notable leaders have contributed addresses on the developments in electrical engineering, emphasizing the need and desirability of the electrical engineer participating both individually and collectively in national as well as local affairs. Several high-grade technical papers were scheduled for presentation, presenting gratifying advancement in the field of this specific art, as well as leading to much valuable and pertinent discussion.

The full report of the Convention will appear in the August issue of the JOURNAL.

Pacific Coast Convention to be Held in Salt Lake City, Sept. 6-10

This year the Pacific Coast Convention will be held in Salt Lake City, Utah, beginning September 6 and continuing through for four days. A number of very fine papers have been arranged for and the well-known hospitality of Salt Lake City and the points of interest in and nearby this city insure an enjoyable meeting.

The technical papers will deal with such subjects as high-voltage transmission, corona, surge recorders, stability of alternators, distribution stations, the growth of population, power-factor correction, protection of oil tanks against lightning, transcontinental telephony, carrier communication on submarine cables, electricity in lead-silver mines, safety in mine application and engineering education.

The general committee in charge of arrangements for the meeting is as follows: C. R. Higson, Chairman; P. P. Ashworth, H. G. Baker, V. L. Board, D. L. Brundige, R. J. Corfield, G. S. Covey, John Harisberger, R. A. Hopkins, C. P. Kahler, J. A. Kahn, E. A. Loew, C. A. Malinowski, J. F. Merrill, E. B. Meyer, H. T. Plumb, R. C. Powell, C. C. Pratt, Paul Ranson, L. W. Ross, John Salberg, H. H. Schoolfield, M. M. Steck, A. Vilstrup, H. B. Waters and B. C. J. Wheatlake.

A Fine Niagara Regional Meeting

A regional meeting of outstanding accomplishment was held by the Northeastern District of the Institute at Niagara Falls, N. Y., May 26-28. The meeting was notable for excellent papers, earnest discussion, well attended sessions and entertainment of high grade. About 580 attended the meeting. All sessions were held in the Niagara Hotel, the convention headquarters.

The meeting was opened on Wednesday morning, May 26, by Prof. H. B. Smith, Vice-President in the Northeastern District, after which J. A. Johnson, Chairman of the local convention committee, welcomed the assembled members in a short address. The first technical session, a symposiun on measurement of dielectric power factor, was presided over by Prof. A. E. Knowlton. Seven papers were presented which were as follows: *Phase Difference in Dielectrics*, by J. B. Whitehead; *Standards for Measuring Power Factor of Dielectrics*, by H. L. Curtis; *The Significance of Errors in Dielectric-Loss Measurements*, by C. F. Hanson; *Use of Dynamometer-Wattmeter for Measuring Dielectric Power Loss*, by E. S. Lee; *Commercial Dielectric-Loss Measurements*, by R. E. Marbury; *Three Methods of Measuring Dielectric Power Loss and Power Factor*, by E. D. Doyle and E. H. Salter and *The Dielectric-Loss-Measurement Problem* by B. W. St. Clair.

A full discussion followed to which the following contributed: P. L. Hoover, E. W. Davis, I. M. Stein, J. D. Stacy, D. DuBois, Brian O'Brien, N. L. Morgan and R. Notvest.

This symposium was continued on Wednesday afternoon with W. A. Del Mar presiding. Two papers were presented as follows: *Compensation for Errors of the Quadrant Electrometer*, by D. M. Simons and W. S. Brown; *Zero Method of Measuring Power with a Quadrant Electrometer*, by W. B. Kouwenhoven and P. L. Betz.

Discussion on these papers was given by J. B. Whitehead, H. L. Curtis, C. F. Hanson, E. S. Lee, E. H. Salter, D. M. Simons, B. W. St. Clair, W. B. Kouwenhoven, C. A. Adams and Delafield DuBois.

A delightful trip to Toronto was enjoyed by about 200 members, following the session on Wednesday afternoon. The party traveled by trolley down the Niagara Gorge to Lewiston and across Lake Ontario to Toronto on a lake steamer. At Toronto the steamer was met by the lady guests of the convention who had gone in the morning to Toronto, where they were entertained by the ladies of the Toronto Section. On the return trip across the lake dancing was enjoyed on one of the decks.

The Thursday morning technical session was opened by J. A. Johnson, the presiding officer and two papers on rectifiers were presented as follows: *Steel-Enclosed Power Rectifiers*, by O. K. Marti; *Rectifier Voltage Control*, by D. C. Prince. These papers were discussed by R. H. Wheeler, Otto Naef, F. A. Faron, D. C. Prince, E. B. Shand, and S. Q. Hayes.

E. F. W. Alexanderson next presented his paper *Polarization of Radio Waves* and this was followed by *Current Transformers*

with Nickel-Iron Cores, by Thomas Spooner. I. F. Kinnard and W. K. Dickinson discussed the latter paper.

K. B. McEachron then described informally some experimental work he has done on the calibration of Lichtenberg figures, and J. H. Cox also added some discussion on this subject. Two more papers were then presented, namely, *A Flux-Voltmeter for Magnetic Tests*, by G. Camilli, and *Circulation of Harmonics in Transformer Circuits*, by T. C. Lennox. These were discussed by R. L. Sanford, W. H. Cooney and C. H. Kline.

On Thursday afternoon inspection trips were made, the principal trip being a scenic trip in the Gorge on which stops were being made to inspect the power plants on both sides of the river.

The high point of the meeting was reached on Thursday evening in the banquet at which about 400 were present including a large number of Institute officers and other notables of the electrical profession. Vice-President H. B. Smith was toastmaster and he first introduced P. A. Schoellkopf, President of the Niagara Falls Power Company, who said a few words of welcome. He was followed in short addresses by Giuseppe Faccioli, past-vice-president in the Northeastern District, A. I. E. E.; F. L. Hutchinson, National-Secretary; H. M. Hobart, Vice-President-elect in the Northeastern District; C. C. Chesney, President-Elect of the A. I. E. E.; C. F. Scott, Past-President, and Edward D. Adams, one of the founders of the original power development at Niagara Falls.

Mr. Adams gave a most interesting account of the difficulties of starting the Niagara Falls development in 1890 and 1891. At that time, he recalled, polyphase electric power was virtually unknown in this country and the only alternating-current apparatus consisted of small single-phase belted generators. The decision to adopt alternating current was strongly opposed by such authorities as Edison and Lord Kelvin. However, it is now obvious that this decision is largely responsible for the remarkable advances made by the electric light and power industry for the success of Niagara has spread its influence over the earth. Niagara has stimulated and focussed attention on water-power development, electric transmission and the utilization of electricity. It is symbolic of engineering courage, daring and achievement.

Following Mr. Adams' address the winners of the prizes for papers presented in the Northeastern District in 1925 were announced by C. A. Stevens, secretary of the District executive committee. The prize for the "best" paper was awarded to K. B. McEachron and E. J. Wade for their paper *Study of Time Lag of the Needle Gap*. The prize for the best "first" paper was awarded jointly to C. A. Nickle and R. W. Wieseman,—their respective papers being *An Electro-Mechanical System Analyzer*, (Nickle) and *A Two-Speed Salient-Pole Synchronous Motor* (Wieseman).

The final event of the dinner was a lecture on *Modern Reproduction of Sound*, by L. T. Robinson. He talked particularly on the recording of sound on electrically cut phonograph records and reproduction by the phonograph. He illustrated his talk through the reproduction of several musical selections by means of a phonograph operating a loud speaker whose volume of sound filled the banquet room.

After the banquet a trolley trip was made to view the Falls which were being illuminated with many changing and shifting colors.

At Friday morning's session, H. C. Don Carlos in the chair, four papers were presented. The first was *Variable Armature Leakage Reactance*, by V. Karapetoff. This was discussed by P. M. Lincoln and E. B. Shand. J. A. Johnson and E. J. Burnham then presented *Fire Protection of A-C. Generators*. This was discussed by H. L. Barns, H. U. Hart, R. B. Williamson, L. W. Riggs, S. Q. Hayes, A. F. Hamdi, M. W. Smith, J. Allen Johnson, James A. Johnson and L. W. Riggs.

F. V. Smith then presented his paper *Automatic and Supervisory Control of Hydroelectric Stations* and this was discussed by W. H. Gerrie, C. F. Publow and A. G. Darling.

The paper *Retardation Method of Loss Determination as Applied to the Niagara Falls Generators* by J. A. Johnson was then presented. Those discussing it were R. B. Williamson, E. M. Wood, V. Karapetoff, O. K. Marti and W. J. Foster.

Friday afternoon's session on power transmission was presided over by P. H. Thomas. S. Q. Hayes first presented a lecture illustrated with slides on *Interconnection and Superpower*. Mr. Hayes showed the large interconnected systems in this and other countries. L. E. Imlay then presented a paper on *European Transmission Practises* by G. F. Chellis. Following this three more papers were presented, namely, *Lightning and Other Experience on 132-kv. Transmission Lines*, by M. L. Sindeband and P. S. Sporn; *Notes on the Vibration of Transmission-Line Conductors*, by Theodore Varney; *Transmission-Line Sag Calculations, by H. B. Dwight.* Extended discussion followed by F. W. Peek, L. E. Imlay, L. C. Nicholson, E. S. Healy, S. S. Hertz, M. G. Lloyd, H. B. Vincent, A. E. Knowlton, N. J. Neall, C. F. Scott, A. O. Austin, J. H. Cox, V. Karapetoff, and H. Halperin.

On Friday evening there were two interesting features. The first was a piano recital by Professor Vladimir Karapetoff who chose for his subject Wagner's opera Parsifal. Prof. Karapetoff made the rendition of the music especially attractive by a previous explanation of the story of the opera, by lantern slides showing principal events and by explanatory verbal interpolations.

The meeting ended with a lecture by G. S. Anderson on the *Present and Future Development of Niagara Falls* which was illustrated with beautiful motion pictures.

This, the third regional meeting held by the Northeastern District, was in all ways a success, and the committees in charge deserve the highest commendation for the organization of the meeting and the smoothness with which all the events were conducted.

Institute Award of Prizes

The Committee on Award of Institute Prizes, composed of Messrs. E. B. Meyer, Chairman of the Meetings and Papers Committee, L. F. Morehouse, Chairman of the Publication Committee and Percy H. Thomas, Chairman of the Power Transmission and Distribution Committee, reported on the date of June 15, as follows:

"The Committee on Award of Institute Prizes has carefully considered the various papers submitted during the year 1925. They are all of a high calibre and show care in their preparation, and thoroughness of the work done. Some cover highly technical research work, important in a particular field of electrical progress, while others are of somewhat more general interest. All contribute information of value and it has been a matter of considerable difficulty to determine the prize paper in both of the groups.

"After careful deliberation we have selected the following:

First Paper Prize for the Year 1925

A Two-Speed Salient-Pole Synchronous Motor, by R. W. Wieseman (Published in April 1925)

Honorable Mention is awarded to

Effect of Repeated Voltage Application on Fibrous Insulation, by F. M. Clark (Published in January 1925)

Overvoltages on Transmission Systems Due to Dropping of Load, by E. J. Burnham (Published in June 1925)

"In reviewing the papers coming under the transmission group, it also was extremely difficult owing to the general excellence of the papers offered, to select one which might be considered to surpass the rest. The Committee, however, has agreed on the following:

Transmission Prize

The Klydonograph and Its Application to Surge Investigation, by J. H. Cox and J. W. Legg, (Published in October 1925 issue of the JOURNAL)

Honorable Mention is awarded to

Power System Transients, by V. Bush and R. D. Booth, (Published in March 1925 issue of the JOURNAL)

Fundamental Considerations of Power Limits of Transmission Systems, by R. E. Doherty and H. H. Dewey, (Published in October 1925 issue of the JOURNAL)."

Arrangements were made for the presentation of these prizes at the Annual Convention of the Institute, White Sulphur Springs, West Virginia, on Tuesday morning, June 22.

Revised Report on Standards for Electrical Measuring Instruments Available

A completely revised report on A. I. E. E. Standards for Electrical Measuring Instruments (Section 33 of the Revised Standards) is now available, without charge, for distribution to all those interested in the subject, members or non-members.

This report is issued for purposes of criticism and revision before final adoption as an A. I. E. E. Standards. The Standards Committee will greatly appreciate any suggestions based upon the application of the proposed Standards to general practise. All communications should be addressed to H. E. Farrer, Secretary A. I. E. E. Standards Committee, 33 West 39th St., New York, N. Y.

National Exposition of Power and Mechanical Engineering

Preliminary plans for the Fifth National Exposition of Power and Mechanical Engineering interests indicate that the coming event which is to be held at Grand Central Palace, New York City, December 6-11 inclusive, will be larger and more comprehensive than any of their previous Expositions. Approximately 140 exhibitors have arranged displays in the heating and ventilating field, some 75 in machinery and considerable space will be devoted to exhibits on power generating equipment. In all, the exhibitors will total over 400. Mr. I. E. Moultrop of the Edison Illuminating Co. of Boston is chairman of the Advisory Board and the managers of the Exposition are Charles F. Roth and Fred W. Payne, International Exposition Company, Grand Central Station, to whom all inquiries should be addressed.

New York Electrical Society Develops a Neglected Field

ELECTS OFFICERS FOR 1926-27

At the annual meeting of the New York Electrical Society held on the afternoon of June 14, 1926 at Institute headquarters, 33 West 39th Street, the retiring President of the Society, H. A. Kidder, Superintendent of Motor Power, Interborough Rapid Transit Company, called attention to the much broadened aim and scope of the New York Electrical Society as instanced in its work during the past year. He outlined the new policy, as follows: "To interpret to thinking people the newest things in discovery and science; to present in its meetings the latest achievements in the art and in industry; to acquaint the public with the proper status of teachers, scientific workers and engineers, and with the social value of their work." The determined attempt to shape the work of the Society in the direction indicated has been marked with rapid and increasing success. Attendance at meetings has jumped to an average of approximately 850. Through popularization, the meetings have evidently gained greatly in favor with those within the industry. It is felt that such work as the New York Electrical Society is trying to do, should be done nationally, for if accomplished it would constitute an important and valuable public service. The better people understand the nature of scientific and industrial research and the nature and social value of the work of the engineer, the greater will be the resources at the command of such workers.

The plans for the fall meetings are still tentative. One of particular interest, which is sure to be held, will be a demonstration of "Synchronized Talking Motion Pictures and Music" with popularized explanation of the process of development and operation.

The following officers were elected for the administrative year 1926-27: President, S. P. Grace, Commercial Development Engineer, Bell Telephone Laboratories, Inc.; Vice-Presidents; E. E. Dorting; Lighting Engineer, Interborough Rapid Transit Co.; Dr. E. E. Free, Consulting Engineer, J. P. Alexander, Sales Engineer, General Electric Co.; Treasurer, David Darlington, Assistant Treasurer, New York Edison Co.; Secretary, H. E. Farrer.

Automotive Engineers to Discuss Aircraft Progress

Three technical sessions, an inspection trip to the Naval Aircraft Factory and an Aeronautic Banquet will be the attractions at the annual aeronautic meeting of the Society of Automotive Engineers, to be held in Philadelphia on September 2 and 3 at the Bellevue-Stratford hotel. This meeting immediately precedes the National air races to be run in Philadelphia consecutively from September 4 to 11.

In view of the great amount of night flying that is now being done and that will increase greatly in the future, a joint address on equipment and methods for illumination of air routes, to be presented at the same session by C. T. Ludington, of the B B T Corporation, and H. C. Ritchie, of the General Electric Co., will be of much interest.

Direction finding by radio in an airplane is a recent development of prime importance, particularly when the landscape is obscured by darkness, fog or storms. The remarkable advancement that has been made in the practical application of directional radio to air transport will be described by Lieut. L. M. Wolfe and Capt. W. H. Murphy, of the Air Service radio laboratory at McCook Field, Dayton, O.

National Research Council

Doctor Charles M. Upham Receives New Appointment

The engineering world will be interested in the announcement that Charles M. Upham, who, for five years was North Carolina's Chief Highway Engineer, has tendered his resignation effective June 1st, and will shoulder the duties of Managing Director of the American Road Builders' Association, and in addition, accept a few connections as consulting engineer, among them, the reorganization of the construction division of the Mexican Federal Highway Commission, he already having reorganized the engineering section.

Doctor Upham received two degrees from Tufts College and a third from the North Carolina State University. He is Director of the Highway Research Board of the National Research Council, Vice-President of the National Traffic Association, President of the North Carolina Society of Civil Engineers, Member of Concrete Institute, Permanent International Association, of Road Congresses and other engineering and highway organizations.

The John Ericsson Medal Award

The first award of the John Ericsson gold medal was made to Doctor Svante Arrhenius on the evening of May 29th at the Hotel Willard, Washington, D. C. This was following the unveiling of the memorial Ericsson Statue on the Mall at which the Swedish Crown Prince, Princess Louise, President Coolidge were present, besides many other distinguished international figures.

Graduate Instruction in the Moore School

Beginning with the academic year 1926-27, graduate instruction will be offered in the Moore School of Electrical Engineering, with the degree of Master of Science in Electrical Engineering.

A prescribed course will be offered, the purpose of which is to prepare young men for engineering research or for teaching. The course includes the following subjects: Introduction to Mathematical Physics, Advanced Mathematics for Engineers, Advanced Electric Circuit Theory, Electron Theory and its Engineering Applications, and a Thesis.

To be admitted to this graduate course, the applicant must have completed with credit an undergraduate course in Electrical Engineering substantially equivalent to that given in the Moore School.

In order to encourage students who are properly qualified to add a fifth year to their University training, four graduate fellowships are offered. Each fellowship carries free tuition and a cash stipend of $500, payable in equal installments, October 1 and February 1. Applications for these fellowships should be addressed to the Dean, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

PERSONAL MENTION

THOS. W. WOOTTON has resigned from the Adirondack Power and Light Corporation of Schenectady, N. Y., and is now located in the engineering department of the Duquesne Light Company, Pittsburgh, Pa.

R. L. MCLELLAN, managing director of the Cia Westinghouse Electric Internacional, S. A., of Argentine, has recently been elected president of the United States Chamber of Commerce in Argentine.

W. R. WHITNEY, director of the research laboratory, and E. F. W. Alexanderson, consulting engineer who gained international fame with his radio inventions and developments, were awarded the honorary degree of doctor of science on Monday, June 14, Dr. Whitney at Syracuse University and Mr. Alexanderson at Union College.

ANSON W. BURCHARD, chairman of the board of directors of the International General Electric Company and vice-chairman of the General Electric Company, recently received the degree of doctor of laws from Union College.

W. J. FOSTER, consulting engineer of the General Electric Company, had the honorary degree of doctor of science conferred upon him by Williams College at its commencement exercises on Monday, June 21. Mr. Foster, an alumnus of Williams College, took graduate work at both Williams and Cornell. With the General Electric Company he has specialized in alternating-current apparatus design.

HOMER CLYDE SNOOK, a fellow of the Institute, has just received the degree of Doctor of Science from Ohio Wesleyan University. Doctor Snooks has been referred to as "originator of many fundamental patents in X-ray and wireless inventions; organizer of electrical manufacturing companies; holder of the Edwards Longstreth Medal of the Franklin Institute; staff engineer, Bell Telephone Laboratories, New York; gifted with insight and technical proficiency to have rendered in scientific fields a service of high order."

Obituary

Rudolf Schmolck, who was enrolled as an Associate of the Institute during the year 1925, died May 5, 1926, in Chicago. Mr. Schmolck was born in Germany in 1892, and was educated at the University of Heidelberg and the University of Berlin. Since December 1923 he had been employed by the Automatic Electric Co. of Chicago as a research engineer.

Olin J. Emmons died at his home in Elgin, Illinios, on the 9th of May. For ten years he had been an Associate of the Institute. Mr. Emmons received his electrical education at the University of Iowa, where he took the B. S. degree in 1907 and the E. E. in 1914. At the time of his death he was a wire chief at the Chicago Telephone Co.

Benjamin T. Viall, chief electrician for the Sunnyside Mining and Milling Co. at Eureka, Colorado, died at Silverton, Colorado, Feb. 3, 1926. Mr. Viall was born in 1873, and was graduated from Leland Stanford University in 1900. After three years spent with the General Electric Co. and the Edison Electric Co. he went with the Los Angeles Traction Co. in 1903. The same year he became an Associate of the Institute.

Charles W. Schaifer died in Schenectady, N. Y., on the 4th of April. For eleven years he had been in charge of the section handling "Special Testing of Electrical Machinery and Devices" in the General Engineering Laboratory of the General Electric Co. Mr. Shaifer was a graduate of the Agricultural and Mechanical College of Missippi of the class of 1912, and an Associate of the Institute since 1925.

Charles Griffith Young, Fellow of the Institute, died suddenly in Porto Rico, June 16, while there on a professional engagement. Mr. Young was born at Bath, Steuben County, New York, November 1, 1866. He attended the Haverling Academy there, taking special courses on technical subjects under private tutelage. His first work in the field was with the Schuyler Electric Company, of Hartford and Middletown, Conn., with whom he took an expert course in their every deparment during a two years' period. In 1887 he became general superintendent and electrician for the Mount Morris Electric Light Company, New York City, remaining with them until 1892, when he was chosen construction manager for the White-Crosby Company and the J. G. White Engineering Co., with foreign and domestic practise. Under his direction and operation of public utilities and construction engineering, over 2000 miles of electric railways were built in this and other countries. Mr. Young specialized upon investigations of professional undertakings, both proposed and actual, ultimately leading into the development of his own company, The C. G. Young Co., Inc., of which he was president. His engineering work extended over a wide range,—Canada, South America, Central America, China, Japan, and the Phillippines, New Zealand, Australia, Siberia and several of the European countries. He joined the Institute as an Associate in 1889, but in 1913 was transferred to the grade of Fellow. He was a respected and active member of the National Electric Light Association, the New York Electrical Society, the American Electric Railway Transportation and Traffic Association, the American Electric Railway Engineering Association, Associate Member of the American Society of Civil Engineers, member of the Pan American Society, the Pan American Chamber of Commerce, the Steuben Society, beside belonging to the Engineers' Club, the Railway Club, the Indian House Club and the Circumnavigators. He was the author of a paper of technical worth entitled, "Logical Basis for Valuations." This, besides being reprinted in separate pamphlet form, was published in the *Electric Traction* weekly of Jan. 21, 1911. Mr. Young had been three times around the world.

A. R. Rivet, an Associate of the Institute since 1903, died the 23rd of May in St. Louis, Mo. He was a former editor of the *Electrical Era*, a monthly published in that city, and at the time of his death was financial and commercial editor of the *St. Louis Globe-Democrat.* Mr. Rivet had had much practical electrical experience. He was born at Florissant, Mo., and for over a year was connected with the Municipal Electric Lighting Co. there, having charge of the contracting and estimating of cost of erection of Commerical Arc Lamps. He also was in charge of the motor department of the General Electric Co. in that city for about a year. For several years, he served as expert in the purchase of electrical machinery for isolated plants and was considered a valuable authority by all employing

his services. Mr. Rivet was an inveterate student and in his personal library he had all volums of the *Electrical World* for 15 years back and the *Street Railway Journal* for ten years.

George D. Shepardson, member of the Institute and head of the Electrical Engineering Dept. of the University of Minnesota died at Florence, Italy, of pneumonia, May 26. He left last spring for a trip around the world on a sabbatical leave of absence until next September.

Prof. Shepardson was born November 20, 1864 at Cincinnati Ohio. He attended the Granville Ohio High School and graduated from Denison University 1885 A. B. and A. M. 1888, specializing in Latin, Greek, German and French. He received his degree of Mechanical Engineer from Cornell in 1889. During his other sabbatical year in 1912, he received a degree of Doctor of Science from Harvard. One of his hobbies was the collectiong of old forms of lighting devices. While on his trip he had already gathered a number of primitive and ancient lamps of various designs for the museum of the Electrical Engineering Department of the University. These are now lying in bond in Minneapolis.

Prof. Shepardson has taught at the Young Ladies Institute at Granville, Ohio, Cornell University and since 1891 until his death has been Head of the Department of Electrical Engineering at the University of Minnesota. During the period of his professorship at the University of Minnesota the department has grown from almost nothing to a point where it is the largest in the College of Engineering, graduating 80 senior electrical engineers this spring and now housed in a new building costing $375,000.

Prof. Shepardson was a very prolific writer, having published more than 125 technical articles, in addition to several books, one of the latter "Elements of Electrical Engineering" for now being used in several colleges as a textbook for s phomore electrical engineers.

He was a member of a number of technical societies, among them the Society for the Promotion of Engineering Education, American Association for the Advancement of Science.

John J. Flather, head of the Department of Mechanical Engineering at the University of Minnesota and Associate of the Institute, died suddenly on May 14th at his home in Minneapolis.

Professor Flather was born at Philadelphia, June 9, 1862. He was educated in private schools in Scotland, at the High School in Bridgeport, Conn., and at the Sheffield Scientific School, Yale University, from which he was graduated in 1883. He took graduate studies at Yale, Cornell and the University of Edinburgh, receiving his Ph. B. from Yale in 1885 and his M. M. E. from Cornell in 1890. His early practical experience covered a full machinist's apprenticeship in various New England shops, including Flather & Co., Nashua, N. H.; he served also as foreman at the Ansonia Electric Supply Co. and as superintendent for the Hotchkiss Mfg. Co. In 1888 he became instructor in Mechanical Engineering at Lehigh University, remaining there for three years, followed by seven years at Purdue University. In 1898 he became Professor of Mechanical Engineering at the University of Minnesota, where he remained until the time of his death. He was a prolific writer, and his consulting work covered some import engineering projects of the Northwest, including municipal water works, electric light plants, factories and power plants. He entered the research field in 1888 investigating gas and combustion performances with natural gas, artificial gas, gasoline and kerosene power for machinery drive; also locomotive tests, train resistance tests, rope, belt and gear drive, refrigeration and many other fields of engineering interest. He joined the Institute in 1892 and was also a member of the Society of Industrial Engineers, the American Association of University Professors, the Minneapolis Engineers' Club, the Newcomen Society of London, the Authors' Club and the honorary societies of Sigma Xi, Tau Beta Pi and Pi Tau Sigma. He was secretary and vice-president of Section D of the American Association for the Advancement of Science and served as treasurer and vice-president to the Society for the Promotion of Engineering Education.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—J. Roy Barclay, 3424 Harrison, Kansas City, Mo.
2.—I. V. Beall, Wright Hotel, 4th & Hinkson Sts., Chester, Pa.
3.—Reynolds Bellows, 28 East 39th St., New York, N. Y.
4.—William A. R. Brown, c/o Radio Corp. of America, 33 West 42nd St., New York, N. Y.
5.—Aleck. Burk, c/o Lempert, 1327 Wilkins Ave., New York N. Y.
6.—J. F. Clinton, 3682 Broadway, New York, N. Y.
7.—A. G. Corbin, 753 Crescent Ave., Buffalo, N. Y.
8.—Hugh Denehy, The Inst. of Elect. Engrs., Savoy Pl., Victoria Embankment, London W. C. 2, Eng.
9.—John P. Flood, 414 No. Iowa Ave., Eagle Grove, Iowa.
10.—John Fowler, 25 Bettswood Rd., Norwalk, Conn.
11.—Clyde D. Grim, 623 Chestnut St., Reading, Pa.
12.—Frank I. Grover, 1831 E. 82nd St., Terrace, Kansas City, Mo.
13.—Stephan G. Guth, 419 Hampton Ave., Wilkinsburg, Pa.
14.—A. R. Henry, 633 Coristine Bldg., 20 St. Nicholas St., Montreal, Que, Can.
15.—William A. Hiney, Colonial Apts., Media, Pa.
16.—J. W. Hopkins, 136 E. 3rd St., Keyport, N. J.
17.—Niels K. Knudsen, N. Y. Edison Co., 44 E. 23rd St., New York, N. Y.
18.—Alexander Knut, 11th Ave. & 17th St., New York, N. Y.
19.—F. A. Lindlof. 610 So. Spring St., Los Angeles, Calif.
20.—Charles Wm. Lucck, 1454 First Ave., New York, N. Y.
21.—Shu-Sing Man, 541 West 124th St., New York, N. Y.
22.—Irving Menschik, 48 W. 4th St., New York, N. Y.
23.—Arthur R. Michaelson, Mezzine Dv., Cresskill, N. J.
24.—Erwin H. Mitchell, 481 6th St., Brooklyn, N. Y.
25.—Daniel T. Morgan, Power, W. Va.
26.—Jose P. Ortiz, 23rd St. & 4th Ave., New York, N. Y.
27.—Olof E. Permanson, 44 E. 23rd St., New York, N. Y.
28.—J. C. Peterson, 5125 Kimbark Ave., Chicago, Ill.
29.—Chester A. Raymond, 131 W. 17th St., Erie, Pa.
30.—Irving T. Roberts, 2355 Prairie Ave., Evanston, Ill.
31.—Wm. D. Robinson, Sterro-Woolley, Wash.
32.—Carl Russell, Albers Apt. G., Chehalis, Wash.
33.—W. J. Strieby, 104 Broad St., New York, N. Y.
34.—Herbert S. Summers, Standard Oil Co., of N. Y., Sofia, Bulgaria.
35.—O. G. Utt, 4738 Oak St., Kansas City, Mo.
36.—Albert C. Weyandt, 1200½ Negley St., Farrell, Pa.
37.—C. A. Winder, Southern Equipment Co., San Antonio, Tex.
38.—Flavel M. Williams, 106 So. Elliott St., Brooklyn, N. Y.
39.—Fred Willoughby, Jr., 500 West 111th St., New York, N. Y.
40.—W. H. Wilson, 13 Westminster Ave., East Park Hull, England.
41.—W. G. Withington, Commercial Nat'l Bank Bldg., Washington, D. C.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES MAY 1-31, 1926

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ALTERNATING CURRENTS.

By Carl Edward Magnusson. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 611 pp., illus., diagrs., tables, 9 x 6 in., cloth. $5.00.

A textbook based on the course given in the University of Washington. The aim has been to aid the student to gain clear concepts of what takes place in alternating-current machinery, to explain the relations between the factors involved and to explain the physical facts in mathematical forms in such a manner that the student shall understand the equations and be able to use them in the solution of industrial problems. The new edition has been thoroughly revised.

AUS DEM REICH DER TECHNIK.

By Max Maria von Weber. Berlin, V. D. I. Verlag, 1926. 188 pp., port., 8 x 6 in., cloth. 7,-r. m.

This collection of stories, long out of print, is now reissued by the press of the Verein deutscher Ingenieure. Weber was born in 1822 and died in 1881. He was educated as an engineer and spent his life in railroad service in Germany and Austria. He is best known, however, for his stories, which unite technical knowledge and poetic ability in an unusual degree. Those here reproduced are based on various incidents of railroad operation. Through them all runs a desire to arouse pride in his vocation in the railroad employer and to show the public the importance to national prosperity of the engineer and the mechanic.

AUSSENDUNG UND EMPFANG ELEKTRISCHER WELLEN.

By Reinhold Rüdenberg. Berlin, Julius Springer, 1926. 67 pp., diagrs., 9 x 6 in., paper. 3,90 r. m.

There are many books on the action of radio sending and receiving mechanisms, but there is not a great deal available on the mechanism of the wave passage from sender to receiver. In this little book the interaction between the currents and voltages in the stations and the electromagnetic waves flowing between them is considered, together with the problem of wave propagation in the intervening medium. The discussion is confined to undamped waves.

CORROSION; CAUSES AND PREVENTION.

By Frank N. Speller. N. Y., McGraw-Hill Book Co., 1926. 621 pp., illus., diagrs., tables, 9 x 6 in., cloth. $6.00.

An important reference work for all who are interested in any of the many phases of the problem of corrosion, combined with a handbook of practical preventive methods of interest to engineers and architects.

Part one treats of general principles. After an explanation of the nature and mechanism of corrosion and of the theories advanced to explain it, the author discusses the influence of methods of manufacture and treatment, of composition and of external factors on corrosion. The principles and methods of testing are then described and a chapter is devoted to the question of the relative corrodability of the various ferrous metals.

Part two discusses measure for preventing corrosion under various service conditions. Corrosion in the air, under water or under ground, corrosion in hot water systems and in steam plants and corrosion caused by chemicals or electric currents are discussed at length. Many references to other work are given in the notes and bibliography.

Dr. Speller's long study of the subject has enabled him to write a book of great value to all engineers.

DIE DRAHTSEILBAHNEN.

By P. Stephan. 4th edition. Berlin, Julius Springer, 1926. 572 pp., illus., plates, 9 x 6 in., cloth. 33,-m. k.

A detailed descriptive work on aerial ropeways and cableways, and telphers. The book is written from the point of view of the user rather than the manufacturer.

After a brief historical introduction, the various elements of ropeways (cables, supports, cars, stations, safety devices, etc.) are described. Examples of the use of ropeways as mountain railways and industrial conveyors, in mines, harbors and mills are then given, after which special types, such as gravity ropeways, single-cable ways, passenger ropeways and cableways are discussed. Economic and legal matters are then taken up, followed by a chapter on erection and operation. The types described are those now manufactured in Germany.

ETHICS OF BUSINESS.

By Edgar L. Heermance. N. Y., Harper & Bros., 1926. 244 pp., 8 x 6 in., cloth. $2.00.

Standards of business conduct, sometimes unwritten, sometimes expressed in definite codes, have been developing during the past quarter-century until today, Mr. Heermance believes, the average American merchant of the better class is probably more ethical than his patrons. In this book he presents these standards and the reasons for them, giving a useful picture of the development of business ethics in the United States. The author also intends his book as an introduction to social ethics, and therefore makes certain generalizations and interpretations of the ethical process in trade associations, as a contribution to ethical theory.

INDUSTRIAL STOICHIOMETRY.

By Warren K. Lewis and Arthur H. Radasch. N. Y., McGraw-Hill Book Co., 1926. (Chemical Engineering Series). 174 pp., diagrs., tables, 9 x 6 in., cloth. $2.50.

While the chemist is always taught the use of stoichiometric methods of computing quantitative analyses, he frequently is not trained to use them in industrial work. This textbook is designed to familiarize the beginner with correct methods for the quantitative interpretation of data in industrial work by a detailed presentation of typical cases of industrial processes, such as the operation of gas producers, lime burning, kiln and furnace design, plant design, sulfur burning, and iron smelting.

INSULATED ELECTRIC CABLES, v. 1; Materials and Design.

By C. J. Beaver. N. Y., D. Van Nostrand, 1926. 264 pp., illus., diagrs., tables, 10 x 7 in., cloth. $11.00.

Intended to supplement recent publications about insulated cables, which are chiefly devoted to their electrical properties, by a statement of the principles that underlie their design and manufacture. These, the author says, have not been comprehensively treated in any previous work.

The present half of the work discusses the materials—metals, insulants and protective substances—, the design of conductors,

the design and properties of dielectrics, and the factors in voltage rating. The second volume will treat of manufacture and installation.

JAHRBUCH DER ELEKTROTECHNIK . . . . 1924.

Edited by Karl Strecker. Mün. u. Ber., R. Oldenbourg, 1926. 269 pp., 10 x 7 in., paper. 14,20 mk.; bound, 15,40 mk.

A digest of over five thousand articles on electrical engineering which were published in some two hundred periodicals during 1924. The digests are the work of specialists and give a valuable summary of advances in each line, conveniently arranged for reference use. Machine design, power transmission and distribution, power plants, lighting, railroads, electric driving and other industrial uses of electricity, primary and secondary batteries, electrochemistry and electrometallurgy, telegraphy, telephony, signaling, electrical measurements and scientific investigations are included in the book. References are given to the original papers and author and subject indexes are supplied.

NEW VIEW OF SURFACE FORCES; A COLLECTION OF THE SCIENTIFIC PAPERS OF WILSON TAYLOR. Toronto, Univ. of Toronto Press, 1925. 240 pp., illus., diagrs., tables, 9 x 6 in., cloth. A Memorial Volume. Price not quoted.

When the author died, in 1923, after four years of research in physics, he left a number of papers, chiefly upon surface tension and molecular physics. Those here printed discuss the coalescence of liquid spheres and the law governing it, cohesion and adhesion in liquids and solids, the potential energy of free molecules, etc. One paper is devoted to flotation oils and their mode of action.

DE ONTWIKKELING VAN DE ELECTRICITEITSVOORZIENING VAN NEDERLAND. 1925.

By Vereeniging van Directeuren van Electriciteitsbedrijven in Nederland. Amsterdam, P. N. Van Kampen & Zoon, 1926. 568 pp., illus., maps, 11 x 9 in., cloth. 25 guilders. (This volume can be supplied by the Central Bureau of the Association, Maastricht, Breedestraat 11, at the price quoted).

In commemoration of its tenth anniversary, the Association of Managers of Electricity Supply Works in the Netherlands has issued this handsome volume. It contains elaborately illustrated accounts of the service provided by the utilities controlled by members of the Association, which furnish practically the entire electrical supply of the country. In addition to descriptions of equipment, service, etc., detailed statistics and maps are included, so that the book is a complete presentation of the development of electricity supply in the Netherlands.

RAILWAY ENGINEERING AND MAINTENANCE CYCLOPEDIA. 2nd edition, 1926, [of Maintenance of Way Cyclopedia]. N. Y., Simmons-Boardman Publ. Co., 1926. 1072 pp., illus., 12 x 9 in., cloth. $8.00.

The Cyclopedia is a convenient, authoritative assemblage of information on current practise in the engineering and maintenance of railroad track, bridges, buildings, water service and signals. This information is arranged in sections, each of which discusses the work of one of these branches. A general section cares for matters of interest to all. A dictionary of terms gives convenient definitions and serves as an index. Condensed catalogs of manufacturers are included. The sections were edited by a number of specialists actively engaged in railroading.

S. A. E. HANDBOOK, March 1926. N. Y., Society of Automotive Engineers, 1926. Various paging, diagrs., tables, 7 x 4 in., fabrikoid. $2.50 to members. $5.00 to non-members.

The standards and recommended practises of the Society of Automotive Engineers, some six hundred in number, have been revised and published in a bound volume of convenient pocket size, replacing the former data sheets supplied to its members. The contents are divided into sections relating to the power, plant, lighting, electrical equipment, parts and fittings, materials, transmission, axles and wheels, tires, frames, etc. Revisions are to appear twice each year hereafter.

TECHNISCHES WORTERBUCH . . . . DES MASCHINEN-UND SCHIFFBAUES, v. 2; Englisch-Deutsch.

By Erich Krebs. 2nd edition. Ber. u. Lpz., Walter de Gruyter & Co., 1926. 163 pp., 6 x 4 in., cloth. 1,50 r. m.

A convenient English-German pocket dictionary of technical terms used in mechanical engineering and naval architecture. Apparently includes all the principal terms, with satisfactory equivalents, and is remarkably cheap.

LA TELEPHONE AUTOMATIQUE.

By H. Milon. Paris, Gauthier-Villars et cie, 1926. 414 pp., illus., plates, 10 x 7 in., paper. 90 fr.

A concise textbook on automatic telephony, prepared especially for French students. The author omits any history of the development of the apparatus and confines himself, after giving an outline of the essential characteristics of the different systems, to a detailed account only of those in use in France. These include the Automatic Electric, the Thomson-Houston, the Siemens and Halske, the Western Electric and several semi-automatic systems. Data for the design of installations are given.

THEORY AND PRACTISE OF ALTERNATING CURRENTS.

By A. T. Dover. Lond. & N. Y., Isaac Pitman & Sons, 1926. 539 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

Devoted to general principles, circuits, polyphase systems, non-sinusoidal wave-forms, the magnetization of iron, instruments, measurements, and an elementary treatment of the initial conditions in the simpler electric circuits. Intended for use as a college text, introductory to the study of alternating-current machines and apparatus, it treats these principles on a broader basis than some textbooks do. Among the special features are an extended application of the circle diagram to series, parallel series-parallel circuits; the reduction of the general circuit to its equivalent series-parallel form and the development of a load diagram therefor; the calculation of currents in unbalanced polyphase circuits; and the theory of the principal types of measuring instruments.

Past Section and Branch Meetings

SECTION MEETINGS

Atlanta

Developments of the Columbus Electric and Power Company, by R. M. Harding. November 6. Attendance 60.

The Traffic Problem in Atlanta, by P. S. Arkwright, Georgia Railway and Power Co. January 18. Attendance 10.

Recent Developments in the Manufacture of Chemical Fiber, by F. H. Griffith, The Viscose Co., and

Cellucose, by R. C. Dort, the American Cellucose and Chemical Co. March 18. Attendance 27.

Ceramics, by A. V. Henry, Georgia School of Technology. April 22. Attendance 17.

Baltimore

Radio Broadcasting Station, Consolidated Gas and Electric Company, by F. A. Fallon, and

Radio Equipment, by P. M. Rainey, Graybar Electric Co. January 15. Attendance 65.

Mercury-Arc Rectifier as Applied to Power Development, by H. D. Brown, General Electric Co. Illustrated with slides. February 19. Attendance 90.

Mechanical Power and Trend of Civilization, by C. E. Skinner, Westinghouse Electric and Mfg. Co. March 19. Attendance 110.

Automatic Testing of Watt Hour Meters, by J. S. Cruickshank, Consolidated Gas, Electric Light and Power Co., and

Maintenance and Care of Storage Batteries, by A. Albaugh and F. Fried, Consolidated Gas, Electric Light and Power Co. April 16. Attendance 87.

Annual Banquet. Joint with A. S. M. E. April 29. Attendance 156.

Boston

Business Meeting. Election of Officers. Banquet preceded the meeting. May 18. Attendance 238.

Cincinnati

Research, by Dean Herman Schneider, University of Cincinnati. Illustrated with slides. May 20. Attendance 216.

Cleveland

Mental Attitude, by Dr. M. I. Pupin,, National President, A. I. E. E. May 18. Attendance 100.

Connecticut

Fatigue Prevention is Accident Prevention, by Dr. H. W. Haggard, Yale University. The following officers were elected: Chairman: A. E. Knowlton; Secretary-Treasurer, R. G. Warner. May 19. Attendance 40.

Denver

The Changing Status of the Engineer, by Dr. F. B. Jewett, American Telephone and Telegraph Co. The following officers were elected: Chairman, W. H. Edmunds; Vice-Chairman, A. L. Jones; Secretary-Treasurer, R. B. Bonney. May 28. Attendance 500.

Erie

Talk by Giuseppe Faccioli, General Electric Co., on a trip through Europe in a machine, with special reference to engineering conditions. The following officers were elected: Chairman, F. A. Tennant; Secretary, L. H. Curtis. May 25. Attendance 94.

Ithaca

The Social and Economic Aspects of Niagara Falls, by W. K. Bradbury, Niagara Falls Power Co. Illustrated with slides and motion pictures. A dinner preceded the meeting. May 7. Attendance 125.

Lehigh Valley

Oil Switches, by Wm. S. Edsall, Condit Electric Mfg. Co., and

Application of the Electric Motor to Steel Mills, by G. E. Stoltz, Westinghouse Electric and Mfg. Co. A dinner preceded the meeting. April 23. Attendance 135.

Lynn

Street and Highway Safety, addresses by Dr. George W. Haywood, President of Lynn City Council; Hon. Ralph S. Bauer, Mayor of Lynn; Deputy-Commissioner Good of Boston; C. A. B. Halvorson, General Electric Company, and S. C. Rogers, Street-Lighting Department, Lynn. June 3. Attendance 150.

Madison

A talk was given by D. W. Mead, University of Wisconsin, on some of his experiences in building hydro-electric plants. The following officers were elected: Chairman, E. J. Kallevang; Secretary, H. J. Hunt. May 26. Attendance 24.

Milwaukee

The Inadequacy of American Patent and Trade-Mark Protection, by R. S. Hoar, The Bucyrus Co. May 19. Attendance 100.

Minnesota

Dinner Dance. May 11. Attendance 61.

Nebraska

Long Distance Telephone Transmission—Fifty Years of Progress, by A. F. Rose, American Telephone and Telegraph Co. Demonstrated. May 12. Attendance 85.

Pittsfield

Street and Highway Safety—addresses by W. A. Whittlesey, engineer of the Pittsfield Electric Co., and Chief of Police John L. Sullivan. May 27. Attendance 150.

Portland

Manual, Supervisory and Automatic Control, by Albert Kalin, Westinghouse Electric and Mfg. Co. A motion picture, entitled "From Mine to Consumer," was shown. May 12. Attendance 85.

Rochester

A motion picture, entitled "The Yoke of the Past," was shown. The following officers were elected: Chairman, E. C. Karker; Vice-Chairman, R. G. Thompson; Secretary-Treasurer, J. R. Clark. May 7. Attendance 40.

San Francisco

Elements of Transmission-Line Stability Problems, by A. W. Copley, Westinghouse Elec. & Mfg. Co., and Roy Wilkins, Pacific Gas and Elec. Co. A dinner preceded the meeting. May 28. Attendance 80.

Supervisory Systems for Control and Indication, by C. E. Stewart. Illustrated with motion pictures and slides. June 3. Attendance 58.

Sharon

Mechanical Power and the Trend of Civilization, by C. E. Skinner, Westinghouse Electric and Mfg. Co. The following officers were elected: Chairman, H. L. Cole; Secretary-Treasurer, L. H. Hill. June 1. Attendance 75.

Springfield

Electric Time Equipment, by G. F. Harter, The Standard Electric Time Co. May 24. Attendance 45.

Syracuse

Radio and Interference, by E. P. Peck, Utica Gas and Electric Co. March 8. Attendance 175.

Developments in Radio Wave Propagation, by E. F. W. Alexanderson, Radio Corporation of America. March 29. Attendance 225.

Engineering Mechanics at the Bureau of Standards, by L. B. Tuckerman. April 12. Attendance 195.

Toledo

Inspection trip to the Toledo Furnace Company. May 19. Attendance 32.

Urbana

Business Meeting. The following officers were elected: Chairman, J. T. Tykociner; Secretary-Treasurer, L. B. Archer. May 12. Attendance 12.

Utah

New Electrical Developments, by A. L. Jones, General Electric Co. Illustrated with slides. May 26. Attendance 40.

Vancouver

Annual Meeting. The following officers were elected: Chairman, R. L. Hall; Secretary, C. W. Colvin. June 1. Attendance 46.

BRANCH MEETINGS

Alabama Polytechnic Institute

The Oscillograph, by Prof. J. A. Douglas. Mr. W. B. Fish also gave a demonstration of a Dudell-type machine. May 12. Attendance 14.

University of Arizona

Business Meeting. April 17. Attendance 11.

The Orthophonic Reproduction of Sound, by Dr. Earl Warner. Motion pictures, entitled "Electric Transmission of Speech," and "The Single Ridge Method," were shown. April 24. Attendance 24.

Rectification of Alternating Current, by R. O. Wright;

Textile Engineering, by W. R. Brownlee, and

Commercial Phases of the Telephone, by W. T. Voss. May 1. Attendance 12.

Business Meeting. May 8. Attendance 12.

Super-Power Systems, by Geo. Diamos. May 15. Attendance 20.

A motion picture, entitled "The Audion," was shown. The following officers were elected: President, J. W. Cruse; Vice-President, T. E. Davis. May 22. Attendance 20.

University of Arkansas

Illinois Central Switching Yard, by F. H. Smith, and

Frog-Leg Windings, by Fred Ross. June 1. Attendance 9.

Brooklyn Polytechnic Institute

Vacuum-Tube Crest Voltmeters, by Paul Heise, student;

Induction Motors, by Wallace Griesman, student. Mr. Fred Siemers gave a demonstration with a Tesla coil giving a 30-inch spark. The following officers were elected: President, Ferdinand Wankel; Vice-President, William Dalton; Treasurer, Fred Wahlers; Secretary, Joseph Heller. May 21. Attendance 38.

Bucknell University

Business Meeting. The following officers were elected: President, A. Fogelsanger; Vice-President, G. Timm; Secretary-Treasurer, J. D. Johnson. May 17. Attendance 38.

California Institute of Technology

Motion pictures, entitled "King of the Rails" and "The Potter's Wheel," were shown. May 17. Attendance 46.

The Operation of a Large Power Company, by H. A. Barre, Southern California Edison Co. The following officers were elected: Chairman, Thomas Gottier; Vice-Chairman, Don Hinkston; Secretary, Alan Capon; Treasurer, Carter Blankenberg. May 28. Attendance 24.

Carnegie Institute of Technology

The Uses of Aluminum in the Electrical Industry, by Theodore Varney, Aluminum Company of America. April 28. Attendance 35.

Banquet. The following officers were elected: Chairman, J. R. Power; Vice-Chairman, W. F. Simpson; Secretary, R. O. Perrine, Treasurer, J. T. Chidester. May 18. Attendance 55.

University of Colorado

A motion picture, entitled "The Single Ridge," was shown. May 12. Attendance 25.

Business Meeting. The following officers were elected: President, A. D. Thomas; Vice-President, W. G. Edwards, Jr.; Secretary, J. A. Setter; Treasurer, R. W. Gutshall. June 2. Attendance 22.

University of Denver

Business Meeting. The following officers were elected: Chairman, Harold Henson; Vice-Chairman, Carlyle Connor; Secretary-Treasurer, Allea Ohlson. May 13. Attendance 18.

Drexel Institute

Electrical Show. May 7 and 8. Attendance over 2000.

Business Meeting. The following officers were elected: Chairman, H. D. Baker; Vice-Chairman, G. V. Craddock; Secretary, J. E. Eininger; Treasurer, T. J. Ballantyne. May 19. Attendance 23.

University of Idaho

Business Meeting. The following officers were elected: President, J. W. Gartin; Vice-President, Cecil Balkow; Secretary-Treasurer, S. Blore. May 25. Attendance 32.

State University of Iowa

Evacuating Electric Lamps, by Nathan Whiting, and

The American Institute of Electrical Engineers and Its Purposes, by Prof. A. H. Ford. May 12. Attendance 37.

Automatic Train-Control Devices, by LeRoy Wyant, Rock Island Railroad, Mr. Lyon, Ragan Automatic Train Control Device Co., and E. Wanamaker, Rock Island Railroad. May 21. Attendance 37.

Business Meeting. May 26. Attendance 33.

Kansas State College

Electrical Power Applications in the Printing Industry, by Mr. Higgenbottom. The following officers were elected: President, A. M. Young; Vice-President, K. B. Mudge; Recording Secretary, L. S. Hobson; Corresponding Secretary, John Yost; Treasurer, C. C. Tate. May 10. Attendance 66.

University of Kansas

Business Meeting. The following officers were elected: President, W. L. Immer; Vice-President, R. M. Alspaugh; Secretary, H. R. Hilkey; Treasurer, Glen Kireckhaus. May 13. Attendance 40.

Michigan State College

Business Meeting. June 3. Attendance 18.

University of Michigan

Business Meeting. The following officers were elected: Chairman, M. H. Nelson; Vice-Chairman, R. R. Swain; Secretary, H. R. Stevenson; Treasurer, W. I. Poch. May 26. Attendance 19.

Engineering School of Milwaukee

Inspection trip to the Westinghouse Lamp Works. May 21. Attendance 44.

Automobile Headlight Illumination, by E. J. Lehnen. A motion picture, entitled "Telephone Inventors of Today," was shown. June 8. Attendance 24.

University of Minnesota

The Development of the Steam Turbine, by C. C. Douglas, General Electric Co. Illustrated with slides. May 12. Attendance 70.

Montana State College

Business Meeting. The following officers were elected: Chairman, W. E. Pakala; Vice-Chairman, Wayne Kobbe. May 13. Attendance 147.

College of the City of New York

Porcelain Insulators, by Mr. Hirsch. Illustrated with slides. May 20. Attendance 14.

Production Methods in the General Electric Company, by W. W. Hambly. June 3. Attendance 26.

Business Meeting. The following officers were elected: Faculty Chairman, Professor H. Baum; Student Chairman, Harold Wolf; Vice-Chairman, Harry Hirsch; Secretary, Joseph Leipziger; Treasurer, E. F. Day. June 10. Attendance 19.

New York University

Business Meeting. The following officers were elected: Chairman, H. U. Hefty; Secretary, Henry Och. May 6. Attendance 20.

University of North Carolina

Short talks were given by the following students: Messrs. Wilson, Smith, Coe, Farmer, Ryan, Cantwell and Mason. May 6. Attendance 38.

Banquet. The following officers were elected: President, H. L. Coe; Vice-President, G. M. Wilson; Secretary, C. M. Lear; Treasurer, J. L. Cantwell. May 20. Attendance 46.

Ohio University

A New Method of Measuring Sound Intensity, by D. B. Green. Illustrated. May 13. Attendance 27.

Oklahoma Agricultural and Mechanical College

Banquet. May 20. Attendance 30.

University of Oklahoma

Business Meeting. The following officers were elected: President, G. B. Brady; Vice-President, Ralph Tyler; Secretary, J. C. Glaze. May 19. Attendance 16.

Oregon State Agricultural College

The Transmission of Pictures by Wire, by A. K. Morehouse, Pacific Telephone and Telegraph Co. Illustrated with slides. May 11. Attendance 55.

Business Meeting. May 28. Attendance 31.

Pennsylvania State College

The Transmission of Pictures by Wire, by J. W. Horton, Bell Laboratories, Inc. Illustrated with slides. May 12. Attendance 50.

Business Meeting. May 26. Attendance 20.

Banquet. June 3. Attendance 78.

University of Pennsylvania

Spring Dance. May 7. Attendance 100.

Business Meeting. The following officers were elected: Chairman, F. H. Riordan, Jr.; Vice-Chairman, W. L. Carns; Treasurer, J. T. Naughton, Jr.; Secretary, Wm. H. Hamilton. May 19.

Social Meeting. May 23. Attendance 150.

Purdue University

Public Utilities, by Stanley Green, Indiana Central Power Co. May 18. Attendance 30.

South Dakota State School of Mines

Business Meeting. The following officers were elected: Chairman, C. Allen; Secretary-Treasurer, Harold Eade. May 24. Attendance 10.

University of South Dakota

Developments of Electrical Machinery in 1925, by Louis Stverak, and

A Modern 220-Kv. Power Transmission Line, by Richard Brackett. January 5. Attendance 9.

Latest Developments in Electrical Instruments, by Will Doohen. Illustrated with slides. The following motion pictures were shown: "The Glow of the Lamp," and "White Coal." February 13. Attendance 72.

Transmission Lines in South Dakota, Mr. G. W. Day. March 9. Attendance 7.

Rearranging the Dynamo Room, by Will Doohen and Louis Stverak. April 12. Attendance 8.

A Piezo-Electric Oscillator Working at 3000 kc. and 4000 kc. per Second, by Richard Brackett. May 11. Attendance 14.

Stanford University

Business Meeting. May 26. Attendance 15.

Business Meeting. June 2. Attendance 12.

Business Meeting. The following officers were elected: Chairman, A. V. Pering; Vice-Chairman, R. H. Brandt; Secretary, J. G. Sharp. June 8. Attendance 17.

Syracuse University

A motion picture, entitled "Temperature and Motor Endurance," was shown. May 3. Attendance 18.

Water Power in New York State, by V. R. Kimball. May 24. Attendance 18.

University of Tennessee

Illustrated lecture by Mr. Nelson, General Electric Co. April 15. Attendance 35.

Business Meeting. The following officers were elected: President, F. N. Green; Vice-President, J. R. McConkey; Secretary-Treasurer, B. M. Gallaher. May 6. Attendance 20.

University of Texas

Business Meeting. The following officers were elected: President, F. W. Langner; Vice-President, R. F. Calhoun; Secretary-Treasurer, F. B. Menger; Corresponding Secretary, H. W. Zuch. May 13. Attendance 10.

Virginia Military Institute

Business Meeting. The following officers were elected: Chairman, R. P. Williamson; Secretary, M. L. Waring. May 25. Attendance 28.

University of Virginia

Hydro-Electric Possibilities Along the St. Lawrence River, by T. M. Linville;

Recent Developments of Moore Gaseous-Conductor Lamps, by H. M. Dixon, Jr., and

Recent Developments in the Reproduction of Music, by J. S. Miller. Motion pictures, entitled "The Telephone, A Modern Marvel," "The Land of the White Cedar," and "Story of a Telephone Conversation," were shown. May 19. Attendance 52.

Business Meeting. The following officers were elected: Chairman, R. C. Small; Secretary, G. L. Lefevre; Treasurer, J. Bronaugh. May 28. Attendance 10.

State College of Washington

Business Meeting. The following officers were elected: President, S. H. White; Vice-President, S. A. Bobe; Secretary, H. R. Meahl; Treasurer, Walter Beattie. June 1. Attendance 20.

Washington University

Business Meeting. The following officers were elected: President, E. B. Kempster, Jr.; Vice-President, Y. O. Waller; Secretary-Treasurer, George Simpson. May 21. Attendance 22.

University of Washington

The Superpower System, by Mr. Hutton, Pacific Coast Engineering Co. Annual Dinner. The following officers were elected: President, C. M. Murray, Jr.; Secretary-Treasurer, R. H. Crosby. June 2. Attendance 29.

West Virginia University

Inspection Trips at Carnegie Tech., by R. W. Beardslee; *Inspection Trips under Auspices of Westinghouse Elec. & Mfg. Co.*, by J. U. Neill; *The Springdale Power Plant*, by M. W. Naylor; *The Colfax Power Plant*, by E. A. Berry; *The Manufacture of Steel Shapes*, by D. S. Roush; *Interesting Things Seen at the Westinghouse Works*, by R. L. Cole; *Machine-Switching Telephone Exchange*, by R. A. Osborne; and *Submarine Indicators*, by I. L. Smith. May 21. Attendance 28.

University of Wisconsin

Hydro-Electric Construction, by Professor Meade. Banquet. May 26. Attendance 60.

Worcester Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, D. A. Calder; Vice-Chairman, R. A. Beth; Treasurer, A. M. Tarbox; Secretary, C. H. Kauke. May 6. Attendance 16.

University of Wyoming

Business Meeting. The following officers were elected: President, John Hicks; Vice-President, William Buchholz; Secretary-Treasurer, James O. Yates. May 19. Attendance 10.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.

53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

PUBLIC UTILITY EXECUTIVE, thoroughly seasoned for general management. X-73.

EXPERIENCED TRANSFORMER ENGINEER, familiar with design and practise relating to high-tension potential transformers and high-tension small distribution and special purpose transformers. Must be capable of original work, both theory and practise. Positions with a new division of an old line manufacturing company, not previously engaged in the manufacture of high-tension electrical apparatus. Location, Connecticut. R-9452.

DISTRICT SUPERINTENDENT, to take charge of the distribution and commercial work in a fast growing and progressive town of eighty thousand. Should be technically trained, experienced with overhead city distribution problems, customers' relations, rate interpretation, motor applications and illumination. Good working knowledge of Spanish essential. Climate healthful. Apply by letter with full particulars regarding past experience, salary, when available, references and enclose recent photograph. Location, Porto Rico. R-9898-C.

MANUFACTURING ELECTRICAL ENGINEER, who can design and plan the production of a complete line of electric stoves. Only engineer who has had practical experience producing electrical stoves will be considered. Apply by letter. Location, West. R-9839-C-R-226-S.

STEAM PLANT BETTERMENT AND SERVICE ENGINEER, with five-ten years' public utility operating experience, principally in steam electric generation. Work is in connection with plant betterment and service division of large public utility management organization. Essential that applicant be fully informed as to operation, maintenance and design of up-to-date

high-pressure steam electric stations and capable of analyzing operating results and costs, as well as rendering all kinds of service in connection with the operation of the steam and utility plants. Some traveling. Apply by letter stating salary expected, when available, and full statement of education, age, and past experience. Headquarters, New York. X-49.

STEAM PLANT BETTERMENT ENGINEER, for steam plant betterment division of large utility management company. Must have at least five years' operating experience in public utility plants. Knowledge of Spanish desirable, not essential. Underfeed stoker experience required. Apply by letter stating age, salary expected, education, when available, and full description of past experience. Headquarters, New York; location, foreign. X-50.

MEN AVAILABLE

EXECUTIVE, graduate electrical engineer, age 32, married, desires permanent position with manufacturing organization where actual selling, purchasing and manufacturing control experience can be used to advantage. Experienced in shop practise and management with knowledge of factory cost and accounting systems. Skilled in production methods, waste elimination, bonus systems and rate setting. A-4070.

GRADUATE ELECTRICAL ENGINEER, 30, married, several years practical and business, some educational experience, desires teaching position offering opportunity for research and advanced study. Excellent scholastic record, naturally adapted to educational work. Can handle electrical or power plant engineering or mathematical subjects. Westinghouse shop course and sales experience. Excellent references. C-1071.

ELECTRICAL ENGINEER, 28, B. S. in E. E., desires teaching position in electrical engineering department of university or college of standing. Desires position with prospects of advancement. Five years' experience in design, estimation and installation of electrical and mechanical equipment. Present position instructor in electrical engineering in well known Western college. Available September. B-9894.

ELECTRICAL ENGINEER, 28, single, desires position with manufacturer electrical apparatus. Five years' experience with large manufacturer electric control apparatus. Some sales experience. B-6274.

ELECTRICAL ENGINEER, graduate Lond., Eng., two years' Canadian hydro experience, five years plant maintenance. At present located Quebec, desires to improve position in Canada. Thorough practical and theoretical experience. Available in one week. At present employed. C-1419.

GRADUATE OF DREXEL INSTITUTE IN ELECTRICAL ENGINEERING, 23, five years general wiring, one year power plant construction, six months underground transmission and distribution work, including test on 13200 volt Conduit Oil Switches. De ires position electrical engineering work. Loca.ion, immaterial. C-1477.

ELECTRICAL ENGINEER, 30, married, experienced in the electrical design of power plants, substations, transmission lines, special studies, investigations, reports, etc. Technical graduate, business training. Will consider a connection with a consulting organization or an operating company. C-995-507.

ELECTRICAL AND CIVIL ENGINEER, 35, with fifteen years' experience in electrical and hydro-electric developments. Theoretical training well seasoned with actual experience in all stages from preliminary reports to construction and operation. Executive accustomed to assuming responsibility and delivering results. Fluent Spanish. B-1173.

ELECTRICAL ENGINEER, 30, married, graduate E. E., M. E., seven years' varied experience on central and substation estimating, design, construction and installation, also safety and research work. Five years in responsible positions with private corporation and public utilities. Good record and references. Desires responsible position requiring ingenuity and good judgment with industrial, engineering or small power company, preferably New York or neighboring state. Available on reasonable notice. B-5505.

RECENT COLLEGE GRADUATE, E. E., desires position as instructor in electrical engineering, preferably in New York City. C-1514.

ELECTRICAL SALES ENGINEER, wishes to represent manufacturers of electrical power and control equipment, also special illuminating equipment for industrial use. Location, St. Louis. C-1479.

ASSISTANT ENGINEER, 25, single, B. S. in E. E., two years on Westinghouse test. Desires work with public utility. Location, East, Virginia or North Carolina. C-1314.

ELECTRICAL ENGINEER, college and technical graduate, twenty-five years' broad experience in power plant and substation design, H. T. bus construction, power and light distribution, underground and line transmission, quantity surveys, specification writing, executive correspondence, and office charge, desires position with reliable utility company. Atlantic Coast preferred. B-3231.

ELECTRICAL ENGINEER, 35, married, M. I. T. education, fourteen years' experience, office and field, electrical design of power stations, substations, industrial buildings, desires position with a substantial organization where the experience stated herein can be used to the advantage of employer and employee. Familiar with appraisal work. Holds New York State Professional Engineer's license. Salary $4200. Location, New York City. B-5393.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, desires permanent position engineering work Pacific Coast. Two years drafting, designing with electrical manufacturing company, two years substation design, rate engineering large public utility. Good character, pleasing personality, efficient worker. Several languages. European university graduate, 27, married. Minimum salary $175 a month. Present employed. Available month's notice. C-1109.

DISTRIBUTION ENGINEER, technical graduate, married, 33, five years' experience substations, steam and electric power stations, five years' experience in electrical distribution with large public utility in East. Desires location in East. Available one month. B-1410.

POWER SALES ENGINEER. Young man with ability, 34, married, desires connection with public utility who needs a real salesman for new business or contract department. Has had ten years' engineering and selling experience. Technically educated. Salary and expenses. Available August 1st. A-1330.

SUPERINTENDENT ELECTRICAL AND MECHANICAL CONSTRUCTION AND OPERATION-EXECUTIVE, 48, married, technical education, wide experience, five years in Orient, design, construction, installation and operation, power, light and industrial plants, steam, hydro-electric. Special experience all kinds electrical apparatus and equipment, turbines, boilers, auxiliaries, high tension transmission, substations, distribution systems, building construction, mill machinery in public utility and industrial plants. Available short notice. Location immaterial. C-408-127.

GRADUATE ELECTRICAL ENGINEER AND MECHANICAL ENGINEER, 27, married, one year G. E. test, one year of substation design with large public utility. Work consisted mostly of switchboards, control and protection schemes, and checking drawings. Available on reasonable notice. Location, Middlewest or East. C-1068.

MECHANICAL ELECTRICAL ENGINEER, married, eighteen years' experience covering General Electric test, substation and power station design and operation for steel and wire mills, electrical cable manufacturing and sales. Executive and industrial development ability. A-4652.

SALES ENGINEER, 34, well acquainted with Eastern public utilities, and large electrical jobbers; twelve years' experience. At present connected with large manufacturer of line material and substation equipment. Salary and expenses. Available June 30th. C-1551.

EDITOR-ENGINEER, will edit house organ for transportation company, public utility company, manufacturing company, or get up catalogue, advertisements or historical booklet or descriptive matter. Three and one-half years' experience as department editor of magazine, and electrical engineer of a number of years' standing. C-1490.

GRADUATE ELECTRICAL ENGINEER, Canadian, 27, married, finished Alexander Hamilton Institute Modern Business Course. Three years naval wireless work. Canadian General Electric Students' Test Course, nine months operating department, two years electrical design on hydraulic generating stations. Wishes position as engineer or executive with small growing manufacturing company or public utility. Location, Eastern States. Available fifteen days' notice. C-1524.

ELECTRICAL ENGINEER OR EXECUTIVE, twenty years' experience in electrical design and construction of generating and substations, also transmission and distribution, also industrial installations. Can also sell electrical equipment and commercial power. Desires responsible executive position. Permanence more important than location. B-3711.

LICENSED ELECTRICAL CONSTRUCTION ENGINEER, at present employed electrical field superintendent of large firm doing heating, plumbing, electrical contracting business. Four years' experience with above firm estimating, sales, purchasing, seven years with large public utility electrical engineering and new business departments. Minimum salary $5000. Location, New York or vicinity. Available reasonable notice. C-1548.

RADIO COMPASS ENGINEER, technical graduate, desires position with reliable concern in this capacity. Present employed by U. S. Navy Department on position and direction finding radio. C-723.

ASSISTANT EXECUTIVE, B. S. and E. E. degrees, five years' well balanced experience in all phases of distribution and power substations and their commercial aspects, and one year's experience in administrative office of manufacturing company, three years in supervisory capacity. Desires position with electrical company requiring technical, commercial, and executive ability. Minimum salary $3600. Location preferred, lower Great Lakes States. B-7315.

ELECTRICAL ENGINEERING GRADUATE, (B. S. in E. E.) 30, single, ten years' electrical construction and maintenance of industrial plants, substations, etc., one year electrical design. Desires position in electrical construction with public utility or contracting company. Field work preferred. Minimum salary $2600. Eastern location. C-1525.

POWER ENGINEER, 38, married, electrical graduate, also special study M. I. T., Allis-Chalmers test, 13 years' experience installation power plant machinery, maintenance, general construction, operation and supervision in public utility. Desires position distribution engineer with a public utility or similar work with opportunity for advancement. Location, United States. Available at once. A-4018.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JUNE 23, 1926

*ALBERTI, JOHN NORMAN, Designing Engineer, General Electric Co., Schenectady, N. Y.

ALEXANDER, R. WARREN, Elec. Engg. Dept., Commonwealth Power Corp., Jackson, Mich.

ALLEN, JAMES GILLESPIE, Illuminating Engineer, Duquesne Light Co., 800 Duquesne Bldg., Cecil Way, Pittsburgh, Pa.

ALLISON, ROY S., Dist. Manager, Niagara, Lockport & Ontario Power Co., Macy Bldg., Avon, N. Y.

AMBROSE, LEE O., Mech. & Elec. Engineer, The Austin Co., 16112 Euclid Ave., Cleveland, Ohio.

AMES, ALBERT WILSON, Salesman, Lighting Dept., City of Seattle, Seattle, Wash.

ANDERSON, HAROLD LESLIE, Resident Engineer, Commonwealth Power Corp., 244 Michigan Ave., W., Jackson, Mich.

ANDREWS, CHARLES L., Engineer, The Pacific Tel. & Tel. Co., 15 North Park St., Portland, Ore.

ANSON, EDWARD HIRAM, Asst. Engineer, Gibbs & Hill, Pennsylvania Station, New York, N. Y.

*ANTHONY, ROYAL BAKER, Asst. Division Supt., Penna. Power & Light Co., South Oak St., Mt. Carmel, Pa.

ARBUCKLE, JAMES STEWART, Electrical Engineer, American Brown Boveri Electric Corp., Camden, N. J.

ATKINSON, JOHN NORMAN, Hydro-Elec. Power House Operator, Newfoundland Power & Paper Co., Ltd., Deer Lake, Newfoundland.

ATWOOD, DAVID STODDARD, Elec. Engg. Dept., Llewellyn Iron Works, 1200 N. Main St., Los Angeles, Calif.

AUTEN, LLOYD D., Operator, Cleveland Railway Co., Cleveland; res., East Cleveland, Ohio.

BALLANTINE, ROBERT A., Salesman, Penn Electrical Engineering Co., 517 Ash St., Scranton, Pa.

BALLARD, WILLIAM CYRUS, Jr., Professor Elec. Engg. Dept., Cornell University, Franklin Hall, Ithaca, N. Y.

BARTHOLOMEW, FRANCIS JOHN, Director of Bartholomew, Montgomery & Co., Ltd., 614 Standard Bank Bldg., Vancouver, B. C. Can.

BARTON, SYDNEY, Chief Operator, Federal Telegraph Co., Clearwater; res., Long Beach, Calif.

BAUDRY, RENE ANDRE MARCEL, Draftsman, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

BAYLES, CHARLES GILBERT, Engineer, Black & Veatch, 701 Mutual Bldg., Kansas City, Mo.

BEAUMONT, LEONARD, Asst. Engineer, Distribution Dept., Shanghai Municipal Electricity Dept., Foochow Road, Shanghai, China.

*BECKETT, RUSSELL VOHR, Oscillograph Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pittsburgh, Pa.

BELL, CHARLES REGINALD, Junior Engineer, Cleveland Electrical Illuminating Co., 1013 Illuminating Bldg., Cleveland, Ohio.

BENNETT, JOHN WILLIAM, Distribution Engineer, Eastern N. J. Power Co., Allenhurst, N. J.

BERGHOLTZ, HERMAN, Jr., Testing Dept., General Electric Co., Schenectady, N. Y.

BETTINGER, LEROY WILLIAM, Electrician's Mate, Second Class, U. S. N., U. S. S. *Concord*, c/o Postmaster, New York, N. Y.

BINDER, GURDON A., Salesman, Ohio Brass Co., 1714 Fisher Bldg., Chicago, Ill.

BISAZZA, RUGGERO, Testing Dept., General Electric Co., Schenectady, N. Y.

BISHOP, LOUIS EDWARD, West Penn System, West Penn Bldg., Pittsburgh, Pa.

BLANCH, FREDERICK D., Electrical Engineer, Alternating Current Engg. Dept., General Electric Co., Schenectady, N. Y.

BORGESON, SIDNEY E., Electrical Development Engineer, Western Electric Co., Inc., Hawthorne Station, Chicago, Ill.

BOTHWELL, FORDYCE ARGO, General Electric Co., Schenectady, N. Y.

BOURA, FELIX G., Asst. Engineer, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

*BOYER, WILLIAM ARTHUR, Test Man, General Electric Co., Schenectady, N. Y.

BRAGG, ARTHUR DICKINSON, Testman, General Electric Co., Schenectady, N. Y.

BRENNON, LEONARD A., Chief Operating Engineer, General Electric Co., Erie, Pa.

BRISTOW, THOMAS NORWOOD, Salesman & Manager, H. B. Squires Co., 552 First Ave., Seattle, Wash.

BROUGHTON, WILLIAM GUNDY, Student Engineer, General Electric Co., Schenectady, N. Y.

BROWN, FREDERICK WILLIAM, 3rd Operator, Public Works Dept., Mangahao Power Station, Shannon, N. Z.

BROWN, LOWELL, Asst. Distribution Engineer, City of Seattle, Lighting Dept., County City Bldg., Seattle, Wash.

BUERY, GEORGE EVERETT, Chief Electrician, Peninsula Lumber Co., McKenna Ave., Portland, Ore.

BURCKETT, DOUGLAS MELLEN, Asst. Engineer, Great Northern Railway, Seattle, Wash.

BURT, ARCHIE RAY, Supervisor, Substations, Underground Trans. Constr. & Maintenance, Kansas City Railways Co., 8th & Woodland, Kansas City, Mo.

BUSTILLO, FRANCESCO E., Electrical Engineer, Mexican Light & Power Co., Gante No. 20, Mexico D. F., Mex.

BUTLER, WILLIAM COOK, Engineer, The Pacific Tel. & Tel. Co., 800 Fairview Ave., N., Seattle, Wash.

BUTT, FRANK HENRY, Sales Correspondent, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Dormant, Pittsburgh, Pa.

BUTTERFIELD, HOLLIS SPURGEON, Electrician, Atlantic City Electric Co., Kentucky & Pacific Aves., Atlantic City, N. J.

CAMPBELL, ALFRED E., Foreman, Underground Cable Div., Distribution Dept., The Ohio Power Co., Canton, Ohio.

CAMPBELL, THOMAS LORNE, Estimator, Toronto Hydro-Electric System, Duncan & Nelson Sts., Toronto, Ont., Can.

CANGUCU, O. G., Telegraph Engineer, Paulista Railway, Sao Paulo, Brazil, S. A.

CARRICK, JOHN F. C., Resident Agent, General Electric Co., 533 Gluck Bldg., Niagara Falls, N. Y.

CASTRO, LEOPOLDO, Jr., Student Engineer, General Electric Co., Schenectady, N. Y.

CHAMBERS, HENRY DONALD, Electrical Draftsman, Puget Sound Power & Light Co., Seattle, Wash.

CHANDLER, WALTER G., Supervisor of Cable Bureau, Brooklyn Edison Co., Inc., 14 Rockwell Place, Brooklyn, N. Y.

CHENEY, WALLACE E., Engineer, Switchgear Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

CHRISTIANSON, ELMER C., System Operator, Puget Sound Power & Light Co., 1306 A St., Tacoma, Wash.

CIRELLA, LAWRENCE E., Laboratory Assistant, Simplex Wire & Cable Co., Cambridge; res., Arlington, Mass.

*COOPER, RALPH FENIMORE, Electrician, Armature Winder, Miller Rubber Co., Akron, Ohio.

COOPER, WILLIAM J., Electrician, St. Paul's Hospital, 1100 Block Burrard St., Vancouver, B. C., Can.

COSTELLA, ALBERT PIETRO, Electrical Foreman & Partner, The Camden Storage Battery Co., 40 Haddon Ave., Camden, N. J.; res., Philadelphia, Pa.

COULSON, WILLIAM, Engineer in charge of Workshops, The Electrical Installation & Repairing Co., 40 Berry St., Belfast, Irelnda.

CRAGO, PAUL HUGHES, Electrical Engineer, Union Switch & Signal Co., Swissvale; res., Forest Hills Boro, Wilkinsburg, Pa.

CRAVEN, FRANK ELMER, Engineering Assistant, Bell Telephone Co. of Pa., 261 N. Broad St., Philadelphia, Pa.

CRAWFORD, JAMES M., Asst. General Foreman, Testing Dept., General Electric Co., Schenectady, N. Y.

CROCK, ISRAEL Z., Specification Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.

CROWELL, RALPH MILTON, Operator, Utah Power & Light Co., 133 S. West Temple, Salt Lake City, Utah.

CRUMP, LEONARD WADE, Draftsman, Puget Sound Power & Light Co., 1306 A St., Tacoma, Wash.

*CURTIS, GEORGE V., Testing Dept., General Electric Co., Schenectady, N. Y.

CUTHBERT, JAMES TAYLOR, Chief Electrician, Duquesne Light Co., Pittsburgh, Pa.

DAMON, ALFRED C., Test Dept., Simplex Wire & Cable Co., 66 Sidney St., Cambridge; res., Cochituate, Mass.

DAUGHERTY, THOMAS CLARKE, Telephone Traffic Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.

DAVIS, JOHN CASSIUS, Jr., Trouble Dispatcher, Edison Electric Illuminating Co., 1165 Massachusetts Ave., Roxbury; res., Dorchester, Mass.

DAVIS, WILLIAM, Asst. Engineer, Toronto Hydro-Electric System, Toronto, Ont., Can.

DAVISON, CHARLES, Land Line Inspector, Mexican Telegraph Co., Calle de Escandon No. 99, Orizaba, Vera Cruz, Mexico.

DAY, WILLIAM POWELL, Head, Turbine Test Dept., General Electric Co., Schenectady, N. Y.

DEAN, CHARLES PHILIP, Laboratory Supervising Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., Summit, N. J.

DE CELIS, FRANCISCO, High Tension Inspector of Meters, Mexican Light & Power Co., Mexico City, Mex.

DEDEK, FRANK G., Asst., Electrical Laboratory, Burroughs Adding Machine Co., Second Blvd., Detroit, Mich.

DELLINGER, FLOYD ELLIOTT, Overhead Electrical Engineer, Los Angeles Gas & Electric Corp., 810 S. Flower St., Los Angeles, Calif.

DENEEN, ROBERT J., Dist. Sales Manager, Ohio Brass Co., 1714 Fisher Bldg., Chicago, Ill.

DENNIS, WILLIAM EDWIN, Asst. Electrical Engineer, Bombay Baroda & Central India Railway, Church Gate St., Bombay, India.

DERRONE, MARCEL, Electrical Engineer, S. F. de M. D'e. A. Tekka, Gopeng, Perak, F. M. S.

DE VRIES, BERNARD E., Electrical Engineer, Engg. Dept., Duquesne Light Co., Duquesne Bldg., Pittsburgh, Pa.

DICKERSON, FRANCIS ARTHUR, Asst. Engineer, New York Telephone Co., 104 Broad St., New York.; res., Brooklyn, N. Y.
DIEHL, WILLIAM ARTHUR, Asst. Maintenance Engineer, National Malleable & Steel Castings Co., Cleveland, Ohio.
DOANE, PHILIP, Electrical Tester, New York Edison Co., 92 Vandam St., New York; res., Brooklyn, N. Y.
DODDS, VINCENT G., Local Manager, Aluminum Co. of America, 100 State St., Albany, N. Y.
DOWE, GEORGE PHILLIPSON, Draftsman, The Canadian Crocker-Wheeler Co., St. Catharines, Ont., Can.
*DREYFUS, JAMES, Equipment Engineer, New York Tel. Co., 360 Bridge St., Brooklyn, N. Y.
DRING, LOUIS GABRIEL, Telephone Inside Man, New York Telephone Co., 15 Dey St., New York, N. Y.
DUEVEL, CHARLES OTTO, Jr., Heating & Ventilating Engineer, Consumers Central Heating Co., 108 E. 11th St., Tacoma, Wash.
DUFFY, LEE, Substation Operator, Puget Sound Power & Light Co., 1428 Boylston Ave., Seattle, Wash.
DUNHAM, DAVID, Engineer, Southland Electric Power Board, Invercargill; res., Gore, N. Z.
EBERHARDT, PAUL WILLIAM, General Safety Inspector, Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.
EDWARD, JOHN ANDREW, Hydro-Electric Power Station, Snoqualmie, Wash.
EHRKE, ERNEST BORMAN, Outside Salesman, Pacific States Electric Co., 236 S. Los Angeles St., Los Angeles, Calif.
ELLIS, DONALD WAYNE, Chief Electrician, Beech Bottom Power Co., Power, West Va.
ERICKSON, ELLIS O., Engineer, Supply Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
EVELAND, GEORGE HARMON, Engineer, Feather River Power Co., Hobart Bldg., San Francisco, Calif.
EWING, CHARLES, Electrical Engineer, Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.
FAGAN, HENRY JOSEPH, 1555 Walton Ave., Bronx, New York, N. Y.
FALK, VICTOR EMANUEL, Electrical Designer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.
FALOR, HAROLD LEROY, Chief Operator, Northern Ohio Power & Light Co., Terminal Bldg., Akron, Ohio.
FAUERBACH, WALTER FREDERICK, Salesman, Westinghouse Elec. & Mfg. Co., 150 Broadway, New York; res., Hollis, N. Y.
*FAWCETT, O. EMMETT, Asst. Electrical Engineer, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.
FEINDEL, ABBOTT, Cable Tester, New York Edison Co., 708 1st Ave., New York; res., Brooklyn, N. Y.
FLORY, CARL LEONARD, Asst. Engineer in charge, Radio Corp. of America, Tuckerton, N. J.
FONTAINE, JAMES, Research Assistant, Engineering Experimental Station, North Carolina State College, Raleigh, N. C.
FORSYTH, JOSEPH WILSON, Engineer, City of Philadelphia, 6000 Rising Sun Ave., Philadelphia, Pa.
FREE, JOHN E., Supt., Electric Construction, General Electric Co., Witherspoon Bldg., Philadelphia, Pa.
*FRENCH, MURVIN ARVILLE, Inspector, Underground Cable Construction Dept., Chas. H. Tenney & Co., 200 Devonshire St., Boston; res., Framingham, Mass.
FUHS, RAYMOND H., Electrical Engineer, Indianapolis Light & Heat Co., 48 Monument Place, Indianapolis, Ind.
GALE, ARTHUR P., Director of Public Relations, Wisconsin Power & Light Co., 900 Gay Bldg., Madison, Wis.
GAMBITTA, A. FILADELFIO, Research Work, 6 W. 28th St., New York, N. Y.
GANTENBEIN, E. F., General Foreman, Line Dept., Puget Sound Power & Light Co., 601 Capitol Way, Olympia, Wash.
GARNER, FRED E., Dist. Sales Manager, Daven Radio Corp., 158 Summit St., Newark, N. J.
GARNETT, HARRY SEYS, Asst. Engineer, Messrs. Merz & McLellan, 32 Victoria St., Westminster, London, Eng.
GARRETSON, FRANCIS MARION, Jr., Research Engineer, Cooper Hewitt Electric Co., 95 River St., Hoboken; res., East Orange, N. J.
GAUCHET, CLIFFORD EDWARD, Street Lighting Specialist, General Electric Co., Pierce Bldg., St. Louis, Mo.
GHEN, MELVILLE W., Supervisor of Underground Construction, Duquesne Light Co., 800 Duquesne Bldg., Pittsburgh, Pa.
GIANGRANDE, DOMENIC MICHAEL, Draftsman, The New York Edison Co., 130 E. 15th St., New York, N. Y.
GIBNEY, EUGENE L., Draftsman, Lighting Dept., City of Seattle, 514 Prefontaine Bldg., Seattle, Wash.
GIBSON, FOSTER COLLINS, Dist. Manager, Edison Storage Battery Co., 509 Polson Bldg., Seattle, Wash.
GILLIS, MELVIN D., Foreman of Electrical Test, General Electric Co., Erie, Pa.
GILSON, WALTER JAY, Designing Engineer, Canadian & General Finance Co., 357 Bay St., Toronto, Ont., Can.
GOARD, LAMAR C., Distribution Supt., The Ohio Public Service Co., Ashland, Ohio.
GOYNE, THOMAS STUART, Sales Engineer, Goyne Steam Pump Co., Ashland, Pa.
GRANT, ALEXANDER JAMES, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pittsburgh, Pa.
GRAUL, EDGAR ALBERT, Technical Clerk, Vice-President's Office, Duquesne Light Co., 300 Philadelphia Bldg., Pittsburgh, Pa.
GRAY, JOSEPH WILLIAM, Professor of Elec. Engg., Ohio Northern University, Ada, Ohio.
GREENE, EDWIN M., Draftsman, Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
GREENE, J. H., Sanderson & Porter, 52 William St., New York, N. Y.
GRIFFIN, GEORGE HENRY, Student, Union Carbide Co., Saulte Ste Marie, Mich.
HADLEY, GEORGE F., Process Engineer, Westinghouse Elec. & Mfg. Co. East Pittsburgh; res., Pittsburgh, Pa.
HAERTLEIN, ALBERT, Supt., Plans & Schedules Div., Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.
*HANSEN, TED A., Automatic Substation Inspector, Puget Sound Power & Light Co., Electric Bldg., Seattle, Wash.
HARKINS, PERCY STONER, Division Plant Engineer, Bell Telephone Co. of Pa., 1230 Arch St., Philadelphia, Pa.
*HARNETT, DANIEL EDWARD, Electrical Engineer, Pacent Electric Co., 91 7th Ave., New York, N. Y.
*HARRELL, FREDERICK EDMUND, Sales Engineer, Reliance Electric & Engineering Co., 1088 Ivanhoe Road, Cleveland, Ohio.
HARTLE, WILBERT GRAY, Student Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.
HARTRANFT, ARMAND C., Load Dispatcher, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia; res., Germantown, Philadelphia, Pa.
HASKENS, ALBERT JACOB, Draftsman, Union Switch & Signal Co., Swissvale, Pa.
*HEFFELMAN, MALCOLM C., Electrician Foreman, Chile Exploration Co., Chuquicamata, Chile, S. A.
HELANDER, WALTER NATHANIEL, Meter Dept., Puget Sound Power & Light Co., 601 Capitol Way, Olympia, Wash.
HENDERSON, CHARLES L., Asst. Supt., Sub-Sta. Operation, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.
HENDERSON, EUGENE WAYNE, Chief Electrician, Colfax Plant, Duquesne Light Co., Cheswick, Pa.
HERRERA, RAFAEL O., Student Engineer, General Electric Co., Schenectady, N. Y.
HILLOCK, JAMES FRANCIS, Senior Engineer, Customer's Section Duquesne Light Co., Duquesne Bldg., Pittsburgh, Pa.
HILTEBEITEL, JESSE, Chief Engineer, H. N. Crowder, Jr., Co., 446 Union St., Allentown, Pa.; res., New York, N. Y.
HITE, JOHN W., Electrical Inspector, Reliance Electric & Engineering Co., 1088 Ivanhoe Road, Cleveland, Ohio.
HOEFFLIN, ALBERT S., Elect. Operating Dept., Louisville Gas & Electric Co., 311 W. Chestnut St., Louisville, Ky.
HOEHN, EDUARD H., Junior Engineer, Union Electric Light & Power Co., 315 N. 12th Blvd., St. Louis, Mo.
HOULE, ARTHUR VICTOR, Tester, The New York Edison Co., 92 Vandam St., New York; res., Brooklyn, N. Y.
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*Formerly enrolled students

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TRANSFERRED TO GRADE OF MEMBER JUNE 23, 1926

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BAILEY, RAYMOND, Chief Electrical Designer, Philadelphia Electric Co., Philadelphia, Pa.

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STINER, H. WRAY, Commercial Engineer, General Electric Co., Cleveland, O.

VAN BOKKELEN, WILLIAM R., Chief Engineer, Coast Counties Gas & Electric Co., San Francisco, Calif.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1926.

Allen, R. L., Archbold-Brady Co., Syracuse, N. Y.

Anderson, C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Baeckler, W., National Carbon Co., Lakewood, Ohio

Banks, H. O., Hartford Steam Boiler Inspection & Ins. Co., New York, N. Y.

Bennett, R. S., General Electric Co., Cincinnati, Ohio

Bramblett, P. F., Northwestern Light & Power Co., Sibley, Iowa

Butterworth, R. I., Bristol Gas & Electric Co., Bristol, Tenn.

Carrasco-Zanini, J., Mexican Light & Power Co., Ltd., Mexico, D. F.

Cecchetti, F., General Electric Co., Schenectady, N. Y.

Chang, Z. Z., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

Curtis, H. C., Cutler-Hammer Mfg. Co., Milwaukee, Wis.

de Mulinen, E. F. H., American Brown Boveri Electric Corp., Camden, N. J.

Donovan, W., General Electric Co., Ltd., Philadelphia, Pa.

Dunkelberg, P. R., Illinois Central Railroad Co., Chicago, Ill.

Dunlap, B., Ozork Pipe Line, Ponca City, Okla.

Fogg, L. E., American Electrical Works, Phillipsdale, R. I.

Gattiker, C. H., The New York Edison Co., NewYork, N. Y.

Gilbert, C. F., Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.

Gilroy, J. R., Commonwealth Edison Co., Chicago, Ill.

Gray, W. S., Stone & Webster, Inc., Boston, Mass.

Gronvold, I. J., Neil Electric Co., Isleton, Calif.

Haentjens, O., Barrett, Haentjens & Co., Hazleton, Pa.

Hall, I. E., (Member), Roller-Smith Co., Bethlehem, Pa.

Hammond, R. J., The Pacific Tel. & Tel. Co., Los Angeles, Calif.

Hastings, D. F., Rossiter, Tuler & McDonnell, New York, N. Y.

Heintz, W. T., Automatic Electric Co., 427 Bourse Bldg., Philadelphia, Pa.

Herne, W. W., Great Western Power Co., San Francisco, Calif.

Hildebrandt, J. L., Consolidated Elec. Lt. & Pr. Co., Baltimore, Md.

Hudd, A. E., Automatic Electric Inc., Chicago, Ill.

Humphries, P. H., Harvard University, Cambridge, Mass.

Ischinger, A. E., with Joshua R. H. Potts, Philadelphia, Pa.

Jones, R. E., (Member), Hydro-Elec. Power Commission of Ontario, Toronto, Ont., Can.

Kohlhepp, W. S., Cumberland Tel. & Tel. Co., Louisville, Ky.

Larkin, J. J., Brooklyn-Manhattan Corp., Brooklyn, N. Y.

Lessing, O., Counties Gas & Electric Co., Norristown, Pa.

Long, M., Bell Telephone Co. of Pa., Philadelphia, Pa.

MacCormick, C. M. C., General Electric Co., Schenectady, N. Y.

Mahnke, K., Pennsylvania Power & Light Co., Williamsport, Pa.

Mahoney, J. F., Brooklyn Edison Co., Brooklyn, N. Y.

Marquardt, M., Electrician, Passaic, N. J.

Nakamura, H., Toho Electric Power Co., Tokio, Japan; (For mail, Wilkinsburg, Pa.)

Nivin, D. G., (Member), Chief Elec. Inspector, City of Miami, Miami, Fla.

Palm, I. R., Sargent & Lundy, Chicago, Ill.

Patrick, R. A., Truckee River Power Co., Reno, Nev.

Pinckert, W. F., Draftsman, 1264 Bush St., San Francisco, Calif.

Rehwaldt, A. W., Sargent & Lundy, Chicago, Ill. (Applicant for re-election.)

Robinson, C. C., (Member), Member of Firm, C. M. Robinson, Richmond, Va.

Rogers, F. H., Consolidated Gas & Electric Co., Baltimore, Md.

Rudorff, D. W., Mexican Light & Power Co., Ltd., Necaxa, Puebla, Mex.

Scharf, P. B., Goodyear Industrial University, Akron, Ohio

Schuman, J. J., (Member), The Edison Elec. Ill. Co. of Boston, Boston, Mass.

Skelton, W. J., Wisconsin Telephone Co., Milwaukee, Wis.

Souza, V., Contratista de Instalaciones, Mexico City, Mex.

Staggs, N. K., The Telephone Engineering & Equipment Co., Seattle, Wash.

Stotler, E. J., Sears, Roebuck & Co., Newark, N.J. (Applicant for re-election.)

Swanson, E. R., Wisconsin Power & Light Co., Fond du Lac, Wis.
Tandberg, L. G., Wagner Electric Corp., Los Angeles, Calif.
Tillquist, D., New York Telephone Co., New York, N. Y.
Terhune, W. I., Public Service Production Co., Newark, N. J.
Tulloss, J. C., (Member), 50 Vanderbilt Ave., New York, N. Y.
Watts, W. E. G., (Member), Luscar Collieries, Luscar via Edmonton, Alta, Can.
Way, R. S., Worcester Suburban Electric Co., Uxbridge, Mass.
Weaver, R. A., Cincinnati & Suburban Bell Tel. Cincinnati, Ohio
Whisenand, O. B., Citizens Gas Co., Indianapolis, Ind.
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Zorn, F. W., (Member), American Laundry Machinery Co., New York, N. Y.
Total 66.

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Anthony, P. A. W., with A. E. Harding Frew, Brisbane, Queensland, Aust.
Baxendale, F., British-Thomson Co., Ltd., Rugby, Eng.
Bucktin, F. C., Springs-Ellesmere Power Board, Templeton, Christchurch, N. Z.
Crane, S. F., Southland Electric Power Board, Invercargill, N. Z.
Dobbs, L. J., Southland Electric Power Board, Invercargill, N. Z.
Evans, H. C. H., Newcastle City Council, Newcastle, N. S. Wales, Aust.
Keenan, H. B., Waiarapa Electric Power Board, Carterton, N. Z.
Maneckji, J. B., (Member), Industrial Engr. & Advisor, Bombay, India
Master, J. J., Tata Hydro & Andhra Valley Elec. Pr. Supply Co., Bombay, India
Masu, S., Toho Electric Power Co., Tokio, Japan
Pergler, F., Chief Engineer, City of Prague, Prague, Czechoslovakia
Pradhan, G. K., Baroda State's Power House, Baroda, India
Tzichevsky, J. A., Elec. Station Constr., U. S. S. R. Gov't., Moscow, U. S. S. R. Russia
Wight, W. C., Municipal Electricity Dept., Idgah, Simla, India
Total 14

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Billman, Albert G., South Dakota State College
Birkett, Charles M., School of Engg. of Milwaukee
Brienza, Anthony, Columbia Univ.
Brown, Cecil L., Univ. of Idaho
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Caruthers, Lawrence H., Yale Univ.
Caven, Waldo E., Carnegie Tech.
Chable, William J., Virginia Military Inst.
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Curtis Lorin, Univ. of Idaho
Delaplane, R. Reyburn, Purdue Univ.
De Roo, Howard Drummond, Mass. Inst. of Tech.
Dodd, Samuel A., Cornell Univ.
Elliott, Robert G., Univ. of Idaho
Ernsberger, Edward L., Univ. of Idaho
Evans, Edmund A., Rensselaer Poly. Inst.
Fisher, John H., Northeastern Univ.
Francis, M. Clifford, Univ. of Missouri
Haber, Frank L., Univ. of Wisconsin
Hall, Clarence F., Rensselaer Polytechnic Institute
Harman, Leonard F., Univ. of Idaho
Hayward, Doyle E., Univ. of Idaho
Hertsche, Jr., J. C., Stanford Univ.
Hockings, Clarence E., Univ. of Wisconsin
Holbrook, Joseph T., Univ. of Idaho
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Kellogg, Cyrene W., School of Engg. of Milwaukee
Kirk, Royal B., Purdue Univ.
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Malpass, Donald, Penn. State College
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Thomason, Jesse L., Univ. of Idaho
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Utah	John Salberg	D. L. Brundige, Utah Pr. & Lt. Co., Box 1790, Salt Lake City, Utah.
Vancouver	A. Vilstrup	C. W. Colvin, B. C. Elec. Railway Co., 425 Carroll St., Vancouver, B. C.
Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
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Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
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Drexel Institute, Philadelphia, Pa	E. B. Middleton	W. N. Richards	E. O. Lange
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South Dakota, University of, Vermillion, S. D.	L. J. Stverak	R. T. Brackett	B. B. Brackett
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Texas A. & M. College, College Station, Texas	L. H. Cardwell	C. A. Altenbern	F. C. Bolton
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Washington, University of, Seattle, Wash.	M. E. Johnson	C. M. Murray, Jr.	George S. Smith
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West Virginia University, Morgantown, W. Va.	R. W. Beardslee	W. F. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis.	Benj. Teare	N. B. Thayer	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass.	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyo.	E. Murray	V. D. Shinbur	G. H. Sechrist
Yale University, New Haven, Conn.	S. A. Tucker	G. C. Bailey	Charles F. Scott
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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Regulators.—Bulletin 1734, 56 pp. Describes regulators for generator-voltage control. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Transformers.—Bulletin 2055, 4 pp. Describes the construction and operation of the Pittsburgh transformer tap changer. Pittsburgh Transformer Company, Columbus & Preble Avenues, Pittsburgh, Pa.

Static Condensers.—Bulletin 20286, 4 pp. Describes static condensers for power factor correction on motor circuits of 220, 440, and 550 volts. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Grounds.—Bulletin, 8 pp., "Electrical Characteristics of Driven Grounds;" bulletin, 4 pp., "Non-Rusting Ground Rods;" bulletin, 4 pp., "Non-Rusting Overhead Ground Wires." Copperweld Steel Company, Rankin, Pa.

Circuit Breaker Time Limit Attachments. Bulletin 530, supplement, 4 pp. Describes Roller-Smith direct-acting time limit attachments for standard type circuit breakers. Roller-Smith Company, 12 Park Place, New York.

Insulator Protection.—Bulletin, 32 pp., "Taking the 'T' Out of Lightning." Describes Locke grading shield and arcing horn equipment for the protection of insulators. Locke Insulator Corporation, Baltimore, Md.

Power Factor Correction.—Bulletin 146, 24 pp., "Power Factor Correction by the Consumer." Describes the experience of the American Gas & Electric Company with power factor correction. Wagner Electric Corporation, St. Louis, Mo.

NOTES OF THE INDUSTRY

The Master Electric Company, Dayton, Ohio, announces the opening of a district office at 1725 Brandywine Street, Philadelphia, where a stock of motors will be carried. The new office will be in charge of William F. Grau.

Lapp Insulator Co., Inc., LeRoy, N. Y., announces the appointment of the Van Rosen Company, 141 Milk Street, Boston, as representative for the New England territory. The Van Rosen Company also represents the Delta-Star Electric Company and the Packard Electric Company.

The Timken Roller Bearing Company, Canton, Ohio, has promoted G. W. Curtis from industrial equipment engineer to district manager of sales, industrial division, for the Milwaukee territory. Mr. Curtis will work with R. W. Ballentine, who previously handled this territory. S. M. Weckstein succeeds Mr. Curtis as industrial equipment engineer.

The Sangamo Electric Company, Springfield, Ill., announces the appointment of Reginal M. Campbell, special representative, with headquarters at 50 Church Street, New York, who will have complete management of all watthour meter business in the metropolitan district. Mr. Campbell will be assisted by W. S. Boult. T. B. Rhoades will continue in charge of radio and amperehour meter sales as well as of the service department.

The Burndy Engineering Company, New York, manufacturers of high-tension bus equipment, announces the appointment of the H. M. Thomas Company, San Francisco, as California representative. The growth of business in the field, and the necessity of quick action in the filling of orders, led to the appointment of a special representative. Preparations are being considered to warehouse the standard Burndy line of connectors for copper tubing and cable in San Francisco, thus establishing a quick shipping point for the west coast.

Banks Huge Investors in Electric Utilities.—In the first four months of this year the financial institutions of the United States, which includes insurance companies, savings banks, national and state banks and trust companies, invested more than $427,000,000 in the bonds of the electric utility industry. In the same four months more than $68,000,000 of electric utility shares were sold to the public. That total of $495,000,000 invested in the electric industry does not include many millions of dollars of securities distributed through the customer-owner plan. The total electric utility stock and bond issues from June 1, 1925 to May 1, 1926, was $979,000,000.

The Conowingo Project—Giant of Hydroelectric Developments.—Second only to that of the Niagara Falls Power Company, and surpassing Muscle Shoals, will be the enormous hydroelectric plant which is being built by Stone and Webster for the Philadelphia Electric Power Company on the Susquehanna River, within four miles of tidewater in the state of Maryland. A dam 4800 feet long—three hundred feet longer than the Muscle Shoals dam—is being built across the river to form a reservoir of 8100 acres. The impounded water will drive waterwheel-driven electric generators of large size, and the energy will be sent over high voltage transmission lines into Philadelphia, 75 miles away.

Ultimately this hydroelectric station will contain 11 generators, each rated at 50,000 horse power, or 36,000 kilowatts. The initial installation will include seven of these units, giving the station 350,000 horse power; the Niagara Falls Power Company development produces 452,500 horse power, and Muscle Shoals 260,000 horse power. Four of the huge waterwheel-driven generators for Conowingo are now being made by the General Electric Company. They are technically rated at 40,000 kilovolt-amperes, 90 per cent power factor, and 13,800 volts, with a speed of 81.8 revolutions per minute. It is expected that 1,360,000,000 kilowatt-hours of energy will be produced by the Conowingo plant in the average year; three-quarters of a million tons of coal a year will be saved thereby.

The electric current, produced by the generators at 13,800 volts, will be stepped up to 220,000 volts by transformers and at this pressure sent over two transmission lines to Philadelphia. Each line will have sufficient capacity to carry the full load in case of trouble with the other one. When the final four generators are added to the power station, a third transmission line will be constructed.

The Conowingo hydroelectric development will be coordinated with the great steam-turbine generating plants of the company so that the water power will be used to supply the base load of the system when the flow of the river is ample, and the steam stations to supply the peak load. When the river flow is low, the steam stations will be used for carrying the base load, and the water power will be called upon only for peak loads. When the river flow is sufficient for full operation, Conowingo will supply 231,000 kilowatts for base load; when the river is low, the enormous reservoir will be called upon, and statistics covering a period of 35 years show that in the driest period of the year Conowingo will be able to supply 190,000 kilowatts for peak loads.

Construction of the 8100-acre reservoir means that the little town of Conowingo, with 200 inhabitants, must be abandoned; fifteen miles of a line of the Pennsylvania Railroad must be relocated; and five miles of main highway from Baltimore to Philadelphia must be built, with a bridge over the dam to replace the one which will be submerged.

The Susquehanna watershed of 27,000 square miles includes a large part of the central section of Pennsylvania, considerable of southern New York state, and a bit of northeastern Maryland. The average river flow is 40,000 cubic feet per second.

JOURNAL OF THE A·I·E·E·

AUGUST 1926

A E E I

PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST. NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Salt Lake City, Utah, Sept. 6-9

MEETINGS OF OTHER SOCIETIES

World Power Conference, Basle, Switzerland, Aug. 31-Sept. 8

Illuminating Engineering Society, Spring Lake, N. J., Sept. 7-10

National Electric Light Association

Rocky Mountain Division, Glenwood Springs, Col., Sept. 13-16

New England Division, Poland, Maine, Sept. 20-23

JOURNAL

OF THE

American Institute of Electrical Engineers

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Current Electrical Articles Published by Other Societies

National Electric Light Association Bulletin, June 1926

A New Electrical Production Control System, by L. Ederer

Growth of the Electric Light and Power Industry under Regulation, by J. F. Shaughnessy

Observations on Some Problems of the Electrical Industry, by O. D. Young

Some Comments on the Economics of Electricity Supply, by S. Insull

# Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV August, 1926 Number 8

Research in Pure Science

The National Academy of Sciences is making a strong effort to raise a national research endowment of \$20,000,000 for research in pure science. The committee under which this movement is being fostered is under the chairmanship of Herbert Hoover and contains the names of such well-known scientists and engineers as John J. Carty, Frank B. Jewett, Gano Dunn, Robert A. Millikan and Henry S. Pritchett in addition to many names of prominent financiers and executives. Such an endowment will make possible uninterrupted investigations in pure science which now are necessarily limited.

The economic and financial advantages of such research cannot be overestimated. Its purpose is to increase and strengthen American contributions to the mathematical, physical and biological sciences by the creation of a national fund for skilled investigators, who will be selected, by the best qualified authorities in the National Academy of Sciences, from among the ablest and most productive investigators engaged in pure science research. Appropriations will be made for a fixed period of years, subject to renewal if circumstances warrant it.

Such fundamental research as these investigators are engaged in is the foundation upon which modern economic and industrial progress depend. Without their efforts the welfare of mankind would materially suffer and industrial development would be at a standstill.

A. I. E. E. Convention Affords Proof of Engineering Competency

Exceedingly well worth while was the annual convention of the American Institute of Electrical Engineers, held at White Sulphur Springs, West Va., last week. The executives of the Institute stressed the importance of engineering participation in all national affairs. The technical committees made reports which showed the status of the art and outlined the developments needed. Several fine technical papers were presented which gave rise to profitable discussions. The meeting, in short, gave evidence of entire competency on the part of electrical engineers to meet their responsibilities.

The subject of standards received an unusual amount of attention, and it is interesting to note that the American Engineering Standards Committee and the embryonic International Standards Association owe their formation to the fact that electrical engineers had shown by their own organizations that standards could be made and were needed. The A. I. E. E. standards committee and the International Electrotechnical Commission can well be proud that they were the originators of standardizing agencies of still broader scope.

Surveyed as a whole, the art of electrical engineering is well in hand and yet has very great possibilities for development. The address of Dr. Pupin showed the great tasks still to be done before electrical engineers can rest content. Yet a perspective view of this convention gives rise to the conviction that under the banner of the Institute electrical engineers will conquer all difficulties.—*Electrical World.*

Some Leaders of the A. I. E. E.

E. Wilbur Rice, Jr., thirtieth president of the Institute, 1917-1918, was born at La Crosse, Wis., May 6, 1862.

Graduating with honors in his class in the Central High School of Philadelphia in 1880, he became assistant to Professor Elihu Thomson in the American Electric Company, New Britain, Conn., then newly formed to manufacture arc lighting apparatus under the Thomson-Houston patents.

Two years later the American Electric Company was re-named the Thomson-Houston Electric Company and removed to Lynn, Mass., Mr. Rice becoming Works Superintendent and Consulting Engineer. In that dual capacity, he built up the technical and manufacturing side of the enterprise.

After the organization of the General Electric Company, Mr. Rice was made chief engineer and chairman of its Manufacturing Committee, in charge of all engineering and manufacturing operations, and in 1896 was elected vice-president. A record of his engineering activities thenceforward for a quarter of a century is an integral part of industrial history in the electrical field during that period—the history of the development of long distance electrical transmission of energy, distributing systems of polyphase currents, the rotary converter, the Curtis type of steam turbine, the tungsten lamp, and of many other applications now classed as epochal.

In 1903, Mr. Rice received his degree from Harvard University; the degree of D. Sc. in 1906 from Union

College; the degree of Doctor of Engineering in 1918 from Rensselaer Polytechnic Institute; and in 1923 the degree of D. Sc. from the University of Pennsylvania.

Apart from his work as an individual, always valuable and noteworthy in itself, he possessed, to a marked degree, the high qualities of a teacher. An example of his power to mobilize a high form of human effort and give it effective use, is the research laboratory at Schenectady, with its brilliant personnel and complete and up-to-date equipment for investigation and experiment. Others helped to plan this famous institution, even to a greater extent than he, according to his own testimony, making it what it is, but it was he who supplied the rare combination of courage and vision required to carry it through the early stages of its development.

So conspicuous have been Mr. Rice's activities as an engineer that in the sketches of his career heretofore published little has been said of his service as a business executive, particularly before he was chosen president of the General Electric Company. To him is due the major credit for the development in earlier years of the unique factory system of that corporation, with its wide spread departmental units, each having definite responsibilities and ample scope for self-expression and achievement, but all so correlated as to make needed control from a central point easy as well as effective.

With an engineer's discernment, as well as a clear perception of social and moral values, he was one of America's first industrial leaders to see the importance of that contact which has lately been secured by many corporations through works council plans. The principle of employe representation was applied by him to established procedure, so far as it was then practicable, long before it was publicly enunciated.

Biographies of Mr. Rice refer to his inventive genius. That he has been prolific as an inventor, despite the multitude of administrative duties demanding his attention, is indicated in part by the fact that there have been granted him more than 100 patents.

Besides being past president of the A. I. E. E., he is a member of the Institution of Civil Engineers and the Institution of Electrical Engineers of Great Britain. a member of the Engineers and University Clubs of New York, the University Club of Boston, and The Pilgrims. After the Paris Exposition in 1900, he was created Chevalier of the Legion of Honor, and in 1917 he received from the Emperor of Japan the decoration of the Third Order of the Rising Sun.

Mr. Rice served as President of the General Electric Company for about ten years, relinquishing that office in 1922 and becoming Honorary Chairman of the Board of Directors.

The writings of Mr. Rice have not been voluminous, as the leisure required for sustained literary work has never been his. In a paper presented by him at a memorial service for Steinmetz in October, 1923, the work of that rare genius, from the time that he landed in this country, a penniless immigrant, till his death shocked the scientific world, was vividly portrayed. A comprehensive review entitled "New Fields of Research for Power Development" was prepared by him for the First World Power Congress held in London, June 30th to July 12th, 1924.

Artificial Light For Plant Growth

Slowed-up moving pictures just taken by Carl Wallen and R. S. Green, New York motion picture camera men, of a number of different plants grown under electric light by the Westinghouse Lamp Company, in co-operation with Peter Henderson & Son, seedsmen in their greenhouses in Jersey City, N. J., prove conclusively that through the use of artificial light plants can be forced or retarded to conform to a predetermined schedule. The motion pictures were taken for the purpose of registering the exact degree of acceleration in the growth of the plants when forced by artificial light, and to determine at which stage of the plant's blossoming the light has the maximum effect. The pictures show that the blooming was greatly speeded up, some flowers, such as tulips, for instance, coming from tight buds to full bloom in less than an hour.

Tests made by Westinghouse engineers some time ago proved that artificial light can be used to stimulate the growth of many varieties of plants. At that time photographic records were made of the progress of the plants, which were grown with a combination of daylight and the added assistance of artificial light for several hours nightly, but the "still" photographs having been made at intervals of several days each, they failed to give accurate data, the effect of the light varying at different growing stages. The motion pictures have been taken with a camera which was slowed up to a predetermined number of pictures per hour through the use of gears and a motor, with a rheostat to control the speed.—*The Electrical News* (Toronto).

Radiation from Carbon Arcs

Investigating the radiation from the carbon arc is a matter of great importance in the treatment of diseases by exposure to light, especially sunlight. However, sunlight can not always be obtained, hence the demand for an artificial source approaching sunlight in its characteristics.

An investigation by the Bureau of Standards is being made in duplicate: (1) By mapping the ultraviolet spectrum by means of a quartz spectroradiometer, and (2) by measuring the spectral components of the total radiation emitted by the arc, by using a thermopile and screens which completely absorb certain spectral regions and freely transmit others.

The high-intensity arc (120 amperes) has been found to be closest to the sun in spectral composition. It emits considerable radiation of wave lengths longer than 4 μ, which are not in the solar beam, but this can be eliminated easily by using a window of fused quartz, which absorbs the long infra-red rays.

Abridgment of

Behavior of Radio Receiving Systems to Signals and to Interference

BY LEO JAMES PETERS[1]

Associate, A. I. E. E.

Synopsis.—*This paper develops a point of view and method by means of which it is possible to arrive at many of the transient effects occurring in radio systems by a consideration of steady-state properties alone. The scheme is to replace the voltages in radio receiving systems due to interference and signals by a group of generators having the correct voltages and frequencies. These generators can be thought of as having been in the circuit for an indefinitely long time, so that only the steady-state response of the system need be considered. The generators which replace the voltages induced in an antenna by interrupted continuous wave stations, by spark telegraph stations, by telephone stations and by static are worked out. The desirable properties of radio receiving systems for receiving various types of signals through interference are arrived at and an ideal system is described which may be used as a standard of reference for judging the merits of any actual frequency selecting system. It is shown that this ideal system reduces the interference from all sources to the smallest possible value which can be obtained in a system which makes use of frequency selection to reduce interference. The paper thus arrives at the degree to which interference can be mitigated by frequency-selection methods. In order to illustrate the method of treating actual systems, calculations are given for a simple series receiver. The interference caused by transmitting stations of various types and by static is discussed and the factors determining such interference are pointed out.*

Part I. Character of the Signal Voltages Induced in Antennas and the Desirable Properties of Frequency Selection Systems for Receiving the Signals

1. Introduction and Purpose

THE behavior of a radio receiving system, both to signals and to interference, depends upon the properties of the system, in the transient state. It is very often a difficult problem to arrive at the transient-state properties of a system, whereas the formulation of the steady-state properties is a relatively easy matter. It is the purpose of this paper to develop a very simple but effective way of answering some of the questions which arise in dealing with the effects of both signals and interference upon radio receiving systems when the steady-state properties of the system are known, or of arriving at the best steady-state properties of a system for receiving a given signal through interference. The primary purpose of the paper is to establish a view-point from which to judge the merits and the limitations of receiving systems, and also to arrive at the interference produced by transmitting systems of various types. Since the primary purpose of the paper is to establish a point of view and a method, only a few problems illustrating the method are discussed.

The solution for the transient properties of a circuit network can be made to depend upon the steady-state solution, if the impressed voltage can be represented from $t = -\infty$ to $t = +\infty$ as a Fourier integral. This method has been used by Carson, Fry, and the author for observing the general behavior of circuits in the transient state. Carson has used this method to formulate the response to static impulses of those radio receiving systems in which the principle of frequency selection is used to reduce interference. Milner has used the Fourier series expansion to calculate the arrival current in submarine cables. These general methods, however, lead into fields of mathematics which are unfamiliar to many engineers, but they suggest a very simple and powerful but less general method of handling many problems that arise in radio communication. This paper has a twofold purpose; first, of pointing out these simple methods with the hope that it may aid in giving the method the general use its power warrants, and second, to arrive at some interesting and useful conclusions as to the effects of signals and interference upon radio receiving systems.

2. Introduction to the Method of Treatment

Fig. 1 shows an alternator delivering a pure sine wave feeding a transformer on open circuit through a long

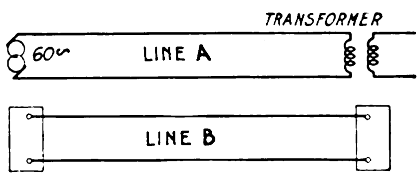

FIG. 1

line, A. Parallel to this line there is another line, B, which may be a telephone circuit. We wish to find the effect of line A upon line B. As is generally known, the current in line A has the form shown by Fig. 2. This current can be broken up into the two sine waves shown by Fig. 3. One of these sine waves has a frequency of 60 cycles per second and an amplitude I. The other has a frequency of 180 cycles per second and an amplitude of $1/4\ I$. If the mutual inductance between the lines is M, then the voltage induced in the

1. Assistant Professor of Electrical Engineering, the University of Wisconsin.

Presented at the Regional Meeting of District No. 5 of the A. I. E. E., Madison, Wis., May 6-7, 1926.

line B is composed of two parts; one part has a frequency of 60 cycles per second and an amplitude of $2\,\pi\,60\,I\,M$, while the other part has a frequency of 180 cycles per second and an amplitude of $2\,\pi\,180\,\frac{I}{4}\,M$. If the amplitude of the 60-cycle voltage is represented by E, then the amplitude of the 180-cycle voltage is $3/4\,(E)$. Then we can forget all about line A if, in line B, we introduce two alternators, one having a frequency of 60 cycles per second and a voltage of E, and the other having a frequency of 180 cycles per second and a

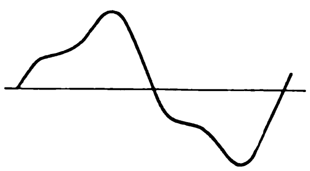

FIG. 2

voltage of $3/4\,(E)$; that is, we can calculate the effect of line A upon line B by considering only the system shown by Fig. 4.

The scheme used above for finding the effect of line A on line B is the one used throughout this paper for finding the effect of any voltage induced in an antenna upon the receiving system; for example, the voltage is replaced by a group of alternators having the correct frequencies and the correct voltages. The receiving system will then be represented schematically, as shown by Fig. 5. The generators are assumed to have no impedance and serve only as a device for fixing the

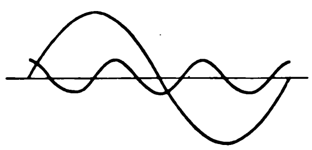

FIG. 3

attention on a sine wave of voltage having a given frequency and amplitude. Use is made of Fourier's expansion for obtaining the voltage and frequency of each alternator. Since each alternator is assumed to have been in the circuit for an indefinitely long time, only the steady-state properties of the receiving system need be considered.

3. INTERRUPTED CONTINUOUS WAVE TELEGRAPHY

The voltage induced in a receiving antenna by an interrupted continuous wave transmitter is assumed to have the form shown schematically by Fig. 6. In this figure, $2\,T$ represents the total time interval of a signal and the succeeding space, $2\,qT$ represents the signal time interval, and $2\,pT$ represents the space time interval. In order to simplify the calculations, it will be assumed that there is a complete number of cycles of the operating frequency in the time intervals qT and pT and that $p = q$. Under these conditions, if the operating frequency of the transmitting station has the value $f_0 = \frac{\omega}{2\,\pi}$, we can arrive at the following information relative to the generators which replace the

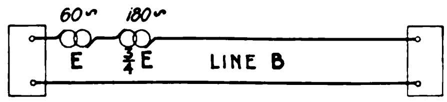

FIG. 4

voltage induced in the receiving antenna by an I. C. W. transmitter.

One generator has a frequency equal to the operating frequency, f_0. This generator has a voltage equal to $\frac{E}{2}$. Other generator frequencies in the vicinity of the operating frequency are:

$$f_n = f_0 \pm \frac{n}{2\,T},\ n = 1, 3, 5, 7 \text{ etc.} \qquad (1)$$

The voltage of the generator having the frequency f_n is:

$$E_n \text{ (peak value)} = \frac{E}{n\,\pi} \qquad (2)$$

These facts are brought out in a striking manner by

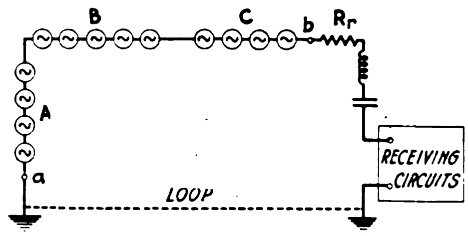

FIG. 5

the curve of Fig. 7. This curve is plotted with the ratios of the absolute value of the generator voltage to E as ordinates and with values of n as abscissa. Values of n are used as abscissa in order to make the curve hold

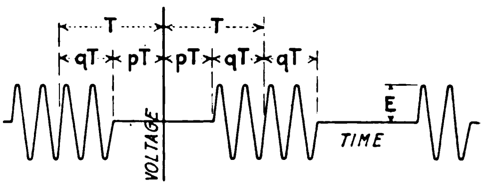

FIG. 6

for all speeds of transmission. To convert the abscissa scale to generator frequencies use is made of the relation:

$$\text{(Gen. freq.)} = f_0 + \frac{n}{2\,T} \qquad (3)$$

At 30 words per minute this relation becomes:

$$(\text{Gen. freq.}) = f_0 + 10\,n \qquad (4)$$

at 150 words per minute it becomes

$$(\text{Gen. freq.}) = f_0 + 50\,n. \qquad (5)$$

Thus, a generator having a given ratio of voltage to E is five times as far removed in frequency from the operating frequency at a transmitting speed of 150 words per minute as at a transmitting speed of 30 words per minute. This fact, as we shall see later, has an important bearing upon the design of the receiving system and also upon the amount of interference created by the transmitting station.

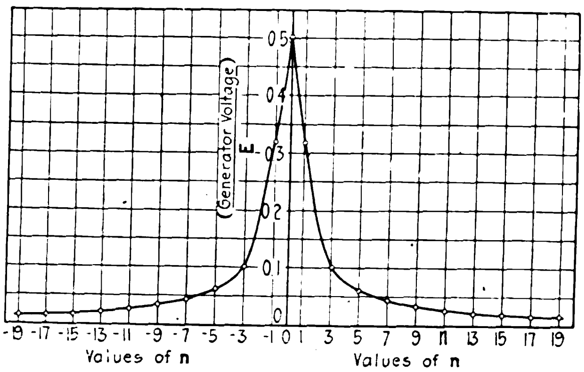

FIG. 7—INTERRUPTED C. W. TELEGRAPHY—VARIATION OF GENERATOR VOLTAGE WITH FREQUENCY—GENERATOR FREQUENCY

$= f_0 + \dfrac{n}{2T}$

$n = 0, \pm 1, \pm 3, \pm 5$, etc.
f_0 — 70 at 30 words per min.
f_0 — 350 at 150 words per min.

The desirable frequency response characteristics of the interrupted continuous wave receiving system can now be obtained. If the system passes currents having the operating frequency f_0, and eliminates currents of all other frequencies a continuous tone would be heard in the receivers and the dots and spaces could not be distinguished from each other; that is, no signals would be received. If the system passes currents of all frequencies with the same ease, the high frequency output would have the same wave form as the induced voltage, Fig. 6. This latter condition would lead to the distinguishing of the signals, but the system would have no selectivity against interference. The best circuit then would be one which passes just enough frequencies to make the signals distinguishable and eliminates all others. Let us assume that, in order to make the signals distinguishable, the receiving system must respond freely to all generators having a voltage greater than or equal to r decimal parts of the voltage of the generator the frequency of which is f_0; that is, the system must respond freely to all generators having a voltage equal to or greater than $\dfrac{r\,E}{2}$. Now the generator with a frequency of $f_0 \pm \dfrac{n}{2\,T}$ has a voltage equal to $\dfrac{E}{n\,\pi}$. We therefore write:

$$\left(\frac{E}{n\,\pi}\right)\frac{2}{E} = r$$

$$n_r \text{ is the odd number closest to } \frac{2}{r\,\pi} \qquad (6)$$

The receiving system, therefore, must pass a band of frequencies $\dfrac{n_r}{T}$ wide centered on the frequency f_0.

Let us define an ideal receiving system as one which has the following properties:

1. A radiation resistance R_r
2. No wasteful resistance
3. Acting as a pure resistance of magnitude $2\,R_r$ to frequencies lying in the range $f_0 \pm \dfrac{n_r}{2\,T}$.
4. Currents having frequencies lying in the range given by 3 shall be passed on to the detector either with a uniform amplification or without attenuation.
5. Currents of all other frequencies shall be eliminated before reaching the detector.

A system having the above properties is called an ideal system because it represents the best possible frequency selection system for receiving I. C. W. signals through interference. This ideal system can be only approximated, more or less imperfectly, in practise; but any actual receiving system, basing its selectivity upon frequency selection, should be made to fulfill the conditions stated as closely as possible.

The band of frequencies which the receiving system must pass freely is $\dfrac{n_r}{T}$. Now as both n_r and T are independent of f_0, so the band width is independent of the operating wave length. n_r is also independent of the speed of signal transmission, while T varies inversely as the speed of transmission. Therefore, the frequency band which the receiving system must transmit freely varies directly with the sending speed. Thus, the transmitted band width at 150 words per minute would be five times as great as at 30 words per minute.

It can be shown that the power available in the waves is

$$P_a = \frac{E^2}{16\,R_r} \qquad (7)$$

and that the power utilized by the ideal receiver is

$$P = \frac{E^2}{8 R_r} \left[\frac{1}{4} + \frac{2}{\pi^2} \sum \frac{1}{s^2} \right] \quad (8)$$

$s = 1, 3, 5 \ . \ . \ . \ n_r$

Calculations indicate that if $n_r = 3$, the intervals and dots will be easily distinguishable. When n_r has this value, the ratio of the power utilized by the ideal receiver to the power available is 0.9.

With the above value of n_r, the ideal system would pass freely a band of frequencies lying between $f_0 - 30$ cycles per second and $f_0 + 30$ cycles per second at 30 words per minute. At 150 words per minute the band passed would be between $f_0 - 150$ cycles per second and $f_0 + 150$ cycles per second.

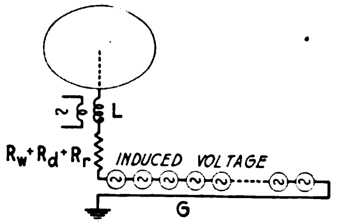

FIG. 8

Let us now consider the simple receiving circuit shown in Fig. 8. This circuit consists of an elevated capacity network, A, a tuning inductance, L, and a detector which has a resistance R_d. The capacitance of the network to ground is represented by C. In addition to the detector resistance the circuit has a wasteful resistance, R_w, and a radiation resistance, R_r. The induced voltage is represented by the group of generators, G. If this station is to receive I. C. W. signals, the characteristics of the generators have already been found. We wish to design the circuit so that it will approach as nearly as possible the ideal receiver described above.

It is, of course, impossible to adjust this circuit so that it will act as a pure resistance to all of the generators lying in the band $n = 0$ to $n = \pm n_r$ and to eliminate the currents due to all of the other generators. We will therefore tune it to the frequency f_0.

Now the number of cycles by which the nth generator is removed from f_0, is $\frac{n}{2T}$. It can be shown that the net reactance of the circuit to the nth generator is:

$$x_n = 2 \pi L \frac{n}{T} \quad (9)$$

Let us now assume that, in order to have the circuit respond to as few frequencies as possible and still have the signals discernible, the reactance to the n_r generator should be equal to βR_t. From (9) we arrive at

$$\frac{L}{R_t} = \frac{T_c}{2} = \frac{\beta T}{2 \pi n_r} \quad (10)$$

T_c is the time constant of the antenna circuit.

$$x_n = \beta R_t \frac{n}{n_r} \quad (11)$$

If we let the detector resistance be

$$R_d = \rho (R_r + R_w) \quad (12)$$

and let

$$K = \frac{R_r + R_w}{R_r} \quad (13)$$

then the average power delivered to the detector is

$$P = \frac{E^2 \rho}{2 k R_r (1 + \rho)^2} \left[\frac{1}{4} + \frac{2}{\pi^2} \sum \frac{1}{n^2\left(1 + \beta^2 \frac{n^2}{n_r^2}\right)} \right]$$

$n = 1, 3, 5$ etc.

If this circuit is used with the same antenna as the ideal circuit, the power available is again given by Equation (7).

Estimations based upon the shape of the antenna current wave and also upon the time constant of the circuit show that when $n_r = 3$, β should equal about 2.

If these values are assigned to n_r and β and if ρ is assigned the best value, (namely unity,) the ratio of the power utilized by the simple series receiver to the power available is,

$$\frac{P}{P_a} = \frac{0.8}{k} \quad (15)$$

4. *Spark Telegraphy.* The voltage induced in a receiving antenna by a spark transmitting station is assumed to have the form shown, schematically, in Fig. 9. The operating frequency is $f_0 = \frac{\omega}{2\pi}$. In most spark systems the damping is such that the voltage

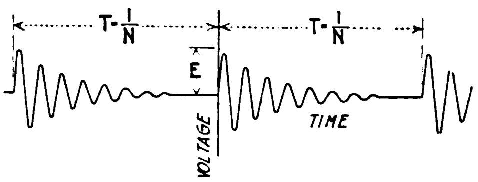

FIG. 9

dies very nearly to zero in the interval of time, T, ($\alpha T > 3$). Under these conditions the voltage is represented as a function of time during the interval $t = - T$ to $t = 0$ by the equation

$$e(t) = E \epsilon^{-\alpha(t+T)} \sin [\omega (t + T)] \quad (16)$$

and in the interval $t = 0$ to $t = + T$ by

$$e(t) = E \epsilon^{-\alpha t} \sin \omega t \quad (17)$$

It can be shown that B_n is stated very closely by the

equation:

$$B_n = \frac{2E}{\omega T} \frac{1}{\sqrt{\frac{4\ \alpha^2}{\omega^2} + \left[\frac{2\ n}{f_0\ T} + \frac{n^2}{f_0^2\ T^2}\right]^2}} \qquad (18)$$

$$n = 0, \pm 1, \pm 2 \ldots \ldots \begin{matrix} + \infty \\ \\ - f_0 T \end{matrix}$$

In this equation the symbols have the following meaning:

B_n is the voltage of the generator with frequency differing from f_0 by $\frac{n}{T}$ cycles per sec.

f_0 is the operating frequency of the spark-transmitting station.

E and α are defined by Equation (**17**).

$\omega = 2\,\pi\,f_0$

T is the time duration in seconds of each spark.

Let

$N = \frac{1}{T}$ represent the number of sparks per second.

$\delta = \frac{\alpha}{f_0}$ represent the logarithmic decrement.

In terms of these symbols (**18**) becomes

$$B_n = \frac{2\ N\ E}{\omega} \frac{1}{\sqrt{\frac{\delta^2}{\pi^2} + \left[\frac{2\ n\ N}{f_0} + \frac{n^2\ N^2}{f_0^2}\right]^2}} \qquad (19)$$

The voltage of the generator having a frequency the same as the operating frequency f_0 is:

$$B_0 = \frac{E}{\alpha\ T} = \frac{N\ E}{\alpha} = \frac{N\ E}{\delta\ f_0} \qquad (20)$$

In order to present at a glance the way in which the generator voltage varies with the frequency in the vicinity of the operating frequency, f_0, and the effect of the logarithmic decrement, δ, the number of sparks per second, N and the operating frequency on this variation, the curves of Fig. 10 have been drawn. The abscissa for all curves are values of the difference between the generator frequency and the operating frequency ($= n\,N$). Generator frequencies are located only at integral values of $n\,N$ divided by N. Thus at 1000 sparks per second, one generator has the frequency f_0 and the generators are located on a frequency scale every 1000 cycles per second above or below f_0. At 120 sparks per second generators are located on the frequency scale at f_0 and every 120 cycles per second above or below f_0. For curve (1) $f_0 = 10^6$ cycles per second, $\delta = 0.01$, $\alpha = \delta\,f_0 = 10^4$, $N = 1000$. The ordinates for this curve are values of the ratio of the generator voltage to the undamped peak voltage, E_1, induced in the antenna. $\left(\text{Ordinates are values of } \frac{B_n}{E_1}\right)$. The voltage assigned to the generators falls off at a fairly fast rate as the operating frequency is departed from. The generator, having a frequency which differs by 16,000 cycles per second from the operating frequency, has a voltage 10 per cent as great as the voltage of the generator with a frequency equal to the operating frequency. That is, the energy associated with a frequency removed from the operating frequency by 16,000 cycles per second is one per cent as great as the energy associated with the operating frequency. This curve also holds good for the conditions $f_0 = 10^5$, $N = 1000$, $\delta = 0.1$, $\alpha = \delta\,f_0 = 10^4$. This fact has an important bearing on the factors which determine the frequency-energy distribution as will be shown a little later.

For curve (2) $f_0 = 10$, $N = 1000$, $\delta = 0.1$, $\alpha = \delta\,f_0 = 10^5$. In order to make this curve directly comparable with curve (1), the ordinates have been taken as values of the generator voltage divided by the undamped voltage peak induced in the antenna by case (1) when both sets of waves have the same energy per wave train or per spark. That is the ordinates in this case are values of $\frac{B_n}{E_2}$ multiplied by $\sqrt{\frac{\alpha.}{\alpha_1}}$*. This curve is much flatter than curve (1) and the generator with frequency removed from f_0 by 16,000 cycles per second, has a voltage 70 per cent as great as the voltage of the generator whose frequency is f_0. This is a striking contrast to curve (1) for which $\alpha = 10^4$.

For curve (3) $f_0 = 10^6 \sim$, $N_2 = 120$, $\delta = 0.01$, $\alpha = 10^4$. The ordinates for this curve are values of $(B_n/E_3)\sqrt{\frac{N_1}{N_2}}$†. This factor is used in order to compare this case with case (1) when both waves have the same energy associated with them. The rate at which the generator voltage falls off in this case with the frequency is about the same as for case 1. This curve is also valid for the conditions $f_0 = 10^5 \sim$, $N = 120$, $\delta = 0.1$, $\alpha = 10^4$.

These curves lead to the conclusion that the factor which determines the rate at which the generator voltages fall off with the frequency in the vicinity of f_0, is $\alpha = \delta\,f_0$. The other factors have but little influence upon the width of the band of frequencies over which most of the energy is spread. This is apparent upon examining equations (**18**) or (**19**).

When n is small, the second term in the bracket under the radical is small compared to the first and may be

*See the discussion of energy relations which follows shortly.
†See the discussion of energy relations which follows shortly.

dropped without serious error. We then have for small values of n,

$$B_n = \frac{E\,N}{\sqrt{\alpha^2 + 4\,\pi^2\,n^2\,N^2}} \qquad \textbf{(20a)}$$

This equation shows clearly the dependance of the band width upon α, because the larger the value of α the larger must be the $n\,N$ product before B_n differs much from B_0.

The ideal system for receiving spark signals has the same properties as the ideal system for receiving I. C. W. signals except that the transmitted band width will be different. In so far as obtaining a good tone in

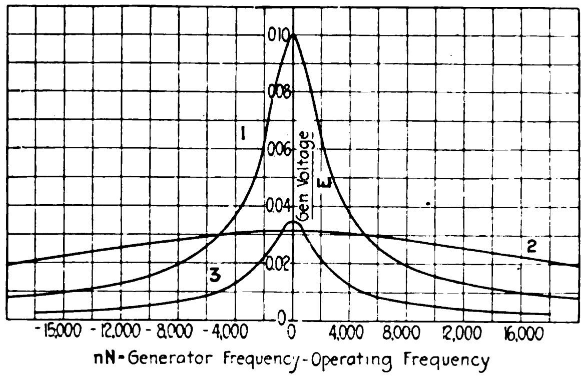

Fig. 10—Spark Telegraphy—Generator Frequency Versus Generator Voltage—Generator Frequencies Located at Integral Values of $\frac{n\,N}{N}$.

Curve 1.
Operating frequency, $f_0 = 10^6 \sim$
Sparks per second, $N_1 = 1000$
Log. Dec., $\delta_1 = .01 : \alpha\,1 = \delta_1\,f_0 = 10^4$
Initial undamped voltage peak A, induced in antenna, $= E$
Also valid for $f_0 = 10^5$, $N_1 = 1000$, $\delta_2 = .1$, $\alpha = 10^4$ $A = E$

Curve 2.
$f_0 = 10^6 \sim$, $N_1 = 1000$, $\delta_2 = 0.1$,

$\alpha\,2 = 10^5$, $A_2 = \sqrt{\frac{\delta_2}{\delta_1}}\,E = 3.16\,E$

Curve 3.
$f_0 = 10^6 \sim$, $N_2 = 120$, $\delta_1 = 0.1$,

$\alpha_1 = 10_1{}^4$ $A_3 = \sqrt{\frac{N_1}{N_2}}\,E = 2.88\,E$

Also valid for
$f_0 = 10^5$, $N_2 = 120$, $\delta_2 = 0.1$,
$= 10^4$, $A = 2.88\,E$

the receivers is concerned, it would suffice to pass only the currents of three generators; this would, however, result in the utilizing of only a small portion of the available energy. Let us therefore make the band wide enough to pass the currents of all generators with voltage equal to or greater than r decimal parts of the voltage of the generator the frequency of which is f_0. From equations (20) and (**20a**) we than have

$$\frac{B_{nr}}{B_0} = \frac{\alpha}{\sqrt{\alpha^2 + 4\,\pi^2\,n_r{}^2\,N^2}} = r \qquad \textbf{(20b)}$$

$$n_r\,N = f_c = \frac{\alpha}{2\,\pi}\sqrt{\frac{1}{r^2} - 1} \qquad \textbf{(20c)}$$

Since n_r must be an integer it is taken as the integer which comes the closest to satisfying (**20c**). $n_r\,N = f_c$ is then one-half of the transmitted band width.

It can be shown that the power available in the damped waves is:

$$P_a = R_r\,I_a{}^2 = \frac{N\,E^2}{16\,\alpha\,R_r} \qquad \textbf{(21)}$$

P_a as given by (**21**) represents the power available in the waves. Since this power varies directly as E^2, directly as N and inversely as α, it is evident that the correction factors applied to the curves of Fig. 10 are the proper ones.

The average power picked up and utilized by the ideal receiver from the waves sent out by a spark transmitter is given by the relation:

$$P = \frac{E^2\,N^2}{8\,R_r}\left[\frac{1}{\alpha^2} + 2\sum_{n=1}^{n_r}\frac{1}{\alpha^2 + 4\,\pi^2\,n^2\,N^2}\right] \qquad \textbf{(22)}$$

If the damping exponent, α, of the waves has value of 10^4 and if r is taken to be 0.3, then the half band width as given (**20c**) is:

$$f_0 = n_r\,N = \frac{10^4}{2\,\pi}\sqrt{11.1 - 1} = 5000 \sim \qquad \textbf{(23)}$$

If the number of sparks per second N is 1000, $n_r = 5$ and the ratio of the power utilized by the ideal receiver to the power available is 0.82.

If the receiving system consists of a simple series circuit, the general discussion given under the I. C. W. case still applies. In the present case, the number of cycles by which any generator frequency differs from the resonant frequency of the system is $n\,N$.

If the reactance of the circuit to the frequency $n_r\,N$ is to equal $\beta\,R_t$ we have:

$$\frac{L}{R_t} = \frac{T_c}{2} = \frac{\beta}{4\,\pi\,n_r\,N} \qquad \textbf{(24)}$$

Equation (**24**) is analogous to equation (**10**) of the I. C. W. case and fixes the freely transmitted band. The net reactance now becomes:

$$x_n = \beta\,R_t\,\frac{n}{n_r} \qquad \textbf{(25)}$$

The average power supplied to the detector of the simple series receiving circuit by the damped waves is,

$$P = \frac{E^2\,N^2\,\rho}{2\,k\,R_r\,(1 + \rho)^2}\left[\frac{1}{\alpha^2} + 2\sum_n\frac{1}{(\alpha^2 + 4\,\pi^2\,n^2\,N^2)\left(1 + \beta^2\,\frac{n^2}{n_r{}^2}\right)}\right] \qquad \textbf{(26)}$$

If there are 1000 sparks per second and if $\alpha = 10^4$ and $n_r = 5$, $\beta = 2$ and $\rho = 1$ then the ratio of the power

utilized by the simple series receiver to the power available in the waves is:

$$\frac{P}{P_a} = \frac{0.6}{k} \tag{27}$$

Equations (**26**) and (**21**) show that for a given transmitted band width, the ratio of the power utilized to the power available becomes smaller as the damping exponent, α, is increased. This is because the greater the value of α the wider is the frequency band over which the energy is distributed.

5. TELEPHONY

The voltage of the generators which may be inserted in the receiving system to replace the voltage induced in the antenna by a radio telephone transmitter can not be written down in a general equation because it depends upon the character of the speech or music which is being sent out. The theory of modulation however shows that the voltage induced in the antenna of the receiving system has a group of frequencies consisting of the carrier frequency, an upper side band, and a lower side band. The carrier frequency is the operating frequency and determines the wave length of the transmitting station. The upper side band consists of a group of frequencies having values equal to the carrier frequency plus the frequencies of the voice or musical notes. The lower side band consists of a group of frequencies having values equal to the carrier frequency minus the frequencies of the voice or musical notes. If the highest musical note of importance is represented by f_c, then, in radio telephony, most of the energy is associated with a band of frequencies $2 f_c$ cycles wide, centered on the carrier or operating frequency, f_0. If only a small portion of the energy is associated with frequencies outside this band, then we may replace the voltage induced in the receiving system by a group of generators having frequencies ranging from $f_0 - f_c$ cycles per second to $f_0 + f_c$ cycles per second. The voltage assigned to a generator having a given frequency will depend upon the nature of the speech or the music which is being received.

The ideal frequency selection system for receiving telephony will have the same properties as the ideal system described for the reception of I. C. W. signals with the exception that it must transmit freely the currents due to all generators having frequencies in the band $f_0 \pm f_c$ cycles per second. This ideal system would utilize practically all of the available energy and would be distortionless. The highest violin note of much importance has a frequency of about 5000 cycles per second. Therefore, for broadcast reception, it suffices to take f_c equal to 5000 cycles per second and the ideal receiver must transmit freely a band of frequencies 10,000 cycles wide centered on the operating frequency f_0.

It is impossible to design the simple series receiving circuit so that it will have no distortion and maintain good selectivity against interference. In the amplifying systems and in the loud speakers used for broadcast reception there is a good deal of distortion and the simple series circuit need not be freer from distortion than the rest of the system. The general discussion of the simple series receiver given under the I. C. W. case and the spark case applies here. If the system is tuned to the carrier frequency, then, from equation (**9**), the reactance of the system to the frequency $f_0 \pm p$ is given by the relation:

$$x_n = 4 \pi L p \tag{28}$$

If the reactance of the system to the generator whose frequency is $f_0 \pm f_c$ is βR_t then (**62**) may be written as:

$$x_n = \beta R_t \frac{p}{f_c} \tag{29}$$

If the r. m. s. value of the voltage of the generator

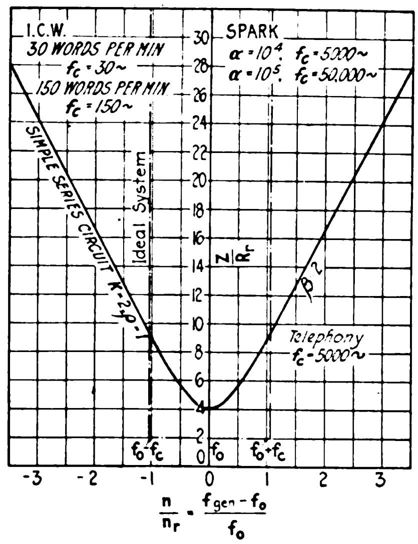

FIG. 11—TRANSMISSION CHARACTERISTICS

having a frequency of $f_0 \pm p$ is E_p the power delivered to the detector by the telephonic waves is,

$$P = \frac{\rho}{k R_r (1 + \rho)^2} \left[E_0^2 + 2 \sum_p \frac{E_p^2}{1 + \beta^2 \frac{p^2}{f_c^2}} \right] \tag{30}$$

The average power received from the generator with a frequency of $f_0 \pm f_c$ is:

$$P_c = \frac{E_c^2 R_d}{R_t^2 (1 + \beta^2)} \tag{31}$$

For distortionless reception this power should be:

$$P_{c1} = \frac{E_c^2 R_d}{R_t^2} \tag{32}$$

We may then take, as a measure of the distortion, the ratio of P_c to P_{c1}. This ratio is,

$$D = \frac{P_c}{P_{c1}} = \frac{1}{1 + \beta^2} \tag{33}$$

If β is taken equal to 2, the highest important voice or musical note will have one-fifth the energy it should

have for distortionless reception. With the distortion as great as it is in the rest of the receiving equipment, this amount will probably not be excessive.

Since the ideal receiving system and the simple series receiving system are the same with the exception of the width of the transmitted band for all the three types of signals considered, it is possible to plot a single transmission characteristic for each one, to hold for all three types of signals. Such curves are plotted in Fig. 11. The abscissa scale is the ratio of the difference in generator frequency and the operating frequency to the cut off frequency f_c. The ordinate scale is the ratio of Z to R_r. Z is the ratio of the generator voltage to the detector current which has the same frequency as the generator voltage under consideration. The transmission characteristic of the simple series circuit is plotted for a value of β equal to 2 and for the best possible values of k and ρ. These curves show at a glance, the degree to which the simple series receiver falls short of the ideal receiver. These curves will be discussed more fully in the sections dealing with the reception through interference.

Part II.—Reception Through Interference

6. Voltage Induced in Receiving Antenna by Static

The voltage induced in a receiving station by an I. C. W., a spark, or a telephone transmitter may be a source of interference as well as of signals. The frequency and voltage of the generator which may be used to replace these voltages in the receiving system have already been worked out. This section will be devoted to a discussion of the generators which represent the voltage induced in the receiving system by atmospheric strays or static. There is not very much information available on the wave form of the voltages induced in antennas by static. Watt and Appleton have published some observed static wave forms in the Proceedings of the Royal Society, 1923. These wave forms were sketched from visual observations made with a Braun tube oscillograph. The majority of the impulses were unidirectional in character and the time of rise and fall was about the same. The time duration of the majority of the impulses was of the order of one thousandth of a second. It is reasonable to expect then that some indication of the voltage and the frequency of the generators which replace the static voltage in the receiving antenna will be obtained if the wave form of the voltage induced by static is assumed as shown by Fig. 12. The Fourier expansion of this wave form leads to the following general conclusions relative to the generators which replace the voltage induced in a receiving antenna by static.

1. The voltage assigned to a generator having a high frequency is less than the voltage assigned to a generator having a lower frequency.
2. The voltage assigned to all of the generators having frequencies which lie in a narrow band in the radio range of frequencies will be about the same.

In regard to assumption No. 1, it may be stated that the wave form assumed indicated that the voltage assigned to a generator was inversely proportional to the square of the frequency assigned to it.

If a voltage wave form having an abrupt rise, a flat top and an abrupt fall had been assumed, then the voltage assigned to a generator would be inversely proportional to the first power of the assigned frequency. Therefore, if the indications of the Watt and Appleton

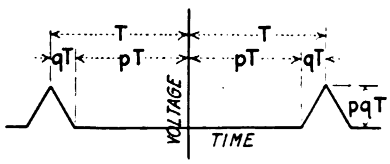

Fig. 12

observations on the time duration of the impulses are anywhere nearly correct, the voltage assigned to a generator will vary inversely as a power of the frequency which lies between 1 and 2.

7. The Reception of I. C. W. Signals Through Static Interference

The receiving system is represented schematically as shown in Fig. 5, and we now have to consider the power received from two groups of alternators. One group of alternators replaces the voltage induced in the antenna by the I. C. W. transmitting station. The other group replaces the voltage induced in the receiving antenna by static. Since the voltage assigned to all the static generators whose frequencies lie in a narrow band is the same we will let E_s be the peak value of the voltage of each static generator. If the generator frequencies are spaced p cycles per second apart on a frequency scale, the power delivered by static to the ideal receiver is,

$$P_s = \frac{2 f_c}{p} \frac{E_s^2}{8 R_r} = \frac{n_r}{p T} \frac{E_s^2}{8 R_r} \qquad (34)$$

From equations (8) and (34), we obtain for the I. C. W. signal power-static, power ratio of the ideal receiver

$$\frac{P_{i.c.w.}}{P_s} = \frac{E^2 p T}{E_s^2} \frac{1}{n_r} \left[\frac{1}{4} + \frac{2}{\pi^2} \sum_s \frac{1}{s^2} \right]$$

$$= \frac{E^2 p}{2 E_s^2 f_c} \left[\frac{1}{4} + \frac{2}{\pi^2} \sum_s \frac{1}{s^2} \right] \qquad (35)$$

$$s = 1, 3, 5 \ldots n_r$$

In equation (35) $\dfrac{E_s^2}{p}$ characterizes the static energy level associated with frequencies in the vicinity of the operating frequency f_0 of the I. C. W. station. This term varies from time to time and decreases as f_0

increases. $E^2\left[\frac{1}{4}+\frac{2}{\pi^2}\sum\frac{1}{s^2}\right]$ characterizes the I. C. W. signal energy level and its distribution over frequencies in the vicinity of f_0. The bracketed term is the same for all I. C. W. stations but E is dependent upon the transmitting station and the transmission efficiency. T characterizes the speed of signaling its value decreasing directly with an increase in signaling speed. Thus the high signaling speeds are more subject to static interference than the low ones. n_r alone characterizes the receiving system. For the ideal receiver n_r has been assigned the minimum value which will permit of the distinguishing of the signals. Thus the ideal receiver reduces the static interference to the lowest possible value that can be obtained with a frequency selecting system.

If the speed of transmission is 30 words per minute and if $n_r = 3$ we have:

$$\frac{P_{i.c.w.}}{P_s} = \frac{E^2\,p}{E_s^{\,2}}\,(0.008) \tag{36}$$

At 150 words per minute, the ratio will be one-fifth as large as at 30 words per minute.

The mathematical formulation of the interference in actual receiving systems is left for a future paper, but it can be pointed out that, for the simple series receiver, the best signal-power, static-power ratio is obtained when f_c is assigned as small a value and β as large a value as possible and yet have the signals distinguishable. This follows because decreasing β or increasing f_c permits the generators removed from f_0 to furnish more power to the circuit. But as shown by the curve of Fig. 7 the voltage of the signal generators falls off rapidly as their frequency departs from the operating frequency whereas it has been shown that the voltage of the static generators remains about the same at all of the frequencies. Therefore, increasing f_c or decreasing β, that is decreasing the time constant of the circuit, increases the static power faster than the interferent power. From this it is apparent that the simple series receiver described is the best possible one for receiving through static.

8. The Reception of Radio Telephone Signals Through Static Interference

In the section on telephone reception it was shown that for distortionless reception the ideal receiving system must pass a band of frequencies running from $f_0 - f_c$ cycles per second to $f_0 + f_c$ cycles per second where f_c was about 5000 cycles. Under these conditions the static power picked up by the system is given by equation (**34**). Since the ideal system picks up energy only from generators which have frequencies lying in the band which must be transmitted, it is evident that the ideal system as described is the best possible frequency-selection system for receiving telephone messages through static interference. Since f_c for telephony is $5000 \div 30 = 167$ times as large as for I. C. W. reception at 30 words per minute, it is evident that 167 times as much static energy must be picked up in a telephone receiver as in an I. C. W. receiver.

The extent to which static interference can be reduced by the simple series circuit depends upon the allowable distortion of speech or music. In plotting the transmission characteristic of the simple series circuit given by Fig. 11, it was assumed that the energy in the 5000-cycle voice or musical note could be reduced to one-fifth of the value which it should have for distortionless reception. ($\beta = 2, f_c = 5000 \sim$).

9. The I. C. W. Transmitter and the Spark Transmitter as Sources of Interference

It has been shown that the voltage induced in a receiving antenna by an I. C. W. transmitter could be replaced by a group of generators having the correct frequencies and correct voltages. Any I. C. W. transmitting station has generators with frequencies located in all frequency bands. It has also been shown that all receiving systems must transmit a band of frequencies centered upon the operating frequency of the station whose signals it is desired to receive. The receiving system must necessarily therefore pick up energy from all I. C. W. stations which induce a voltage in the receiving antenna. With a given receiving system the energy picked up from an interferent I. C. W. station depends upon the difference between the operating frequency of the interferent station and the operating frequency of the correspondent station and the manner in which the voltage assigned to any generator which replaces the interferent voltage in the receiving antenna vary with the frequency assigned to it. The curve of Fig. 7 gives a graphical picture of the dependance of the voltage assigned to any generator upon the frequency assigned to the generator. For I. C. W. telegraphy at 30 words per minute 90 per cent of the energy in the waves is associated with a band of frequencies 60 cycles wide centered on the operating frequency. At 150 words per minute the band containing 90 per cent of the energy is five times this wide. We thus come to the conclusions that the energy associated with the waves of an I. C. W. transmitter is confined to a narrow band of frequencies and the width of this band varies directly with the signal speed. The above statement holds true if the I. C. W. transmitter has no harmonics. If harmonics are present in the waves sent out by the transmitter, the voltages assigned to generators having frequencies in the vicinity of the harmonic will vary as shown by Fig. 7 for the fundamental frequency and any receiving station having a transmitted band in the vicinity of one of the harmonics will pick up an appreciable amount of power from the transmitter.

The spark transmitter causes much more interference than the I. C. W. transmitter. This fact is brought out in a striking manner if the curves of Fig. 10 are compared with those of Fig. 7. The voltage assigned to a generator falls off slowly as the frequency departs

from the operating frequency. From an examination of the curves of Fig. 10 and from the discussion of section (4) it is evident that the interference caused by a spark station is dependent upon the logarithmic decrement times the frequency rather than upon the logarithmic decrement. If $\alpha = \delta f_0 = 10^4$, 82 per cent of the energy in the waves is associated with a band of frequencies 10,000 cycles wide, centered on the operating frequency f_0. If $\alpha = \delta f_0 = 10^5$, then 82 per cent of the energy is associated with a band of frequencies approximately 100,000 cycles wide, centered on the operating frequency. This is in striking contrast to the I. C. W. case where most of the energy is associated with a band of frequencies 60 to 300 cycles wide. From the above discussion it is evident that a station operating at a frequency of 10^6 cycles per second, and having a logarithmic decrement of 0.01, has its energy spread over the same band width as a station operating at 10^5 cycles per second and having a logarithmic decrement equal to 0.1.

10. General Conclusions

With regard to the extent to which interference can be mitigated by frequency selecting systems all sources of interference to radio reception and all sources of signals have a definite frequency spectra and for convenience we can replace the voltages induced in an antenna by a group of generators having the correct voltages and frequencies. In order to receive signals the receiving system must pass freely the currents due to all generators having frequencies in a given band. This band is centered on the operating frequency of the station from which it is desired to receive signals. The width of the band is determined by the class of signals which it is desired to receive. If the interferent voltages have generators with frequencies in this transmitted band, the frequency selection system cannot eliminate the currents due to these generators. Since the ideal receiver as specified in this paper utilizes the maximum possible power from generators lying within the band of frequencies which must be passed and utilizes no power from generators which have frequencies outside this band, it is evident that the interference obtained in the ideal receiver is the minimum which can be obtained with frequency selecting systems. From this it is evident that the minimum interference which is obtainable depends upon the ratio of the voltage of the signal generators to the voltage of the interferent generators which lie in the transmitted band and upon the width of the band of frequencies which it is necessary to transmit. The width of the band of frequencies which must be transmitted depends upon the class of signals which are to be received. Thus while the necessary transmitted band width for I. C. W. telegraphy at 30 words per minute is only 60 cycles, at 150 words per minute it is 300 cycles. The necessary transmitted band width for telephony is about 10,000 cycles and the necessary transmitted band width for spark telegraphy varies from 10,000 cycles to 100,000 cycles depending upon the product of the logarithmic decrement times the operating frequency.

The ideal receiving system thus furnishes a criterion by which we can judge of the merits of any actual frequency selection system for receiving through interference. The writer hopes in a future paper to show how near actual receiving systems of various types approximate the ideal receiver.

Research

Report of Technical Committee on Research*

J. B. WHITEHEAD, Chairman

To the Board of Directors:

The year just closing has revealed the usual activity in the field of electrical engineering research. This activity extends from laboratory investigations of purely scientific character, outward to the development of all equipment, and to the study and improvement of the performance of the largest types of machinery and transmission systems. The importance of scientific research to industry in all its branches is now clearly recognized. The idea of research is "sold". Moreover, it appears to have been a bargain based on good value, for the article sold is in constant use and there is increasing demand for it. Industrial research laboratories are numbered by hundreds. Problems demanding solution are continually appearing, and there is increasing need for skilled research workers.

The National Research Endowment

There has, however, been one new and striking note during the year which has immediate bearing on the future of engineering research. This is the shifting of the emphasis in public discussion from the importance of applied and industrial research to the importance of protecting and stimulating purely scientific research. Advocates of the value of industrial research have

*Committee on Research:

John B. Whitehead, Chairman, Johns Hopkins University, Baltimore, Md.

Edward Bennett,	B. Gherardi,	E. W. Rice, Jr.
V. Bush,	V. Karapetoff,	D. W. Roper,
E. H. Colpitts,	A. E. Kennelly,	C. H. Sharp,
E. E. F. Creighton,	M. G. Lloyd,	C. E. Skinner,
W. F. Davidson,	F. W. Peek, Jr.,	Harold B. Smith,
W. A. Del Mar,	Harold Pender,	R. W. Sorensen.

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, W. Va., June 21-25, 1926.

always pointed to its intimate dependence on a fundamental scientific basis. Industrial research laboratories have realized from their beginnings their dependence upon trained research workers. Recently, however, Secretary Hoover has pointed out that the tremendous development of industrial research has resulted in two tendencies which threaten to dry up the sources of inspiration for research, and to diminish the number of those who are fitted to carry it on. The first of these is the stripping of university laboratories of their men who are trained in research because of attractive offers from industrial laboratories. The second is the great increase in university student attendance which has compelled universities to limit research activities in order to meet the mere volume demand for elementary education. Recognizing this tendency, Secretary Hoover has placed the weight of his great influence back of the suggestion of the National Academy of Sciences that a national research endowment be accumulated, whose chief purpose should be the promotion of purely scientific investigation in American universities, the natural nurseries for the training of competent scientific research workers. As a result Herbert Hoover, Elihu Root, Chas. E. Hughes, Owen D. Young, John J. Carty, Wm. H. Welch, and other distinguished associates are serving as trustees of the National Research Endowment, whose purpose is to raise twenty million dollars to aid American universities in carrying on fundamental research during the next ten years.

This movement is one of the healthiest and most promising events in recent years for the further development and progress of research in all fields of industry. Not only will it tend to conserve the sources of supply of research workers, but it is certain to result in an elevation in the general standards of ability, and in the increase of researches of scientific value, emanating not only from universities but also from industrial research laboratories. Industry itself has been quick to recognize the importance of the move, for the heads of many great corporations have entered actively into the campaign to raise the endowment, and it is not unlikely that industry itself will make substantial contributions.

Electrical Engineering Research

Naturally electrical engineering with its rapid development and expansion, its dependence on physical laws only uncovered in recent years, is always a heavy contributor in the field of engineering research. While there is no single result of outstanding novelty and importance, the past year has nevertheless seen many advances of interest. The range of problems studied has been much the same, but some shifting of emphasis in the various fields may be noted. Thus, for example, in overhead high-voltage transmission, attention has centered more particularly on analytical studies of the regulation, stability, and power limitations of high lines and large systems. At the same time there has been somewhat less attention than in foregoing years to experimental studies, in laboratory and field, of transients, protective apparatus, and high-voltage problems, although these have continued in some measure. The laws of corona, its physical character, and its bearing on transmission-line performance are still unanswered questions, and are therefore receiving some attention.

In the field of electrical machinery the intensive study devoted to fuel economy, with the resulting improvements in steam-power producing machinery, is so striking as to warrant its inclusion here as an important research activity. More directly in the analytical and laboratory class are continued studies of the problem of the ventilation of large rotating units, and of the general relations between temperature and machine rating. Other studies of note are in connection with machinery and the application of delicate vibrating instruments to problems of balance, and the like, the mathematical similarity between mechanical and electrical systems, and the proposal to investigate the former electrically through the equivalent investigation of the mechanical forces arising in short circuits in synchronous machinery. There have been fewer papers than usual on the properties of iron as related to the question of core losses.

There has been a continuation of the marked activity in experimental studies in the field of electric communication. Papers have been presented to the Institute reporting studies of the quality, the recording, and the reproducing of sound, on the importance of loading telephone circuits, and on new methods of carrier-current transmission. The publications of the Bell Telephone Laboratories show an extremely wide range of subject of investigation. Some of them are scientific research of the purest character, and the range extends to the experimental development of equipment and methods for meeting the increasing modern demands for facility in communication.

Results in the radio field are numerous and important. New tubes are being developed, new circuits devised, and new methods adopted for improvement in all directions of this highly specialized branch of electrical engineering. Perhaps the most interesting activity has been that of studying the behavior of short-wave transmission and the resulting new knowledge that has come as to the conducting properties of the upper atmosphere.

In the field of electrical measurements, among other noteworthy advances, may be mentioned the adaptation of the cathode ray oscillograph to the measurement of very short-time intervals, simpler and more convenient forms of oscillograph, and a greatly increased attention to the methods of measurement of dielectric loss at low-power factor and high voltage.

Studies which lie close to the field of pure physical research, and which may prove to have a practical bearing, are those in which the cathode stream of electrons has been brought through the walls of the tube into the surrounding air, the study of atomic hydrogen in its adaptation to arc welding, the obtaining of copper in large crystals showing 13 per cent increase in normal

conductivity, and the continued study of the structure of crystals by the means of X-rays.

Dielectrics and Insulation

The Committee on Research has continued to devote its principal attention to the subject of dielectrics and insulation. It serves as a consulting committee in Electrical Engineering to the National Research Council. Several of its members are also members of the Committee on Electrical Insulation of the Division of Engineering and Industrial Research of the National Research Council, the two committees having the same chairman. The program of the Committee on Electrical Insulation has been outlined in foregoing reports. During the past year considerable progress has been made by the subcommittees in the respective divisions. The Subcommittee on Dielectric Absorption and Theories of Dielectric Behavior has made a report which was also presented at the Midwinter Convention of the Institute. It is a comprehensive survey of existing knowledge of the anomalous properties of dielectrics and of theories that have been offered in explanation, and it includes suggestions of directions in which further experiment will probably result in new knowledge important to the control of the properties of insulation. As a result of this report the Committee on Electrical Insulation is prepared to suggest problems for investigation and research. It also hopes that some plan may be worked out whereby joint and coordinated work of a number of investigators may be undertaken. The report of the subcommittee on Dielectric Strength may be expected in the near future. The literature on these subjects is very extensive, and requires careful reading and discrimination. The members of the Committee are giving their services voluntarily and this work of necessity takes a secondary place in their busy programs.

The Committee is glad to record continued activity in the experimental investigation of the properties of insulating materials of all characters, and believes that its own interest in this field of study has stimulated the interest which lies back of the present activity. During the year there have been presented to the Institute important papers on gaseous ionization in paper-insulated cables, on the theory of dielectric absorption, the measurement of dielectric losses, and a method for the convenient and quick measurement for the absorption in commercial insulation. Attention should also be called to important contributions from abroad. A noteworthy paper on high-voltage, impregnated-paper cables has appeared in England, and there have been a number of papers from Germany bearing on the dielectric strength of different materials with special reference to the mechanism of the failure of high-voltage insulation.

Organized Research

It is a conspicuous feature of research activity in general that it is highly organized in industrial laboratories, but proceeds practically without organization in university laboratories. This situation is natural. The work in an industrial laboratory is usually directed towards the solution of particular questions, and if they are sufficiently important the whole resources of the laboratory may be diverted to their solution. In university laboratories individual workers find such time as they can for research outside of crowded programs, and usually do research without material compensation and only for the love of it.

Considering both extremes it will be seen that the situation is not particularly conducive to the production and publication of important results of research. In a few notable instances industrial research laboratories are making substantial efforts in the field of pure physical research, and it is possible to point to results of great value emanating from these efforts. These examples are few, however, and on the whole it can not be said that results of fundamental scientific value are to be expected in large quantities from laboratories in this class. In only a few university laboratories is any considerable proportion of the resources of men and materials devoted to original investigation. Such as is accomplished usually comes from men who are willing to sacrifice time outside the educational program, and who are prompted to it solely by the love of it.

An exceptional and promising example of organized research is that being carried out at Harvard, Johns Hopkins, Massachusetts Institute of Technology, and the University of Wisconsin, on the impregnated-paper insulation of high-voltage cables. The work is being done under the auspices of the Committee on Cable Insulation Research of the National Electric Light Association, whose member companies have subscribed sufficient funds to ensure the active prosecution of the work. Results of importance and value are already beginning to appear.

It would appear, then, that the several national organizations which have among their principal purposes the encouragement and support of engineering research, might do well to undertake actively the organization of research in university laboratories and the provision of material support of the necessary experienced research workers. The national engineering societies might consider also with propriety, these things as lying among their normal functions. The National Research Endowment is pledged specifically to support pure scientific research in university laboratories. There are some problems of pure research which must be attacked by research engineers, but it appears doubtful whether appeal for work in the engineering field will for sometime receive consideration by the National Research Endowment. It is highly desirable, therefore, that engineering foundations interested in research and the national engineering societies should consider how the sources of the training of research engineers can best be conserved, and how activity in engineering research may be encouraged.

Accuracy Required in the Measurement of Dielectric Power Factor of Impregnated Paper-Insulated Cables

BY C. F. HANSON[1]

Member, A. I. E. E.

Synopsis.—*This paper deals with the effect of errors in the measurement of power factor upon the usefulness of impregnated paper-insulated cables. It points to error in the knowledge of the thermal properties of the cable and the cable duct. The latter error affects the usefulness of a cable to such an extent as to permit a limited error in the power factor without materially reducing the efficiency of the cable. This limited error defines the required power-factor accuracy.*

The required power-factor accuracy in general is found to vary directly with the frequency and the specific inductive capacity of the insulation, and to increase with the number of cables in a duct bank and the ratio of E^2/G, where E is the operating voltage of the cable in kilovolts and G is the geometric factor. For very high-voltage single-conductor cables the power-factor accuracy should be within the order of 0.002.

* * * * *

Introduction

The significance of an error in the measurement of one property of a commodity depends upon the limitations which that error imposes upon the usefulness of the commodity. At first hand, it would seem that this error should be reduced to as low a value as possible in order that the commodity may have a maximum usefulness. However, in the measurements of other properties of the commodity, errors exist which also impose limitations. An error in the measurement of the property, therefore, need not be made as small as possible, but need be reduced only to a value which will impose very little additional limitations upon the usefulness of the commodity.

The purpose of this paper is to determine the significance of an error in the measurement of the dielectric power factor of impregnated-paper insulated cables. The method of attack lies in an endeavor to compare the power-factor error with the error existing in the knowledge of the thermal properties of the cable. This comparison is based upon the effect of each of these errors on cable efficiency. The efficiency of a cable is measured by its capacity to carry current.

No economic gain of any consequence can be realized by reducing power-factor error below a certain limit as long as errors exist in the thermal data of the cable and the cable duct. In other words, for a given accuracy in the thermal data, an appreciable gain in cable efficiency can be realized by increasing power-factor accuracy only up to a certain limit. This limit of power-factor accuracy can be defined, for the purpose of this paper, as the required power-factor accuracy.

If the accuracy of the thermal data should increase, then the required power-factor accuracy would likewise increase. To provide for this situation, it is shown how the latter varies with respect to the former. With this information available, the required power-factor accuracy can be determined and then compared with the estimated power-factor accuracy obtained in the measurements. If the estimated accuracy is less than the required accuracy, then the methods for measuring power factor should be improved. On the other hand, if the estimated power-factor accuracy is far in excess of the required, then the accuracy of the thermal data should be increased.

Three-Conductor Cable

The following formula gives the current-carrying capacity of a three-conductor cable:

$$I = \frac{18.08}{\sqrt{R}} \sqrt{\frac{T_0 - T_G}{R_{th}} - W_{DL}} \qquad (1)$$

This formula is practically the same as formula (24) given by Simons[2]. The term W_{DL} is the dielectric power loss in watts per foot of cable at 60 cycles, and is assumed, for the sake of simplicity, to originate on the surface of the conductors.

W_{DL} is proportional to the power factor $\cos \theta$.

- R = the resistance per conductor in ohms per 1000 ft. at the allowable temperature, T_0, in deg. cent. (two per cent is added for cabling).
- T_G = the base temperature of the earth in deg. cent. used as 20 deg. cent.
- R_{th} = thermal resistance between conductors and base in thermal ohms per foot of cable.
- I = current per conductor at the generator end of the cable in amperes.

The value of the current I is known with an accuracy of one per cent or better. The temperature, T_0, can be established under laboratory conditions with considerable accuracy. When T_0 is established, the value R becomes known to an accuracy within 2 per cent, the allowance required for manufacturing variation. The

1. Habirshaw Cable and Wire Corporation, Yonkers, New York.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

2. "Calculation of the Electrical Problems of Transmission by Underground Cables," Donald M. Simons, The *Electric Journal*, August, 1925, p. 375. To avoid confusion the author has used the same symbols as those used by Simons. The first published formula to include W_{DL} was given by Wm. A. Del Mar in Harold Pender's "Handbook for Electrical Engineers," 1922 edition, p. 2021.

accuracy of the terms T_G and R_{th} is low. These two terms need, therefore, be studied in considerable detail in trying to assign the accuracy required in power-factor measurements.

Simons' equation (**20**) gives the following expression for R_{th}

$$R_{th} = \frac{0.00522\,\rho\,G_1}{n} + \frac{0.00411\,B}{D} + N\,H \qquad (2)$$

ρ = thermal resistivity of insulation in watt-cm. units
G_1 = geometric factor of cable, all three conductor against sheath
n = number of conductors in the cable
B = surface thermal resistivity of lead sheath in watt-cm. units
D = outside diameter of the lead sheath in inches
H = heating constant of duct in thermal ohms per foot
N = number of similar cables in duct bank

The value of the fraction $\frac{T_0 - T_G}{R_{th}}$ can be varied either by assigning different values to T_G or to R_{th}. Any error existing in R_{th} can therefore, in equivalent terms, be added to the error existing in T_G. The foregoing fraction can therefore be rewritten into the following form in which ΔT_G is an equivalent error which combines the actual errors in T_G and R_{th}.

$$\frac{T_0 - (T_G \pm T_G)}{R_{th}}$$

The term W_{DL} contains an error of ΔW_{DL} and can therefore be written in the form $W_{DL} \pm \Delta W_{DL}$. Now, a certain equivalent error of ΔT_G in the base temperature of the earth will affect the value of I by the same amount as a certain error of ΔW_{DL}. Accordingly, the following equation can be written:

$$\Delta W_{DL} = \frac{\Delta T_G}{R_{th}} \qquad (3)$$

From Simon's formula (**17**) in the foregoing citation:

$$\cos\theta = \left(\frac{3144}{f\,k\,E^2/G_2}\right) W_{DL} \qquad (4)$$

E = Phase voltage in kilovolts
G_2 = Simon's geometric factor for three-phase operation
k = The specific inductive capacity and is taken to be 3.4
f = Frequency, and equals 60.

The power-factor error may be represented by $\Delta \cos \theta$ which corresponds to the dielectric power-loss error, ΔW_{DL}. Using these symbols in equation (**4**), the following relation is obtained:

$$\Delta\cos\theta = \left(\frac{15.4}{E^2/G_2}\right)\frac{\Delta T_G}{R_{th}} \qquad (5)$$

In calculating the value for R_{th}, the author has used 500 for the thermal resistivity of paper insulation in watt-cm. units. The surface thermal resistivity of lead sheath B in watts per cm. units, is 1200, the same as that used by Simons. The heating constant H of the duct in thermal ohms per foot is taken as unity in accordance with Simons and Atkinson.

Table I gives the power factor error, $\Delta \cos \theta$, caused by an equivalent error of 1 deg. cent. in the base temperature T_G for ten cables. $\Delta T_G = 1$ in formula (**5**). In this table, T is the conductor insulation thickness and t is the belt insulation thickness with both expressed in 64ths of an inch. The column of $\cos \theta$ gives what may be considered as a basic value of the power factor corresponding to the temperature T_0. To be sure, cables are manufactured having power factors less than those listed here, but on the other hand, cables are also made having higher power factors. In regard to operating voltage E, the table indicates an optimistic outlook on the performance of cables. The reason for this optimism is that the purpose of this survey is to consider power-factor measurements not only for cables being manufactured now, but also possible cables which may be manufactured during the next decade.

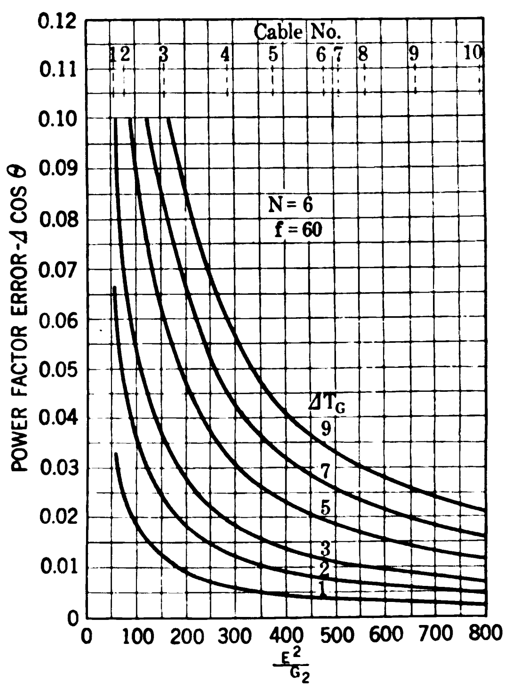

FIG. 1—POWER-FACTOR ERROR IN TERMS OF EQUIVALENT BASE TEMPERATURE ERROR $\Delta\ T_G$ FOR VARIOUS THREE-CONDUCTOR PAPER-INSULATED CABLES

The power factor error $\Delta \cos \theta$, is independent of the basic power-factor $\cos \theta$ according to formula (**5**). In other words, had other values been chosen for the basic power factor, $\cos \theta$, than those listed in the table, the power-factor errors, $\Delta \cos \theta$, would remain the same. This observation leads to an important conclusion. If the allowable power-factor error is limited only by errors existing in the base temperature T_G and the thermal resistance R_{th}, th the power-factor error must be expressed, not in terms of percentage, but in

terms of a constant. For example, a power factor of 0.05 is known to be correct within the limits $\pm$ 0.005 and not $\pm$ 10 per cent.

The relation of the power factor error $\Delta \cos \theta$, and E^2/G_2 is shown in Fig. 1 for various values of ΔT_G. When the power-factor error has been calculated for an equivalent temperature error of 1 deg. cent. ($\Delta T_G = 1$), it is very easily obtained for other temperature errors. The power-factor error increases in the same proportion as the temperature error. For example, if $\Delta \cos \theta = 0.0331$ when $\Delta T_G = 1$, then $\Delta \cos \theta = 0.0662$ when $\Delta T_G = 2$.

The curves in Fig. 1 show that the required accuracy of power factor measurements increases as the value of E^2/G_2 increases. For the sake of illustration, an equivalent error of 3 deg. cent. may be assumed in the base temperature. Under this condition the power factor of cable No. 9 should be measured with an error not to exceed 0.008. On the other hand, cable No. 2 may have a power-factor error not greater than 0.07.

A conversion of the term ΔT_G into its corresponding effect on the current carrying capacity of the cable may be helpful. The following formula provides the solution:

$$\frac{I_e}{I} = \sqrt{\frac{\cos \theta_0 - \cos \theta - \Delta \cos \theta}{\cos \theta_0 - \cos \theta}} \qquad (6)$$

I_e is the current capacity of the cable when its power factor is $(\cos \theta + \Delta \cos \theta)$.

I is the current capacity of the cable when its power factor is $\cos \theta$.

Fig. 1 supplies values of $\Delta \cos \theta$ for various cables and for various values of ΔT_G. Table I contains values

TABLE I
THREE-CONDUCTOR CABLE

$T_0 = 90 - E$ (minimum = 60) $T_G = 20$ $N = 6$ $\Delta T_G = 1$ $f = 60$

Cable No.	Cir. Mils X 10 − 3	T	t	K. V. E	°C T_0	Cos θ	G_1	G_2	Cos θ_0	R_{th}	E^2/G_2	Δ Cos θ
1	500	8	6	7.6	82	0.053	0.70	1.04	2.05*	8.60	55.7	0.0331
2	212	16	4	13.2	77	0.046	1.29	2.31	1.31*	9.15	75.4	0.0231
3	500	9	5	13.2	77	0.046	0.71	1.12	0.678	8.58	156	0.0119
4	350	19	7	25	65	0.033	1.29	2.18	0.286	8.74	286	0.0064
5	500	9	5	20	70	0.038	0.71	1.06	0.246	8.58	376	0.0049
6	350	23	9	35	60	0.029	1.49	2.57	0.156	8.75	478	0.0038
7	350	20	10	35	60	0.029	1.45	2.41	0.142	8.79	509	0.0035
8	350	19	7	35	60	0.029	1.29	2.18	0.130	8.74	561	0.0032
9	500	18	8	35	60	0.029	1.16	1.86	0.113	8.53	658	0.0028
10	350	23	9	45	60	0.029	1.49	2.57	.092	8.75	790	0.0023

*The column of Cos θ_0 is, on first consideration, more ridiculous than interesting. Some of the values are imaginary. This column of figures gives the power factor which each cable would have if it had zero current carrying capacity. Those cables for which the figure is greater than unity will carry current regardless how great the basic power factor cos θ may be (cos θ, of course, will never be greater than unity). On the other hand, when the figure becomes rather low, as for example Cable No. 9, it has a significant meaning. This cable will not carry current at 60 deg. cent, if its power factor is equal to 0.113 at 60 deg. cent.

of $\cos \theta_0$ and $\cos \theta$. Fig. 2 shows the effect of different values of ΔT_G upon the current capacity of the ten cables listed in Table I, when N equals six and when the basic power factor is that listed in the Table.

When N Equals Any Number

The subject thus far has been confined to the condition of six similar cables in a duct bank. The question naturally arises as to how the desired power-factor accuracy would change if some other number of similar cables in a duct bank were chosen. The change can easily be shown by introducing a factor Q.

$$\Delta \cos \theta = Q \, \Delta \cos \theta \, (N = 6) \qquad (7)$$

$$Q = \frac{R_{th} \, (N = 6)}{R_{th}} \qquad (8)$$

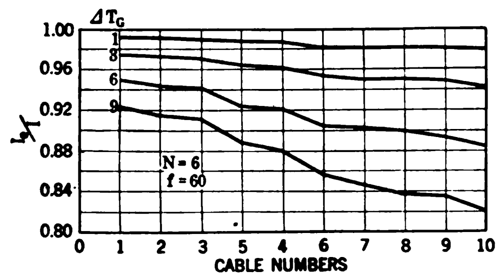

Fig. 2—The Effect of a Change in the Base Temperature Upon Current Capacity of Three-Conductor Paper-Insulated Cables

By trial calculation on the ten cables listed in Table I, Q was found to be constant, within an average deviation of 1.3 per cent. The following values of Q can be safely used for the purpose of this paper:

N =	2	4	6	8	10	12
Q =	1.85	1.30	1	0.81	0.69	0.59

The use of Q can easily be seen by referring to Fig. 1. The values of $\Delta \cos \theta$ for a condition of $N = 4$, may be obtained upon multiplying the values taken from Fig. 1 by 1.30. Likewise, the values of $\Delta \cos \theta$ for a condition of $N = 12$, may be obtained upon multiplying by 0.59. Because Q becomes smaller as N increases, the conclusion follows that power-factor measurements should be obtained with greater accuracy as the number of similar cables in a duct bank increases.

According to formula (6), the power-factor error $\cos \theta$ should become less as $\cos \theta$ increases in order that the ratio I_e/I may remain constant. If the limits of

TABLE II

SINGLE-CONDUCTOR CABLE

$T_G = 20$ $N = 6$ $\Delta T_G = 1$ $f = 60$

Cable No.	Cir. Mils X 10 − 3	T	U	E	T_0	Cos θ	G	R_{th}	Cos θ_0	$R_{th'}$	e^2/G	Δ Cos θ
11	500	40	8	40	67	0.035	0.93	16.8	0.409	9.4	569	0.0087
12	500	60	9	66	60	0.029	1.19	17.2	0.167	9.2	1213	0.00417
13	750	52	10	75	60	0.029	0.97	20.4	0.114	8.9	1830	0.00285
14	600	46	10	100	60	0.029	0.81	17.9	.0515	8.7	4130	0.00129
15	600	46	10	132	60	0.020	0.81	17.9	.0296	8.7	7180	0.00074
16	600	46	10	132	60	0.010	0.81	17.9	.0296	8.7	7180	0.00074

the power-factor error should be based on the condition that the error must not affect the current capacity of a cable by more than a certain percentage, then evidently, the accuracy of power-factor measurements should increase as the value of the power factor increases. This reasoning is not valid. Even though a cable of high power factor should be measured with a higher degree of accuracy, nothing would be gained in current capacity because the equivalent error ΔT_G would not permit a gain. The conclusion, therefore, follows that the required power-factor accuracy cannot be based directly on a limited change in current capacity.

Single-Conductor Cables

A slight modification of Simons' equation (**26**) for current capacity yields formula (**9**):

$$I = \frac{31.6}{\sqrt{R \dfrac{R_{ac}}{R_{dc}}}} \sqrt{\frac{T_0 - T_G - R_{th'} W_{DL}}{R_{th}}} \qquad (9)$$

The ratio $\dfrac{R_{ac}}{R_{dc}}$ is introduced because the skin effect in large conductors becomes appreciable. The term $R_{th'}$ is somewhat different from R_{th} because in the case of single-conductor cables the dielectric power loss is not assumed to originate on the surface of the conductors but actually originates in such a location as to cause a temperature drop from conductor to sheath equal to one half the drop it would have if the dielectric power loss had originated on the surface of the conductor. The value of R_{th} must be calculated in such a manner as to take into account sheath losses which are of relatively large magnitude in single-conductor but negligible in three-conductor cables. The other terms in formula (**9**) are the same as those in formula (**1**).

The ratio of R_{ac}/R_{dc} is taken from Simons' paper[3], p. 369. R_{th} and $R_{th'}$ were calculated according to his method. However, 500 watts per cm. units were used, in place of his 850 watts per cm. units, as the heat resistivity of impregnated paper.

By introducing the terms ΔW_{DL} and ΔT_G in formula (**9**), the following formula is obtained:

$$\Delta W_{DL} = \frac{\Delta T_G}{R_{th'}} \qquad (10)$$

3. *Loc. Cit.*

Stating ΔW_{DL} in terms of $\Delta \cos \theta$ and $\dfrac{e^2}{G}$ formula (**10**) becomes:

$$\Delta \cos \theta = \frac{46.5}{e^2/G} \frac{\Delta T_G}{R_{th'}} \qquad (11)$$

e = voltage to neutral in kilovolts. In single-conductor cable it is the voltage from conductor to sheath.

G = Geometric factor

k = 3.4 and f = 60.

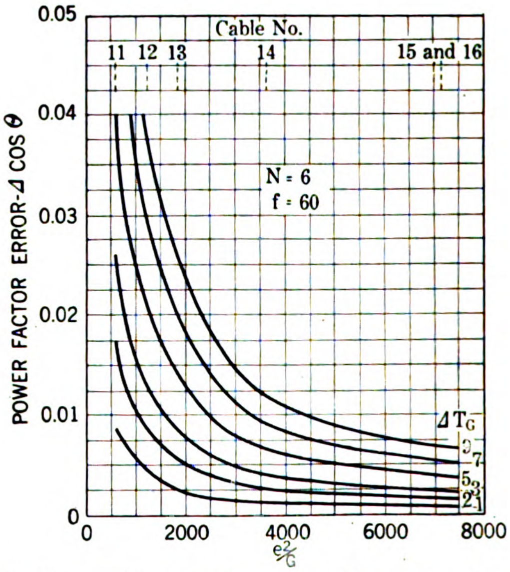

FIG. 3—POWER FACTOR ERROR IN TERMS OF EQUIVALENT BASE TEMPERATURE ERROR ΔT_G FOR VARIOUS SINGLE-CONDUCTOR PAPER-INSULATED CABLES

The power-factor error $\Delta \cos \theta$, is given in Table II when $\Delta T_G = 1$, for six different cables when N equals 6. The center of each of the three cables on a three-phase circuit was assumed to be at the apex of an equilateral triangle, the sides of which were taken to be 12 in. long (S = 12). Cables No. 14, No. 15 and No. 16 each has a hollow core of ¾ in. diameter in the conductor. All the cables are assumed to have a single lead sheath the thickness of which is given as U in 64ths of an inch. The thickness of the insulation in 64ths of an inch is given as T.

In Fig. 3 the relation of power-factor error, $\Delta \cos \theta$, to the ratio e^2/G is shown for various values of ΔT_G.

As in three-conductor cables, the power-factor error is easily obtained for other values of ΔT_G when it is known for one value of ΔT_G. If $\Delta \cos \theta$ equals 0.005 when ΔT_G equals unity, then $\Delta \cos \theta$ equals 0.01 when ΔT_G equals 2. The curves show that for high-voltage single-conductor cables, the permissible power-factor error is much less than it was for the three-conductor cables considered in Fig. 1. If the equivalent error

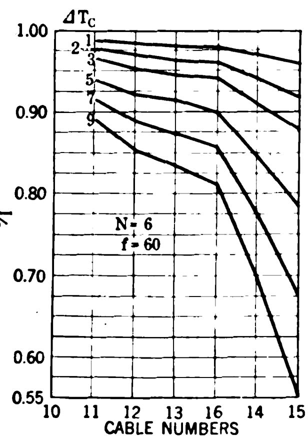

FIG. 4—THE EFFECT OF A CHANGE IN THE BASE TEMPERATURE UPON CURRENT CAPACITY OF SINGLE-CONDUCTOR PAPER-INSULATED CABLES

ΔT_G, in the base temperature is assumed to be 3 deg. cent., then the power-factor error, $\Delta \cos \theta$, should not exceed 0.0022. This accuracy would be required regardless of what the actual power factor of the cable may be.

The frequency used in the calculations is 60 cycles. If some other frequency were used, the permissible power-factor error would change. Although the exact variation of dielectric power loss with frequency is not known, the dielectric power loss may be considered to be proportional to the frequency within the limits of commercial power frequencies. On this basis, the permissible power-factor error, both for single-conductor and three-conductor cables, varies inversely as the frequency. In other words, the greater the frequency, the greater should be the power-factor accuracy.

The effect of ΔT_G upon the current capacity of single-conductor cables can be calculated by formula (**6**). This effect is shown in Fig. 4, when N equals 6 and when the basic power factor is that given in Table II.

If N equals some other number, the power-factor error $\Delta \cos \theta$ may be obtained by formula (**7**). In this case

$$Q = \frac{R_{th'} (N = 6)}{R_{th'}} \qquad (12)$$

The values of Q may be considered as follows:

$N = 3 \quad 6 \quad 9$

$Q = 1.50 \quad 1 \quad 0.75$

132-Kv. Cable

Fig. 4 brings out some rather interesting information. Each curve has a sudden break at cable No. 16, consequently, cables No. 14 and No. 15 have some property which is abnormal relative to the other cables. This property is the power factor $\cos \theta$. Even though cable No. 15 has a power factor which is only 0.02 at 60 deg. cent., this power factor value is relatively much higher than the power factor 0.029 at 60 deg. cent. is for cable No. 12. Cable No. 15 should have a power factor of the order of 0.01 at 60 deg. cent. in order that that cable may perform in accordance with experience with other cables. The equivalent base temperature error ΔT_G, should be low and also the power-factor error $\Delta \cos \theta$. Furthermore, the power factor of the cable and the heat resistance of the cable and the duct line must run very uniform throughout its entire length for satisfactory and economical service.

Fig. 5 shows the power factor—temperature characteristic $A B$—which cable No. 15 may be expected to have, and characteristic $C D$ for Cable No. 16. Each

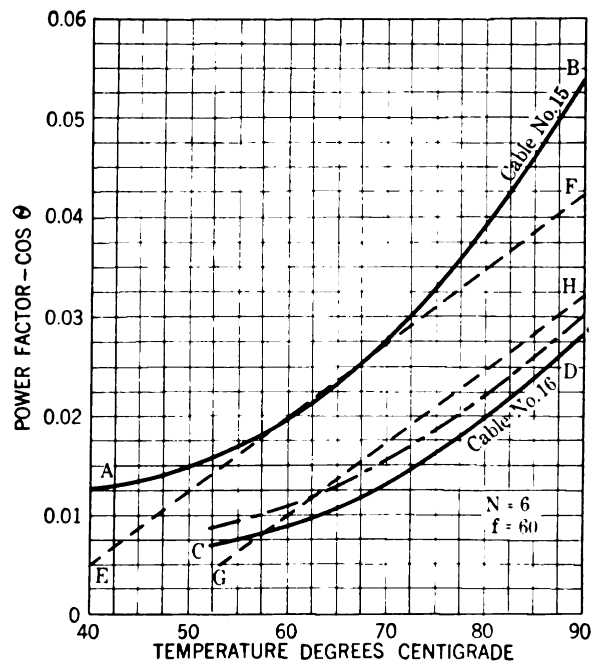

FIG. 5—CABLE NO. 15 WILL HAVE A SHORT LIFE REGARDLESS OF POWER FACTOR ERRORS. AN ERROR OF 0.002 MAY JEOPARDIZE THE LIFE OF CABLE NO. 16

132-kv. cable
One-conductor, 600,000 cir mils
3/4-in. hollow core
46/64-in. insulation

of these characteristics was obtained in actual power-factor measurements of finished cables. The dotted line $E F$ is the unstable power factor—temperature characteristic for Cable No. 15 and likewise the dotted line $G H$ is the unstable characteristic for Cable No. 16.

The current capacity of Cable No. 15 is calculated to be 187 amperes when it is operated with a conductor temperature of 60 deg. cent. and a power factor of 0.020 when N equals 6. If this cable had $E F$ in Fig. 5,

as its power-factor characteristic, it would carry 187 amperes at any temperature from 40 to 90 deg. cent. or more. Nobody knows what temperature the cable would choose.

The unstable characteristic $E\,F$ is obtained with the use of formula (**11**). Instead of using $\Delta \cos \theta$ as a power-factor error, it is used as a power-factor increment. For the term ΔT_G, ΔT_0 is used because an increment change in T_0 produces the same effect as an increment change in T_G according to formula (**9**). Formula (**11**) then becomes:

$$\frac{\Delta \cos \theta}{\Delta T_0} = \frac{46.5}{e^2/G} \frac{1}{R_{th'}} \qquad (\mathbf{13})$$

Formula (**13**) provides the slope of the characteristic $E\,F$. The point, $\cos \theta = 0.02$ and $T_0 = 60$, on the characteristic is already known. The characteristic is, therefore, established by a point and the slope. In the derivation of the slope the change in the resistance R due to an increase in temperature is disregarded. The actual power-factor characteristic of Cable No. 15 is the curve $A\,B$. With a current of 187 amperes flowing in this cable, its temperature will rise to 60 deg. cent. Now, if the current should increase slightly to 190 amperes, the cable temperature would immediately rise indefinitely. Even if the current should drop back to 187 amperes when the temperature has reached 70 deg. cent., the temperature would continue to rise anyway because the cable temperature has passed the critical point of 68 deg. cent. This temperature is generally known as the critical temperature of cumulative heating. Cable No. 15 is not suited for 187 amperes, because a small error in the thermal data or power factor of the cable would cause cumulative heating.

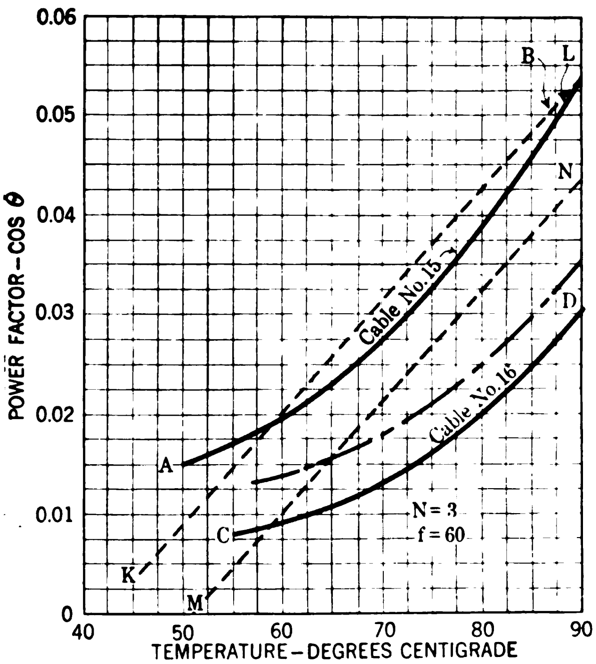

Fig. 6—Elimination of Power Factor Error and Equivalent Base Temperature Error Might Save Cable No. 15. An Equivalent Power-Factor Error of 0.005 May Not Seriously Impair the Use of Cable No. 16

132-kv. cable
One-conductor, 600,000 cir. mils
3/4-in. hollow core
46/64-in. insulation

The current capacity of Cable No. 16 is calculated to be 268 amperes at 60 deg. cent. with a power factor of 0.01 when N equals 6. With a current of 268 amperes flowing through it, this cable with its power-factor characteristic $C\,D$, in Fig. 5, would come up to a temperature of 58 deg. cent. provided no power-factor error exists and that all other cable and duct properties are known exactly. If, however, a power-factor error of 0.002 or an equivalent base temperature error of 3 deg. cent. exists, the cable would come up to a temperature of 63 deg. cent. and stay there as long as nothing changes. A little overload for a few hours might, however, seriously jeopardize the life of the cable.

Fig. 6 tells a similar story except that N equals three. The current capacity of each cable at 60 deg. cent. is calculated to be 303 amperes for Cable No. 15 and 358 amperes for Cable No. 16. The power factors are 0.020 and 0.010 respectively. Cable No. 15 does not offer a continuity of service of 303 amperes because a small error in the power-factor measurement or in the equivalent base temperature might send the temperature up to the point of cumulative heating at 90 deg. cent. Cable No. 16 looks promising for 358 amperes even though a power-factor error of 0.002 might exist. If in addition to a power-factor error of 0.002, an equivalent base temperature error of 4 deg. cent. exists the probable error of the combination would be of the order of 0.005. Even with this equivalent error of 0.005 in the power factor, the cable would probably continue to serve with 358 amperes but no overload should be permitted. Under this condition it would operate at 65 deg. cent.

For the 132-kv. cable, for operation in a three-cable duct bank, the power-factor error evidently should not exceed 0.002 and the equivalent error in the base temperature should not exceed four deg. cent. in order to obtain a cable service similar to that obtained with cables of lower operating voltage.

Conclusions

A survey of the factors which have a bearing upon the accuracy required in power-factor measurements shows that:

1. Power-factor accuracy should be stated as a constant and not as a percentage. For example, a power factor of 0.05 is accurate within $\pm$ 0.005 and not $\pm$ 10 per cent.

2. The power-factor accuracy required increases in direct proportion to the frequency, and also to the specific inductive capacity of the insulation.

3. The power-factor accuracy required increases as

the number of similar cables in a duct bank increases.

4. The required accuracy increases as the ratio E^2/G increases, where E is the operating voltage, in kv. and G is the geometric factor of the cable.

5. The required power-factor accuracy cannot be defined by percentage limits in the current-carrying capacity of a cable.

6. The required accuracy is relative to the accuracy obtained in the measurement of the heat resistivity of the insulation, the surface heat resistivity of the lead sheath, the "heating constant" of the cable duct and the base temperature of the earth.

7. For 132-kv. cable the power-factor accuracy should be of the order 0.002.

Electrochemistry and Electrometallurgy

Annual Report of the Committee on Electrochemistry and Electrometallurgy*

G. W. VINAL, Chairman

To the Board of Directors:

The Committee on Electrochemistry and Electrometallurgy of the Institute makes its annual report dealing primarily with a review of some of the outstanding developments within the field of the Committee's work. At the beginning of the administrative year the Committee was enlarged to include members representing as far as possible the many diverse fields that are included within the scope of electrochemistry and electrometallurgy.

The Committee has endeavored to bring about a closer cooperation between its own work and that of the American Electrochemical Society with which it should be closely identified. The work of our Committee does not overlap that of the Electrochemical Society, and it is apparent that a still greater degree of cooperation between the two organizations would be valuable[1].

In 1925 Mr. F. E. Smith, President of the London Physical Society, advocated the replacement of the present international electrical units by the absolute cm. g. sec. units. This is not a new idea, but it is an indication that we are approaching a time when such a step may be considered possible. The accuracy of the electrical standards must keep ahead of the demands of engineering. Improved facilities and technique for performing experiments within the physical laboratory are making possible a step which is of particular interest within the field of electrochemistry where the transformation of energy in its various forms plays an important part.

The international electrical units upon which the fundamental measurements of electrical engineering are based are defined by standards which are essentially electrochemical. The mercury ohm which serves as the standard for the measurement of resistance involves chemical and electrochemical processes for purifying the materials. The silver voltameter, whose electrolytic deposits serve to define the ampere, is obviously an electrochemical device. The standard cell, whose voltage has been determined by experiment from the international ohm and the international ampere, is essentially a small voltaic cell. Engineers become so accustomed to dealing with volts and amperes and ohms that the fundamental standards for their values are taken more or less as a matter of course. These fundamental standards were re-defined by the International Conference on Electrical Units and Standards which met in London in 1908. They were devised to represent as nearly as possible the absolute units based upon the centimeter, the gram, and the second. It is highly desirable for reasons that are too obvious to require repetition that they should represent these absolute units as closely as possible. With the increasing facilities for experimental work and improved technique, it is now possible to realize by experiment the absolute values of the fundamental units with a higher degree of accuracy than had been obtained prior to 1908. Experimental work is now in progress in the United States to verify the conclusions of experimenters at the national laboratories of England and Germany within the past few years, which have indicated that the mercury ohm does not represent the absolute ohm with as high a degree of accuracy as was previously supposed to be the case. Fifteen years have elapsed since the international experiments using the silver voltameter were made. During that time our electrical units have been carried forward by means of the working standards of the laboratory, that is to say, the wire-resistance standards and the standard cells. Developments in engineering practise are making it more than ever important that the fundamental elec-

*Committee on Electrochemistry and Electrometallurgy:

G. W. Vinal, Chairman

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T. C. Atchison,	Walter E. Holland,	J. B. Whitehead,
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Safford K. Colby,	Wm. A. Moore,	J. L. McK. Yardley.
	Charles H. Moritz,	

1. The committee is indebted to Dr. Fink, Secretary of the American Electrochemical Society, for furnishing certain information used in this report.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va. June 21-25, 1926.

trical standards, maintained with the highest possible degree of accuracy, should be in accord with our cm. g. sec. system of measurements. Therefore, a difference between the value of the international ohm and the absolute ohm amounting to five parts in 10,000, together with its effect upon the value for the standard cell must inevitably give rise to serious consideration.

An outstanding development in electrodeposition during the past year has been made in chromium plating. Although it has long been known that chromium could be electrodeposited, it is only within the past few years that the conditions for its commercial deposition have been defined. There are still many problems requiring study before its general application will be entirely feasible. There are at least twenty laboratories in the country now engaged in the study of chromium plating, and while it is not yet in extensive use, the indications are that it will soon find many important industrial applications. Chromium is a material of extreme hardness and is also notable for its resistance to tarnish and to chemical action. It has been successfully applied to plates used for printing paper currency at the Bureau of Engraving and Printing, and it has materially increased the useful life of these plates. It will probably find application also in other forms of printing where very great numbers of copies are required. It has been suggested also for use on dies and gages. Although the reflecting power of chromium is appreciably less than that of silver, its resistance to tarnish may make it of decided value on reflectors.

In an effort to prevent corrosion, research has been in progress to improve the quality of nickel plating and eliminate the pits and pores which have been the chief cause of its failure to prevent the corrosion of underlying iron or steel.

A process recently developed and known as "galvannealing," is said to be an improvement over the familiar processes of galvanizing. It is claimed that the zinc covering is more uniform and flexible.

The protection of iron by cadmium would not be anticipated from the potential relations of these metals as usually given. Experiments, as well as actual service, indicate that cadmium can be used successfully as a protective material against corrosion of iron and steel.

Chromium plating, while not affording an absolute protection against corrosion unless the deposits are unusually thick, may be used in combination with underlying coats of copper and nickle, to afford a high degree of protection. Efforts have also been made to develop electroplating of simultaneous deposits of copper and nickle similar to monel metal. The importance of corrosion research to industry in general is very great and will doubtless assume even greater importance.

The progress of electrothermics during the past few years has been so rapid that publications of even recent date often must be used with caution lest they be misleading as to present practise in melting and heat-treating furnaces. During the past year, the development in the use of electricity for heating and industrial purposes has been rapid, but the idea sometimes expressed that all industrial heating processes are potentially valuable outlets for electrical energy has been considerably modified. In general, engineers are beginning to realize that, while there are many processes which can be done electrically, there is, nevertheless, a choice to be made which depends upon practical and economical aspects of fuel costs and the present state of manufacturing processes.

Soaking pits, electrically heated by resistors, have been found to yield ingots that can be more easily and economically rolled in certain plants than similar ingots from gas-fired pits.

Results obtained by the use of electric furnaces in the production of steel, ferro-alloys, and other operations of a similar nature depend very largely on the control of the electrical energy applied to the furnace. The electric furnace is not an inherently efficient piece of apparatus unless the electric energy is properly applied. This means that furnaces should operate in such a manner that the power is fully utilized with respect to time factor, load factor, and, when alternating current is employed, power factor. Aside from the more obvious advantages of high power factor, some electrochemical operations may be adversely affected by variations in power factor for reasons that are not at once obvious. Current density often plays an important part in metallurgical operations and when the control of the furnace is accomplished by means of current regulators, material variations of power input may occur. Thus, in operating a three-phase furnace, the variations in power factor during the melting-down period may keep the load in a state of unbalance with respect to the phases. It is sometimes observed that one electrode heats up unduly without, however, doing its share of the work. The electrical energy supplied is the important factor from a thermodynamic standpoint in metallurgical operations where a transformation of one kind of energy to another occurs. For both economic and metallurgical reasons, the control of the energy input is of important consideration. Modifications to meet practical conditions have been made in certain plants. Current control has been replaced by watt control, and individual motors for shifting the electrodes have been replaced by a hydraulic system which offers advantages in the accuracy with which an electric balance can be maintained during the period of melting. Some furnaces are now operating on 98 per cent of the energy supplied to the primary of the transformer, the two per cent loss being divided between the transformer, bus-structure, and electrode holders. The unequal power requirements during the various periods of charging, melting, refining, and tapping of steel furnaces have in some cases been

nearly equalized by staggering the operation of a group of three furnaces, having one transformer unit and one control mechanism. A more continuous load is thus maintained and the labor somewhat diminished, as measured by the weight of steel produced per man.

Because of the various states of oxidation of the metallic constituents of the ferro-alloys and the losses encountered in the reduction of them, some modifications in the usual method of charging the furnaces have been proposed. By very rapidly raising the oxides and reducing agents to the reducing temperature, the formation of intermediate oxide states is avoided. This is applicable to many types of reduction and is accomplished by a continuous charging of the material in a small stream into the hottest part of the furnace.

Up to a few years ago, the common practise in brass-rolling mills was to melt brass in crucibles, using coal or oil for heating. These crucibles generally held 600 lb., and some held as high as 900 lb of metal.

In the period from 1917 to 1922, the introduction and development of the induction type furnace, particularly in the Naugatuck Valley, met with considerable success, as it gave a better control of temperature for pouring, the metal was better (less contamination from gases, etc.), the metal losses were lower, and the cost of furnace linings was less than the equivalent cost of crucibles. These induction furnaces are rated 60 to 75 kw., single-phase, 25 or 60 cycles, and 220, 440, or 550 volts, and can melt 600 to 900 lb. of heat. Pouring temperatures needed for the general run of production requirements are within the working limits of the lining material used in these furnaces. For certain metals, such as nickel, silver, high copper alloys, etc., higher pouring temperatures are necessary, and difficulty has been experienced with the present lining materials.

Because of this situation, experiments have been carried on with a high-frequency induction furnace, and as a result, twelve of the furnaces have just been put into commercial operation in Waterbury. It is interesting to note that the first experiments with high-frequency furnaces were based on the use of 12,000 cycles; standard type generators were not available for this frequency, and mercury-arc oscillators were used, but these were limited in regard to power output. The experiments referred to above showed that much lower frequencies could be used. The high-frequency furnaces are rated to 100-kw. capacity, single-phase, 480 cycles, 1850 volts. For the twelve furnaces, two special frequency-changer sets, each rated 600 kw., are used. Because of the low power factor at which the furnace operates (10 to 12 per cent), a bank of capacitors, rated approximately 950 kv-a., is used with each furnace. The resultant power factor as measured at the frequency-changer set, is close to unity.

The construction of the furnace is relatively simple; it consists of a crucible which holds 600 lb. of metal, surrounded by an edge-wound copper coil, together with a blower, this assembly in turn arranged in a frame in such a way as to permit of tilting and pouring the metal. These furnaces have been in successful operation since the first of the year and additional furnaces are now being installed elsewhere.

An electric furnace for tempering steel parts and employing a forced convection, for obtaining uniform temperature conditions throughout the furnace, has been described recently. Experimental work is again in progress on a zinc furnace which embodies an electrothermic distillation process.

Other uses for electricity in electrometallurgy that have been noted recently include the electric heating of ingots after casting to keep the metal fluid and prevent piping. Heating for this purpose takes the form of an arc playing on the top of the ingot.

Also there has been an increasing use of electricity for annealing purposes, and it is significant that the range of objects which are subjected to an electric annealing process is steadily increasing. Annealing of the non-ferrous metals without oxidation has now become possible. Development of the mechanical operation of furnaces for enameling, to provide a continuous cycle of operation, is desirable.

Efforts are being made to improve the life of resistor products, and developments in the design of some furnaces to permit making repairs without the necessity of cooling the furnace are significant of possible development of continuous operation.

In discussing electrical power for chemical plants, it has recently been pointed out that these are not all dependent upon cheap power such as might be obtained from a hydroelectric development. Many of those which are not thus dependent produce, or could produce, cheap power for their own motor drives as a by-product of process steam. Chemical plants may be differentiated into those which require large quantities of cheap power and those which require large quantities of steam. The former include electrochemical and electrometallurgical plants for electrolytic processes and furnace work, while the latter class include those which require heating at lower temperatures, such as may be obtained from steam. The tendency at the present time in relation to the use of power by chemical plants has been summarized in the following paragraphs.

Where considerable steam is required for heating and process work, the chemical plant should generate its own steam at high boiler pressure and then obtain electrical power for its mechanical drives and electrolytic circuits from that steam before turning it over as exhaust or bled steam to the processes.

Very highly efficient turbo-generator units of medium size are now available.

Where the boiler and prime mover rooms are in close proximity to the electrolytic cell or tank room, the electrolytic power should be generated as d-c. power

Very highly efficient geared d-c. turbo-generating units are now available.

Where appreciable distance intervenes between the boiler and prime mover rooms and the tank house or cell room, or where appreciable steam is not required for heating and process work, so that the electrical power is purchased, then, in the great majority of cases, the best economy will be obtained by converting the electrolytic power from alternating current by means of synchronous converters.

The inefficiency of the motor-generator set as a means of conversion from alternating current to direct current as compared to the transformer synchronous converter unit, is all the more apparent when the operating conditions of the plant drop below full-load conditions.

The power factor of an electrochemical or electrometallurgical plant is relatively high, owing to the large proportion the electrolytic load at unity power factor bears to the total motor load. It is, therefore, seldom necessary to provide power factor corrective means within such plants to bring the overall power factor within the usual commercial range.

One of the arguments advanced by those who urge use of cheap hydroelectric power for electrochemical and electrofurnace processes is that these industrial operations afford very high annual capacity load factor. They are, therefore, a type of user who justifies the relatively high investment per unit of electrical capacity that is necessary with hydro plants.

Several papers of interest to electrical engineers were presented at the Chattanooga meeting of the American Electrochemical Society. The feature of the meeting was a symposium on the relation of the electrochemical industry to the production of fertilizers. Recent developments in nitrogen fixation are significant to the engineer, because the power requirements are changing as a result of the work of the chemist. Synthetic ammonia, which is one of the forms of fixed nitrogen, is not supplying a product for fertilizer purposes as may be generally supposed, but rather is displacing ammonia from other sources for refrigeration and chemical use. The arc process for the fixation of nitrogen has found very little use in this country, but research on the atomic states and modes of energy transfer suggest possible new developments in this line. Concentrated fertilizer materials including ammonia, urea, nitric acid, phosphoric acid, and their compounds, were discussed. The power supply and economics of the situation are only a part of the nitrogen problem. Other factors that vitally affect the electrochemical side of this industry are the physical characteristics of the materials produced, their suitability for a variety of crops, transportation charges, and, not least, the reaction of the farmer himself.

The electrical properties of the copper-nickel-manganese series of alloys have recently been investigated with reference to resistivity, the temperature coefficient, and the thermoelectric power against copper and mechanical properties. A paper describing this work was presented before a recent meeting of the Electrochemical Society. It seems possible that resistance alloys superior to those now in common use may become available. This is important to the electrical engineer, particularly in connection with instruments. which may be subjected to wide variations in temperature

The development of radio has stimulated the production of batteries, including both dry batteries and storage batteries. A new form of caustic-soda battery which requires only the addition of water has also appeared. The battery industry has watched with some concern the increasing efforts to provide battery eliminators for radio sets, but as yet it seems probable that little of inroads on the battery industry has been made. Coincident with this, there has been a marked improvement in the performance of certain types of small rectifiers. The life of the aluminum rectifier has been greatly increased and it is now used as one form of battery eliminator, and, together with several storage cells, makes possible the operation of radio sets from a-c. power. Also other types of small rectifiers for trickle charging of storage batteries have been developed.

Chlorine, which is a product of the electrochemical industry, was discussed at length in a symposium on the subject held by the Electrochemical Society at its recent meeting in Chicago. Papers included the economics of chlorine production, discussion of transportation problems, the chemistry of bleaching powder, and other uses for it.

A UNICONTROL HIGH-FREQUENCY RADIO DIRECTION FINDER

The Bureau of Standards was asked to develop for the United States Coast Guard, a simple type of radio direction finder which should function on 2100 kc. (143 m). Such a device enables a ship so equipped to locate another ship readily. A paper under the above title, by F. W. Dunmore, (Scientific Paper No. 525 of the Bureau of Standards) describes the development of such a direction finder and its installation on a Coast Guard patrol boat. The direction-finder coil consists of four turns of ignition cable, wound on a 20-in. frame. It is installed over the pilot house and rotated from below. A tuning unit and coupling transformer have been designed so that the direction-finder coil may be used on the ship's receiving set without changing its tuning adjustments, which are locked in the 2100-kc. position. A special form of automatic balancing condenser, operated by a special cam rotating with the direction-finder shaft, is incorporated in this instrument. Thus a clear minimum may be obtained at all angular positions of the coil without manual operation of the balancing condenser. The controls necessary when taking a bearing are in this manner reduced to one—that of rotating the direction-finder coil to obtain the minimum signal.

Some Aspects of the Dielectric Loss Measurement Problem

BY B. W. ST. CLAIR[1]
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***Synopsis.**—This paper points out some of the difficulties of making accurate power measurements at very low power factors. It deals with the lack of reference standards of known and constant power factor, especially for moderate sized samples and at high voltages. It also points out that a method of measuring an added loss as a check on a given test outfit's accuracy is not a check at all, although it has been used as such in several instances. Reference is made to calorimetrical methods of calibrating a testing outfit and to special forms of resistors that have very low time constant and are suitable for this class of test work.*

POWER measurements at very low power factors are admittedly quite difficult. The literature of the subject is quite voluminous, and many schemes, most of them modifications of two or three fundamental ones, have been proposed and used by various observers. It is not unusual to get widely varying results when a given sample is tested by different methods in different laboratories. Unfortunately, the real difficulties of this kind of measurement are not so widely appreciated by general testing engineers as perhaps they should be. It is the function of this short paper to point out some of these difficulties. No attempt is made however to have it cover the complete field of dielectric measurements.

A most difficult feature of this general problem centers around the lack of a reference standard of known loss. For work on very small samples, and at relatively high frequencies, this statement might be challenged. For power frequencies and for apparatus such as cables and condensers, there is no suitable reference standard, especially when consideration is given to the relatively high voltages under which tests must be made. Without an adequate reference standard, there can be no definite assurance that the results obtained by a given test set are correct, except as inference can be drawn from various auxiliary tests on the equipment or on the apparatus in test.

An air condenser, or an air condenser plus a known series resistance, has been repeatedly suggested as a suitable standard. There are two real difficulties in this suggestion. One is the difficulty of building an air condenser of adequate size and voltage rating, and the other is in knowing the losses of the condenser or proving the lack of losses at the high voltage necessary for tests on finished apparatus. Air condensers of small size and for low-voltage ratings have been built, but they do not lend themselves to either bridge methods or wattmeter methods on many of our present-day engineering samples. A number of air condensers designed for low loss at moderately high voltages has been built and are in service. Their capacitance, however, is quite low, especially when compared to reel lengths of cable or to condensers for power-factor correction. It is possible to build up a bridge with an air condenser as one of the arms, but the results of the bridge tests are still uncertain because of the very large ratio of the resistance arms necessary if the test work is on sizable samples and at the more usual voltages; and also there is no ready means of checking the results of distributed capacity and capacity between various high-voltage parts of the bridge and ground. A complete demonstration of the dependableness of a bridge scheme might lie in the interchangeability of the standard air condenser and the test sample. At present this is almost hopelessly impossible, at least with samples of moderate size.

Air condensers at present are also inadequate as reference standards for wattmeter methods. If a wattmeter is checked against a known air condenser at low voltages, it cannot be used at high voltages with any real assurance that the calibration can be translated from the low-voltage values. The currents that would circulate in the windings of wattmeters from air condensers at low voltage would be very different from those from actual cable samples or from static condensers. A calibration by air condenser is then generally carried over to another winding of the dynamometer with no really definite way of proving that this change can be made without change of instrument constants or characteristics, or the calibration is carried over to a much higher voltage without assurance that no change has occurred.

Another line of attack has been to eliminate all the known causes of error and then to attempt to prove the over-all accuracy of the equipment by checking a sample and then checking the sample with a known loss added to it as a series resistance. If the results corrected for the known losses were about the same as the results on the sample alone, the assumption was made that the measuring outfit gave correct results.

There are several reasons why this is not a dependable check of the test apparatus. If large changes are made in the losses, so that the dielectric loss plus the added losses are large in comparison with the dielectric losses, the difference is obtained by subtracting two large quantities. With only ordinary precision in the measurement of these large quantities the difference is

1. General Electric Co., West Lynn, Mass.

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subject to large uncertainties. Unless the change is made very great there is no check possible because of certain peculiarities of the trigonometric functions over the range of angles with which this paper deals.

From zero to five deg. the sine and tangent are for this purpose identical and have a linear relationship to the angle, thus

$$\sin X = 0.0174\,X$$
$$\tan X = 0.0174\,X \qquad (1)$$

where

X is expressed in degrees.

Now 5 deg. corresponds to a power factor of 8.7 per cent which is larger than is usually met in dielectric work on finished apparatus at power frequencies. The usual range is from 0.1 per cent to one or two per cent. The phase angle mentioned here is the departure of the current from an exact quadrature position with its voltage. Thus, the power factor of the sample is represented by the sine of this angle. Because of the linear characteristics and identity of the tangent and sine functions the addition of resistance to the test sample results in a change of angle proportional to this resistance and also in a change of power factor proportional to this resistance.

If the sample had no loss the phase angle would be zero. If to this ideal capacitance should be added a series of resistance R, the phase angle of the combination of capacitance and resistance would be

$$\alpha = \tan^{-1} \omega\, C\, R \qquad (2)$$

where

$\omega = 2\,\pi$ frequency
C = capacitance of sample
R = added resistance

The power factor of this group is also $\omega\, C\, R$, thus

$$\text{power factor} = \sin \alpha = \tan \alpha = \omega\, C\, R$$

and the losses in this resistance are equal to

$$I^2 R = E\, I \sin \alpha \qquad (3)$$

The normal losses of a condenser or cable or other dielectric sample can be considered as due to a series resistance added to a pure capacitance. Thus one speaks of the equivalent series resistance of a given sample. Its magnitude is such that $I^2 R$ losses would equal the dielectric losses. This resistance is denoted by R_1, so that the phase angle of the sample is

$$\beta = \tan^{-1} \omega\, C\, R_1 \qquad (4)$$

where

R_1 is this equivalent resistance

and its power factor is

$$\sin \beta = \tan \beta = \omega\, C\, R_1$$

The addition of resistance R to a sample of equivalent resistance R_1 results in a change of phase angle just equal to what the phase angle would be if the sample had no loss, that is, if R_1 were zero. This can be easily shown:

$$\text{phase angle} = \tan^{-1} \omega\, C\,(R + R_1) \qquad (5)$$

Because of the linear characteristic of the tangent function this can be written as

$$\text{phase angle} = \tan^{-1}(\omega\, C\, R) + \tan^{-1}(\omega\, C\, R_1) \qquad (6)$$

The difference between this and equation (2) is

$\tan^{-1} \omega\, C\, R_1$ which is equation (4)

The wattmeter deflection when the sample is tested alone is

$$W = E\, I \sin(\beta + \gamma) \qquad (7)$$

E is applied voltage
I is current in the series circuit of the wattmeter
γ is the phase displacement of the armature current of the watt meter from its voltage. The difficulty of knowing the value of this angle is the chief difficulty in securing correct results in wattmeter methods at these low power factors. It is due to several things and may lag or lead its voltage. It is due to the inductance of the potential circuit resistance and of the armature of the wattmeters, to the capacitance currents flowing between various parts of the potential circuit and ground, and to eddy currents in the wattmeterstructure or windings. The general tendency is to reduce this angle to as near zero as possible by careful attention to the set-up of the test equipment. It remains, however, a more or less unknown quantity as the accurate determination of the inductance of the resistances is made only with difficulty and the capacity currents cannot be computed.

Equation (7) for the wattmeter deflection becomes

$$W = E\, I\,(\sin \beta + \sin \gamma)$$

(At the small angles which are to be considered, the cosine can be taken as unity.)

When the series resistance R is added to the circuit, the wattmeter deflection becomes

$$W_1 = E\, I \sin(\alpha + \beta + \gamma)$$

which reduces to (8)

$$W_1 = E\, I\,(\sin \alpha + \sin \beta + \sin \gamma)$$

The difference in the two deflections is

$$W_1 - W = E\, I \sin \alpha$$

which is just equivalent to the I^2R loss in the resistance R, Equation (3).

Throughout this discussion, I is supposedly unchanged by the addition of R. In practise this is true.

At first, if viewed on a non-mathematical basis, this result seems paradoxical. A wattmeter incorrectly measuring a circuit of unknown loss has a correct increment to its indications when a known loss is added to the circuit. If there were no loss (*i. e.*, no phase angle) in the sample and if the phase angle of the wattmeter potential circuit were zero, the wattmeter would indicate zero. Its indications are directly proportional to these angles. Any angle in either circuit causes a deflection (positive or negative) that is proportional to the angle. The wattmeter can then be thought of as an instrument with an unknown zero point and a linear scale. The addition of a known quantity to the circuits of an instrument of this type results in a correct increment of indication without affording a clue to the total quantity being measured

by the instrument. From the foregoing statements it is apparent that a wattmeter although indicating incorrectly will correctly show differences in two samples of the same capacitance. If the first sample is replaced by a second of identical capacitance the change in indication of the wattmeter is the difference in loss of the two samples, but no clue is given to the absolute magnitude of loss of either sample.

This discussion has been applied to wattmeters where the armature is allowed to deflect. A similar treatment with the same result applies to those cases where phase changing methods are used to reduce the wattmeter deflection to zero.

To reduce the unknown phase angle of the potential circuit to as low value as possible the general tendency is to use guarded circuits of some sort. There are three main points to consider in laying out the potential circuit of an equipment of this sort—inductance of the resistances, distributed capacity and capacity to earth and other parts of the circuit. Some forms of "non-

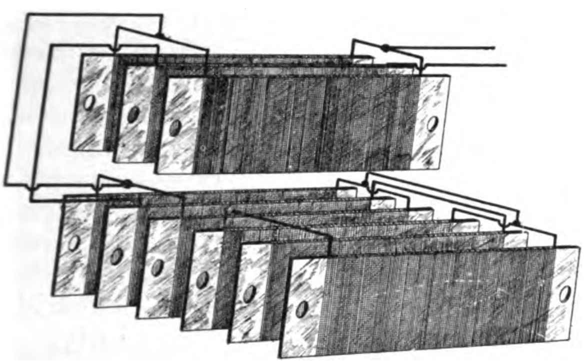

Fig. 1

inductive" windings have rather large distributed capacitance. Some also have residual inductances that though low are difficult to compute. It is also difficult to measure these residual inductances as the time constant must be very small. If the phase angle is not to exceed 1 min. at 60 cycles, the time constant must be less than 7.7×10^{-7} sec. At any event the phase angle should be known to at least 1 min. if the over-all accuracy of the outfit is to be good when working on equipment like condensers. The error 1 min. causes 14 per cent error in losses when working with samples having a power factor of 0.2 per cent and 3 per cent when working on samples of 1 per cent power factor.

A form of resistor that has low leakage, fairly low distributed capacitance, low inductance that is easily amenable to calculation, and is easily insulated for high voltage is the resistance card quite common in a-c. indicating instruments. A scheme of guard circuits that has proven very effective has been devised for this form of resistor. Every card is individually shielded as well as the case containing a group of cards. The general scheme is shown in Fig. 1 and the diagram of connections in Fig. 2.

In wattmeter methods either the potential losses or the $I^2 R$ loss in the series circuit of the wattmeter must be measured. In general, the series loss is by far the smaller of the two so that the scheme of connections shown in Fig. 3 is preferred to those of Fig. 4. If attempts are made to use very small samples, the inductance of these series windings may become excessive and must be allowed for in the computation of results.

The difficulties due to the absence of satisfactory no-loss standards of adequate size and voltage rating can be overcome in some cases where the test samples

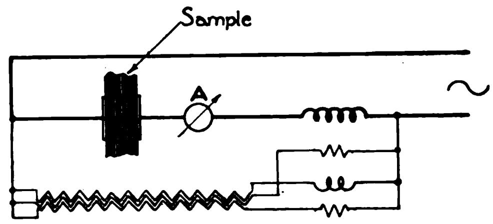

Fig. 2

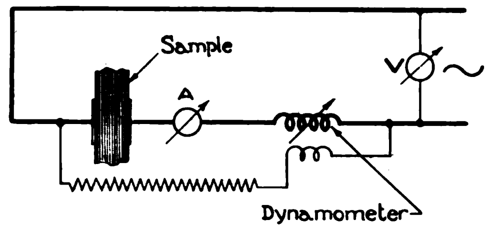

Fig. 3

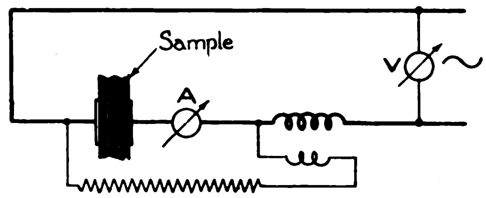

Fig. 4

are of appreciable size so that the losses are large enough to measure by calorimetrical methods.

While fairly satisfactory results are possible, the testing work must be of very high order and unusual care must be taken to prevent the acceptance of erroneous results. Several different calorimeter methods have been used or proposed. In some of them the volume and temperature rise of water flowing over the sample in a suitable case have been used. In others the temperature rise of various parts of identical casings, one of them with an actual sample and the other with a resistor of known value, have been used as reference accuracy standards for dielectric-loss measuring outfits. In another method, identical temperature gradients with dielectric losses as one heating element and a resistor on direct-current as the other have

been used to demonstrate the accuracy of a testing equipment. This method is somewhat more elaborate than the others, and in the hands of a careful experimenter and with sufficiently good temperature conditions and thermometers may yield very good results.

A photograph showing a test of this sort under way

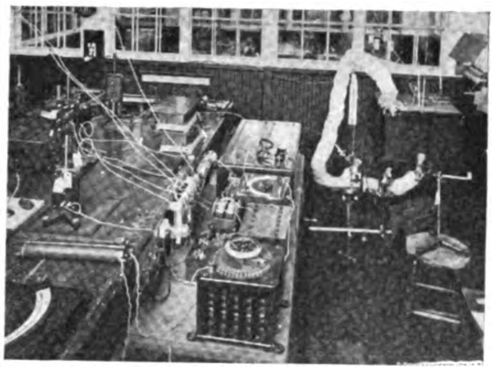

FIG. 5—CALORIMETER TESTS ON STATIC CONDENSER DIELECTRIC LOSSES

is shown in Fig. 5 and a diagram of the calorimeter is shown in Fig. 6.

The whole equipment was installed in a room the temperature variation of which throughout the calorimeter tests was not greater than 0.2 deg. cent. The temperature

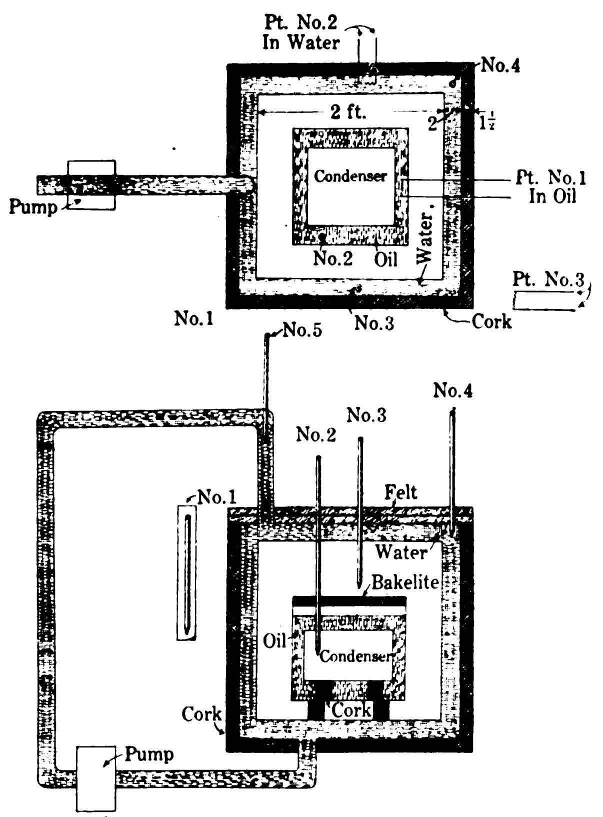

FIG. 6

rise of the water jacket and of the oil above the arbitrary reference temperature was determined to 0.002 deg. cent. This generally required six or eight hours. Immediately, thereafter the condenser was removed from circuit and resistances that had been built into the same case were connected to a d-c. circuit. The losses in these resistances were varied until the same temperature distribution was reached.

At this point it was assumed that the a-c. losses and the d-c. losses were the same. All readings were taken at a distance by telescope to prevent body radiation influencing the thermometers. Accurate speed control of the circulating pump was also in effect although the pump did not add appreciable heat to the water stream and the connections were very well lagged to prevent undue radiation into the constant temperature room.

Another source of disturbance is the change of wave shape of the current in the test sample. Because of the very low losses and the relatively large capacitance the tendency is to seriously accentuate any harmonics that may be present in the voltage wave.

The higher the harmonic the greater the amplification of that harmonic in the current wave. The phase position of the harmonic will also tend to advance beyond its normal position in the voltage wave and the

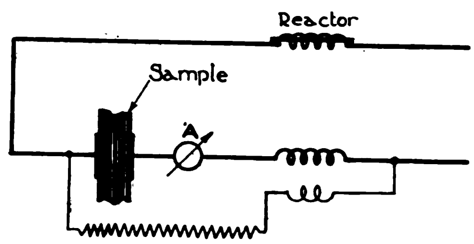

FIG. 7

losses due to the harmonics will in general be enhanced. This tends to reduce the leading tendency of the harmonic so that its phase shift is unknown. If the losses are measured correctly with appreciable wave distortion, the results are not those to be expected from sine wave currents of the fundamental frequency and measured voltage. This distortion of the wave also causes unknown error in the indications because of the unknown amplitude and phase position of these harmonics. A generally useful procedure that obviates this trouble is to obtain the required voltage rise by resonance or to use a reactance of very large value in series with the sample, if resonance is unadvisable. When the samples are small, resonance or a close approach to resonance is impossible or difficult at power frequencies. A circuit diagram is shown in Fig. 7.

In many checks of dielectric loss the shape of the power-factor curve with voltage is of more interest than is an exact knowledge of the actual loss. There is fortunately a fairly simple check that can be applied to a given wattmeter or bridge outfit to show its relative accuracy at varying voltages. This test consists in the selection of four samples of identical capacitance and apparent loss. These samples after check at a given voltage are connected in series multiple and tested at

twice the original voltage. This results in applying the original potential to each sample. The combined capacitance is equal to each of the original samples. Because of the identity of the samples and the application of the original test voltage, the power factor of the group should be the same as the original four samples, and the measured losses should be just four times the loss of any unit at the original voltage. Thus, with an outfit to work to 2500 volts, a comparison of the relative voltage errors of the 400- and 800-, the 600- and 1200-, the 800- and 1600-, the 1000- and 2000-, and 1200- and 2400-volt points might be made. If nine identical samples were available, a check of the 400- and 1200-, and the 800- and 2400-voltage errors might be made, using three series multiple groups and three times normal voltage.

Rural Electrification

BY G. C. NEFF[1]
Member, A. I. E. E.

Synopsis.—*This is a paper on rural electrification, discussing some of the problems connected with this important development. The paper points out the effect of power and machinery on the living conditions of the American farm and the part electricity may play. It discusses the things being done by the agricultural and electrical industries to direct and bring about a proper development of this service.*

According to a report of the United States Department of Agriculture, in the July 1925 issue of *Crops and Markets*, the total gross income of the United States farmers for the year ending June 30, 1925, was approximately twelve billion dollars. This figure includes the value of food and fuel products produced and consumed on these farms. A 1924 report of the Department of Agriculture shows that there are thirty billion man hours of human energy used annually on the farms of the United States and this figure does not include any time allowance for the work done by the women in the house. If the entire gross income of the farms of the United States of twelve billion dollars is used to pay for these thirty billion man hours the hourly wage would be 40 cents. From these earnings the farmers must support and provide for their families, must pay all of the operating expenses in connection with their farms, must pay taxes on property which has a value of approximately sixty billion dollars, and must provide interest on this huge amount of money which is tied up in farm lands and improvements thereon.

The above statement shows that if the farmers of the United States are to be put in a prosperous condition, the hourly wage per worker must be raised. This can be done by either increasing the income or by maintaining the present income with fewer workers. I believe that the latter can be accomplished through a proper and more liberal use of power and machinery. Due largely to wide distribution of electric power by public utility companies, and to the ease with which this power can be automatically controlled, it will play a big part in reducing the number of necessary workers and in increasing general farm prosperity.

A study of general conditions shows that a very close relationship exists between the income of each productive worker and the average amount of mechanical power available to the workers. In China, the mechanical power per worker is very low and the wages are also very low. The average amount of power available to the factory worker of the United States is higher than in any other country in the world and likewise the average wage is higher.

The same relationship holds true in different parts of our country. Again, the United States Agricultural Department Survey shows that the use of power per farm worker in certain southern states is much lower than in certain northern states, and the income per worker is much less in these southern states than in the northern states referred to above. It seems, therefore, that if the average income of the worker is to be raised, it must be through increased production per worker and this can only be done with the help of machinery and this calls for power. Therefore, proper electric power supply on the farm is something which may have much to do with farm prosperity itself.

While many farms are now and for some years will be supplied with electric service from the individual farm lighting units, general and permanent rural electrification will be brought about through a further expansion of our electric public utilities which now so efficiently serve our cities and villages. In fact, this expansion has begun and about four per cent of the United States farmers are now enjoying central station service. It might appear from this that practically nothing has been done by the utility companies in extending electric service to the farms. To correct this impression, please consider the following statements. In that part of the United States lying between the Alleghany Mountains on the east and the Rocky Mountains on the west are approximately 100,000 farms receiving central station service.

On the average, three farms can be served from one

1. Vice-President, Wisconsin River Power Co., Madison, Wis.

Presented at the Regional Meeting of District No. 5 of the A. I. E. E., Madison, Wis., May 6-7, 1926.

mile of rural line. Therefore, there are located in this middle section of the United States approximately 33,000 miles of rural lines. If these rural lines were put into long straight lines, they would extend from Chicago to Tokio on the west, to Constantinople on the east, to the southern tip of South America on the south, and to the North Pole on the north; and there would be enough line miles left over to build a line from New York to San Francisco and back again.

In the more thickly-settled region of the Atlantic Coast and in the region along the Pacific Coast, where electric service is used on farms for irrigation purposes, the number of farmers receiving electric service from central station lines is about equal to the number served in the great middle part of this country. The miles of line on the coast regions which are devoted to rural electric service add greatly to the mileage just described. This shows that an exceedingly large amount of rural lines have been built, that huge amounts of money have been spent, and that an appreciable start has been made in this greatly needed development. The fact that less than four per cent of the farms in this country are served by such a tremendous mileage of distribution lines clearly demonstrates that to extend adequate electric service to a large portion of the farms in this country is a task involving huge sums of money. This fact is fully appreciated and it is with the complete knowledge that the adoption of a wrong policy of development would result in losses very detrimental both to agriculture and the utility industry, and which would also seriously affect other industries, that a very extensive plan of study and investigation has been made in which every angle of the extension of service to the farm and the use of such service is being carefully studied and analyzed. This work is being carried on by representatives of agricultural organizations and agricultural colleges, by agencies of the National and State Governments which have to do with agricultural problems, and by the utility industry and the manufacturers of electrical and agricultural machines and appliances.

This cooperative work is guided by a committee known as the Committee on the Relation of Electricity to Agriculture and through its efforts and the excellent cooperation of various state organizations, there have been established 17 experimental rural lines in 17 different states. These experimental lines really form field laboratories in which to carry on the study of rural electric service. By a joint study of this kind it is believed many mistakes will be avoided which would otherwise be made and, while some mistakes will probably be made, even with the precautions taken, it is believed the major mistakes will be prevented. In the meantime, rural electric service development is going ahead as illustrated by the statistics given above. Thousands of farms are being connected every month and the rate of increase in connection is growing each year.

If rural electric service is to be built on a safe and permanent basis, it must return a profit to the farmer who makes use of the service, and also make a proper return to the electric utility which supplies the service. While there is much to be learned about this new development, those who have studied it most are convinced that both of these two conditions can be met if the development is intelligently directed. By intelligent direction is meant:

(a) Creation of a new department in electric utility organizations, devoted entirely to the proper handling and solving of all rural electric service problems, and made responsible for the direction of the development.

(b) Placing at the head of this new department a man who has had training in agricultural problems and who is sympathetic toward agriculture.

(c) The development of a fair, simple, workable and complete plan under which lines will be extended and service supplied.

(d) The development of a rate schedule which will give the utility proper compensation but which is so made as to encourage increased use by the farmer.

(e) The making of surveys and maps and the collection of such information that the main trunk lines may be intelligently laid out to most efficiently serve the entire rural territory before construction work starts. (This will eliminate much rebuilding, overloaded lines, etc.)

(f) Keeping the rural department fully informed on all experimental and research work now being conducted in agricultural colleges and on the rural experimental lines in many states. This will make possible the most efficient and fullest use of electric service on the farm.

(g) Close cooperation between this rural department and farm customers.

(h) A desire on the part of the utility to supply good and adequate service at lowest cost, and a desire on the part of the farm customer to make fullest profitable use of such service.

In the following "Program for Developing Rural Service" is given a complete plan of operation of a rural department in one of the large utility companies of Wisconsin. This particular department is headed by an agricultural engineer, a graduate of the Wisconsin University, who has had about two years' experience in giving intensive study to electric service on the farm.

Program for Developing Rural Service

Successful development depends upon at least three essential factors:

A. A sound policy of building and financing rural extensions.

B. A rate schedule which fosters large use of current by the farmers.

C. A complete understanding of the rural program and of the reasons underlying its adoption, by every employee who has any direct or indirect contact with rural customers.

I. Planning the Extensions

1. A study of the location of all existing substations at which rural service lines may originate.

2. Decision as to the location of additional substations strategically placed so that the entire territory may be served to the best advantage.

3. The division of the entire territory into definite rural service areas, each to be served by its own substation. The size and shape of these areas will depend on the local conditions.

4. A basic plan or map to be followed in the building of rural service trunk lines. The first of these lines will normally extend through the most thickly-settled areas. These trunk lines should be planned with a view to serving the entire area ultimately, and all building should follow these plans.

Feeders to and stubs from these trunk lines may be built as development progresses.

II. New Rural Customers

1. First, campaign for new rural customers to be made along existing rural lines, in an effort to bring the average of customers per mile as high as possible.

2. Second, effort to be directed along existing pole lines on which it is practicable to string wires for rural service.

3. An intensive canvass of the more promising territories to be traversed by the definitely planned rural service trunk lines mentioned in Section I.

4. Definitely bringing our new rural policy to the attention of each existing rural customer, individually, and providing him with a comparison of rates based on his conditions. This work is to go on at the same time as that mentioned above.

III. Procedure

1. In securing new customers along existing lines, the rural service salesman will proceed as follows:

A. Call on prospect; explain rates and advantages of new rural policy; sign contract in duplicate.

B. Leave one copy of contract with prospect and send other to district office.

C. Make "Rural Prospect Report" in duplicate, sending one copy to local office and other to General office. This will be done whether prospect signs contract or not. Data for this report will be brought out during sales talk.

D. Make daily report showing calls made, contracts signed, miles of line covered, etc.

2. While canvassing the line for new customers, the rural service salesman will also call on each old customer and give him the opportunity to change from old to new rates. The procedure will be:

A, b, c, and d as above.

E. When canvass of line is finished, report length of line, number of old customers, number of new customers, and number of transfers from old to new rate.

3. District and local managers and all others working on rural service extension, but not specifically assigned to that work, will follow the same procedure, omitting (d), the daily report.

4. In extending rural service along existing transmission lines, the following procedure will apply:

A. Decision by engineers as to whether or not it is practicable to carry a rural distribution circuit on the same poles.

B. Estimate of costs by Engineering Department. Since the number of prospects who will become customers is not known, this estimate should show as separate item:

a. Cost of the line itself without transformers, services, or meters.

b. The cost of supplying service to a customer at some specified distance from the line, and

c. The amount to be added or subtracted for longer or shorter service lines.

C. Canvass of prospects by rural service salesmen, district or local managers, or others to create interest, and to discover how many customers may be expected. This makes possible an estimate of the cost per prospective customer.

D. Contracts and reports as detailed above.

5. The location of rural service trunk lines will be made by the Engineering Department in cooperation with the local representative and with the Rural Service Department. The location will depend upon such factors as straightness of roads, tree conditions, villages to be served, lakes, marshes, or rivers to be crossed, density of rural population, soil fertility, farm prosperity, demand for service, etc. When the location of the proposed trunk line has been fixed, procedure will be as shown above in 1 and 4.

IV. Reports to Rural Service Department

1. Daily report of rural service salesman.

2. Rural prospect report to be made in duplicate by any employee who learns of a prospect, one copy to local office, other to general office, Rural Service Department.

3. Completed canvass of rural line showing changes made.

4. Record of proposed location of rural trunk lines with cost estimate.

5. Route all work orders in any way affecting rural customers through Rural Service Department so that needed data may be taken off. Work order to show names of rural customers to be connected or disconnected, phase or service to each, and size of transformer and meter of each. Also estimated contribution to be paid by customer.

6. A complete report by each district manager of current used and bills paid each month by each rural customer.

V. Better Service

1. The closest possible cooperation between Rural Service Department and the Ripon Experimental Line.

2. Study by Rural Service Department of the reports of all electric farm projects and related articles.

3. Securing by Rural Service Department of all possible information relating to the different types and makes of all machines which are likely to be operated electrically.

4. Digests of this literature and of manufacturers' data to be supplied by Rural Service Department to district and local managers; also tables of electric consumption by different machines under various conditions.

5. A careful study of the relation between the appliances used and the resulting current consumption on the average farm. Data for this will come from the rural prospect reports and meter cards. This study will be made by the Rural Service Department and the results will be supplied to all local representatives.

6. The employment of at least one first-class electrical repair man who has a thorough knowledge of really good farming practise; this man to be furnished with a light truck and to travel the rural lines calling on every customer. He will acquaint himself with the needs of the customers, and will seek the best solutions of the electrical problems of each. He will service all faulty equipment, explain ways of making fuller use of electric service, and will carry bulbs and some of the most commonly used standard appliances to supply customers who want them. He must remember that he is a service man, not a salesman, and that he only carries merchandise for the convenience of the customers.

VI. Publicity

1. The discovery and fostering of outstanding examples of the best uses of rural service in each community. Where good farmers can be found to cooperate, each local manager should try to develop electric farms that can be used as object lessons. But this development must not be subsidized.

2. Local managers will place news items in local papers. These will report the addition of new farm customers with brief

statements of how each expects to use service, or tell of the introduction of some novel application, or give definite figures on the performance of some machines, etc.

3. A definite and unified campaign of advertising in farm papers, supplemented by a series of articles explaining the company's policy and the results that may be expected from the use of electricity.

4. Statements of bills as computed under new rates, to be sent with regular monthly bills to old rate customers who would profit by changing to the new rate. Interest on the customers' investment in the line should be included in showing this advantage.

A carefully prepared contract form has been drawn up by this company which gives definite rules under which service will be extended to new farm customers and other customers living in the country. Under these rules, the utility companies finance the rural lines up to an average cost of $400.00 per farm customer whenever the customers agree to comply with certain conditions described in rules.

This contract gives the schedule of rates used in billing as shown in the accompanying table.

RATES FOR FARM CUSTOMERS

(a) Service Charge

Transformer Capacity Required in Kv-a.	Monthly Service Charge
Not more than 1½	$5.50
Over 1½ and not more than 3	6.00
Over 3 and not more than 5	6.60
Over 5 and not more than 7½	7.25
Over 7½ and not more than 10	8.00

If more than two rural customers are served from one transformer, each of them will be allowed a discount on his service charge as follows:

Customers Served	Discount on Service Charge, Per Cent
3	20
4	40
5	50

(b) Energy Charge

For the first 30 kw-hr. used per month....5½ cents per kw-hr.
For all in excess of 30 kw-hr. used per month....3½ cents per kw-hr.

A discount of ½ cent per kw-hr. will be allowed on any bill paid within fourteen days from the date rendered. The rate is made up of a service charge sufficient to cover the fixed costs on the rural extension and an energy rate covering only generating and certain transmission costs. The energy rate is comparatively low and if the farm customer increases the use of energy very materially the addition to the monthly bill will be relatively small. This rate encourages new uses of electric service by the farmers and brings about increased use with decrease in cost per kw-hr. to the farmer. All of which is very desirable to both the farmer and the utility and brings about general satisfaction with the service.

The service charge in this schedule deals almost entirely with the distribution line costs and is based upon an average investment per distribution line of $400.00 per customer. The service charge is intended to cover return on the investment, retirement expenses, taxes, operation, and maintenance expenses. These expenses may be considered as more or less fixed expenses and do not depend upon the amount of energy consumed by the customer. Fixed costs on the investment in power plant and transmission line could be included in the service charge, but in this contract all of these fixed expenses have been included in the energy charge.

The "energy charge" is low and is based upon the production cost plus a certain portion of the fixed charges in transmission lines and generating stations. In arriving at this cost the rural customer has been given the benefit of the system load factory rather than the load factor of the farm electric load. This results in lower costs of energy but it is believed that it is the fair way to handle the situation.

The accompanying table shows the kilowatt-hours used by 1226 farmers served by a Wisconsin company. These farms are largely dairy farms. This table shows that full use is not being made of electric service on the farms listed. A number of the farms shown in the table each use more than 100 kw-hrs. per month and this demonstrates in a practical way that a large use of electric service is possible.

CLASSIFICATION OF RURAL CUSTOMERS BY AVERAGE MONTHLY USE OF ENERGY

Kw-hr. Consumed per Month	Number of Customers	Per Cent of Total Number
Less than 10	123	10
10-19	390	32
20-29	275	22
30-39	158	13
40-49	75	6
50-100	131	11
Over 100	74	6
Total	1226	100

On the various experimental lines previously referred to, the farmers are using from 100 to 500 kw-hrs. per month and the average is continually increasing. It is believed that farm customers, in three or four years, will use on the average 150 kw-hrs. per month and if this can be brought about, those who have been making a study of electric service believe that such service, sold at any fair rate, will be very profitable to the farm customers and at the same time will be a load desired by the electric public utility companies. When this condition has been brought about rural electric service will be established on a sound and profitable basis, and electric service in the country will be taken as a matter of course, much as it is now in the city.

Electrical Communication*

Report of Committee on Communication

H. P. CHARLESWORTH, Chairman

To the Board of Directors:

In presenting this report it is the aim of the Committee on Communication not so much to present a complete report of all the developments which have been made during the last Institute year in the art of electrical communication, but rather to single out those advances which it is thought will be of greatest interest to the members of the Institute.

PRINTING TELEGRAPHY

The year has been marked by a rapid growth in the use of printing telegraph apparatus by the telegraph companies, railroads, news associations for distributing news items, and by general business concerns in connection with private line business. There is a general tendency toward the operation of the apparatus at higher speeds, thus increasing the speed requirements of the line circuits and requiring the use, especially with long and complicated circuits, of repeaters which reform or regenerate the line signals.

Printing telegraphs are now being used in connection with switching arrangements, both manual and automatic. These arrangements have been found valuable for sending information from a central location to one or a number of receiving stations. A recent installation of this type consists of a number of printers controlled by automatic switching apparatus so arranged that any printer equipped with a sending keyboard can communicate individually with any other printer so equipped, or communicate with a group of receiving-only printers. Dials, similar to those used with telephone instruments, are used at the transmitting stations for setting up any desired operating condition.

The ever widening field of usefulness of printing telegraphs was illustrated by a paper on ciphering and deciphering arrangements for secret wire and radio communications read by Mr. G. S. Vernam before the Midwinter Convention of the Institute in New York last February.

In the message business of the telegraph companies there has been a marked tendency to use tape printers instead of page printers. To facilitate the subdivision of the tape into single lengths and the attachment of it to message forms for delivery to customers, effective cutting and gumming devices have been developed.

In addition to the application of tape printers to the Multiplex circuits used in trunk line service, a simplified combination of such a printer with a keyboard transmitter is coming into extensive use for branch office circuits and other short-line service. The application of these printers will probably be quite extensive due to their accuracy, traffic handling capacity, and economy. This type of printer is primarily intended for single-line operation, affording intermittent single-channel service in both directions. It also lends itself readily to use on duplexed circuits when this method is desirable. Printers of this type have a field in private offices of patrons where the amount of business handled warrants their use. Maintenance requirements are few, and the attention required is sufficiently small to make this service desirable.

"TICKER" TRANSMISSION

During the past year the automatic tape transmission system for telegraphic tickers was installed and put into operation at Cleveland, Chicago, Los Angeles, and San Francisco. Long-distance distribution of ticker service was greatly extended from New York, Cleveland, and Chicago.

A particularly note-worthy feature was the establishment of telegraph ticker service in important business centers on the Pacific Coast which heretofore obtained market quotations only by Morse on brokers' private leased wires. Full market quotations are now supplied to Pacific Coast brokers from the New York Stock, New York and New Orleans Cotton Exchanges, and the Chicago Board of Trade. Provision is also made for "dropping" the quotations at various cities along the route of the main circuit which extends from Chicago to San Francisco via Los Angeles, a wire distance of 2895 miles. New York stock market quotations reach the brokers on the Pacific Coast in 30 to 45 seconds from the time that they appear on the tickers in Wall Street.

The system developed for this and similar services elsewhere includes modifications of the two-channel, Multiplex printing telegraph apparatus and repeaters suitable for use on the long lines involved.

The transmitters are controlled by perforated tapes similar to those used in other automatic telegraph systems. Instead of the more familiar five-unit code, a six-unit code is employed, the sixth pulse of each character serving to distinguish between letters and

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*Committee on Communication:

H. P. Charlesworth, Chairman

F. L. Baer,	D. H. Gage.	Lieut. Com. B.B. Ralston,
O. B. Blackwell,	S. P. Grace,	F. A. Raymond,
L. W. Chubb,	P. J. Howe,	Chester W. Rice,
Charles E. Davies,	F. H. Kroger,	J. K. Roosevelt,
H. W. Drake,	N. M. Lash,	H. A. Shepard,
Major P. W. Evans,	Ray H. Manson,	John F. Skirrow,
R. D. Evans,	R. D. Parker,	E. B. Tuttle,
E. H. Everit,	H. S. Phelps,	F. A. Wolff,
L. F. Fuller,		C. A. Wright.

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, June 21-25, 1926.

figures. The receiving instruments at customers' offices are self-winding tickers of a type already widely used in Eastern cities.

The output of the channel printer system in characters per minute per channel is the same as that obtainable with self-winding ticker systems used on shorter circuits having but one channel.

Submarine Telegraphy

The great success of the new type of submarine telegraph cable loaded with permalloy that was mentioned in last year's report has led to the rapid extension of this type of cable, and during the year five important telegraph cables of this type were under construction. The technical features of this type of cable were described in a paper by Mr. Oliver E. Buckley which was presented at the Convention last June and which appeared in the August Journal.

Machine Switching Telephony

With the continued steady growth in the application throughout the country of machine-switching telephone apparatus have come further developments in this form of apparatus. In the panel system, which is the type of system used for large cities, a simplified form of tandem switch has been developed by which, after one selection at the calling office, the final selection of the called office can be made by apparatus located at a distance from the originating office, and used to collect traffic from a number of offices routed over common groups of trunks. This results in a material saving in the trunk plant.

A more efficient method of associating a sender with the calling subscriber has been developed. This results in an appreciable saving in the number of senders required, uses more economical apparatus, and reduces the number of types of apparatus required in an office.

In the step-by-step system, which is the type usually used for the medium and smaller sized cities a line-finder system has been developed which is similar in principle to that being used with success in panel offices. This employs the same selector that is used in the rest of the switching train, effects an improvement in service to the subscriber, and lends itself more readily to efficient equipment layout.

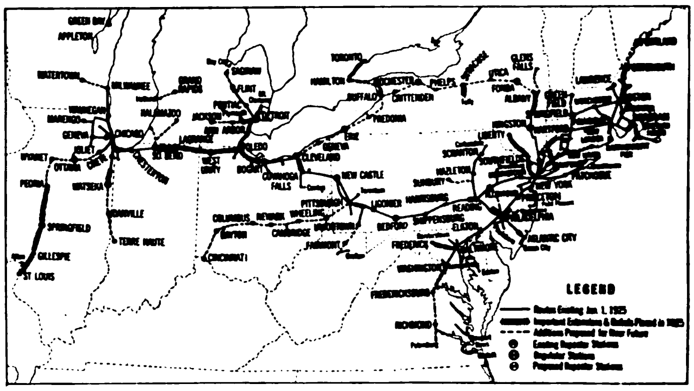
A machine-switching tandem system, employing step-by-step equipment, has been developed for completing toll calls within a 50-mile radius of any given central office area. All calls completed through this system are handled directly by the originating operator over dialing trunks. A tandem system of this kind probably will find its principal application in areas employing step-by-step machine-switching equipment. An installation of this type recently has been put into service in Los Angeles and serves some 75 central offices having a total of approximately 400,000 subscribers. The principal new engineering feature of this system is the means which was developed for dialing and signaling over phantom toll lines.

New types of frames for mounting step-by-step equipment have been developed which take advantage of the ceiling heights ordinarily found in central office buildings, thus effecting a material reduction in floor space requirements.

A cordless "B" switchboard has been developed for completing calls from manual offices to machine offices where the number of manual offices involved makes the use of dialing devices at the manual offices prohibitive in cost. This switchboard employs new trunking principles which result in very efficient and simplified operating equipment.

Telephone Toll Cables

An event of prime importance during the year was the completion on August 11 of the telephone toll-cable system connecting New York and other Atlantic Seaboard cities with Chicago. This system of cables runs from Chicago through South Bend, Toledo, Cleveland, Detroit, Pittsburg, and Harrisburg to Philadelphia and New York, connecting with the cable system extending from New York to New Haven, Hartford, Springfield, Providence, Worcester, Boston, and Albany, and from Philadelphia to Baltimore and Washington. Extensions of this cable westward from Chicago carry the toll-cable system to Milwaukee, and by the end of this year the system will extend to Peoria, Springfield, and St. Louis. Numerous shorter branches carry this network to many other points near the large centers mentioned.



Toll Cable Routes in Northeastern Section of the Country

In addition to this very extensive network in the northeastern part of the country, smaller networks are starting in other parts of the country, notably in various parts of the Pacific Coast and in Florida. The rapidity of growth of this type of telephone plant is illustrated by the fact that during the year 1925 over 1000 miles of toll cable were placed in service, and during the year 1926 more than 1500 miles will be installed. The map reproduced below shows the routes of the present and proposed toll cables.

The possibility of providing satisfactory telephone transmission over very long circuits in cable has come about through a series of remarkable developments in telephony which have been discussed from time to time before the Institute. During the year the network mentioned above was the subject of a paper presented before the New York Section in December by Mr. J. J. Pilliod, and was discussed at other section meetings.

The development of toll-cable networks means a great deal in improving and increasing the service given to the public. Practically the entire country is subject to severe sleet storms from time to time and toll cables furnish a means for providing great security against interruption from such storms or other weather conditions. Furthermore, they furnish a practical solution for meeting the very great demands for service between large urban centers of the country. A single cable contains between 200 and 250 telephone circuits and would require five or six open-wire toll lines with former methods of construction, the largest number of circuits which can be provided by this means; furthermore, furnishing means for supplying circuits so liberally as to give a faster service. As indicative of the increased facilities provided, it may be mentioned that the New York-Chicago toll-cable system contains about 510,000 miles of wire, while at the time this project was started, the facilities for serving the corresponding points consisted of less than 100,000 miles of open wire.

In last year's report reference was made to certain papers describing the development of telegraph systems suitable for use in long telephone cables. The application of these systems has been considerably extended during the past year. The voice-frequency carrier system is of special interest, since, through the development of apparatus for separating to a very high degree currents of different frequencies, it has become possible to operate 12 independent telegraph circuits over a single telephone cable circuit, each of the 12 circuits using a different frequency ranging from 425 to 2300 cycles per second. There are now in operation about 25,000 channel miles of telegraph circuits operated by this system in the telephone cable plant.

Radio Telegraphy

A new radio telegraphy service between the Dutch East Indies and San Francisco has been established, and a new service from New York to Holland has been introduced for handling through traffic from Java.

The work of decreasing the use of spark transmitters with their corresponding interferences, commenced in 1924, has progressed rapidly to such an extent that over 150 American merchant ships are now equipped with tube transmitters.

The use of the radio direction finder for navigation is rapidly increasing and has passed the experimental stage. The Great Lakes are leading in this respect, due to the demonstration of the particular value of this apparatus in the difficult navigation problems inherent in the Great Lakes.

Transatlantic Radio Telephony

The development work which has been in progress during the past few years on transatlantic radio telephony reached a point of considerable interest last winter in the attainment of two-way telephonic conversations. In the earlier tests, telephonic transmission had been but one-way, from the United States to England, with the study of transmission of radio waves in the reverse direction being made by the utilization of radio telegraph stations in England. Two-way talking was made possible the winter of 1925-26 by the completion of a transmitting station by the British General Post Office. The British radio telephone transmitter is, in general, similar to that employed on the American side. Both transmitters are of the carrier-suppression, single-side, band type, which makes the maximum use of the transmission power and which minimizes the frequency band which is required. Receiving on both sides is carried out by means of directional receiving antennas of the wave-antenna type. Reception on the American side has been further improved by establishing a receiving station at a higher latitude where the atmospheric interference is less, located at Houlton, Maine. The Houlton reception is extended into New York by means of wire telephone circuits. Likewise, the voice currents originating in New York are transmitted to the Rocky Point transmitting station over wire circuits. Similarly, in England the radio transmitting and receiving stations are connected into London by telephone circuits. In this way, an integral two-way circuit is established with New York, and London as the terminals.

The carrying on of two-way talking tests between England and the United States created much general interest and arrangements were made to enable a group of American Press representatives in New York, and a similar group of English newspaper men in London, to participate in the tests by conversing with each other. These tests represent the first time that groups of people have been able to converse with each other across the Atlantic.

Papers by Messrs. A. A. Oswald, J. C. Schelleng, and R. A. Heising, describing important technical features of the apparatus used for transatlantic radio telephony were published in the June 1925 *Proceedings* of the Institute of Radio Engineers.

Radio Propagation Tests

A great deal of activity has been shown in studying the properties of the medium, intervening between transmitter and receiver, through which the radio waves must pass. This information is essential before we can utilize, to the best advantage, this remarkable but eccentric medium which nature gives us.

Extensive propagation tests have been reported on

long, medium, and short wave lengths, together with a large amount of theoretical work towards explaining and correlating the apparently contradictory behavior found in different parts of the radio spectrum. This work has confirmed the existence of a positive ionization gradient in the upper atmosphere, postulated independently, many years ago, by Kennelly in this country and Heaviside in England.

The Naval Research Laboratory published the results of experiments which indicate that short waves may, in effect, hurdle the first few hundred miles of their journey and be received at a distant point with a much greater strength than would be expected from the past experience with long waves. In the range of frequencies under exploration (down to about 30 megacycles, or 10 meters) the "skipped" distance appears, in general, to increase with increase of transmission frequency and to be greater at night-time than at day-time. These results have been confirmed by other experimenters. Theories have been proposed (among others, by Baker and Rice in a paper presented before Midwinter Convention of the A. I. E. E., 1926) to explain these phenomena which assume that waves received at a distance are deflected downward from some upper ionized region of relatively low index of refraction and of low attenuation.

The observed indications of rotation in the plane of polarization and directional errors find a qualitative explanation when due account is taken of the fact that the earth's magnetic field, acting upon the free electrons, will change the velocity of the wave and produce rotation. This effect is especially marked in the vicinity of 214 meters, which corresponds to the resonant frequency of an electron in the earth's magnetic field.

Careful investigations of fading and signal distortion, so exasperating to the broadcast listener, have shown that they are closely related to the high degree of frequency selectivity exhibited by the radio medium.

During the total eclipse of January 24, 1925, many observations were recorded which further tended to confirm the recent electron dispersion theory of the radio medium.

An observed variation of signal strength during magnetic storms is also significant. Here the effect is a reduction of the normal signal strength by night and an increase above normal by day.

Increasing use is being made of the short wave range of frequencies as is evidenced by the continued increase in the number of short wave licenses issued to commercial concerns. Experimental work indicates the possibility of twenty-four-hour telegraph service with short waves over distances of several thousands of miles. The transmission varies largely with the time of day, however, one frequency transmitting much better for one period of the day and another frequency for another period, so that the use of several wave frequencies appears to be required to give uniform operation.

Radio Broadcasting

Continued improvement has been made in radio broadcasting on both the receiving and the transmitting sides. The receiving set improvements are, in general, characterized by better quality of reproduction, which means higher grade amplifiers and better loud speakers; but there is still much to be desired in these respects in receiving sets as a whole. The fact that the reliable, high-quality service range of the average radio broadcast transmitting station is relatively short is being more generally recognized and is leading to a more extensive use of long distance wire lines for enabling good programs to be made available at a number of widely separated broadcast stations, and is leading also to the use of greater power in transmitting. As many as 17 stations, spread over the northeastern quarter of the United States, are now regularly supplied for a portion of their time with programs transmitted over special long-distance wire circuits. A number of stations are now transmitting with five kw. power, and one station which is capable of transmitting with as much as 50 kw. has been established during the year.

Another important improvement in radio transmitting stations introduced during the year is the use of master oscillators with piezoelectric frequency control for the purpose of reducing quality distortion in the received signals. In general, there was a considerable improvement in the maintenance of the frequency assignments of broadcast stations, due to a more general appreciation of the need for frequency stability and to the efforts of the Radio Inspection Service in checking up conditions and of the Bureau of Standards in the work of frequency standardization.

The problem which exists in the regulation of radio, in the general public interest particularly in the allocation of wave bands, has been reflected in submitting to Congress several bills designed to strengthen the Government's control of radio, and by the holding of the Fourth National Radio Conference at Washington during the fall of 1925. This Conference recognized the fact that the number of transmissions which can be accommodated in the range of frequencies available for broadcasting is definitely limited, and recommended that the Department of Commerce undertake to limit the number of broadcast stations to be licensed.

Electrical Transmission of Pictures

The commercial service for the transmission of pictures by wire between New York, Chicago, and San Francisco, has continued throughout the year. The results have been promising and it has been decided to add five more complete stations to the picture-transmission network. This extension should enable a thorough test to be made of the commercial demand for this type of service.

An interesting experiment was conducted for the U. S. Signal Corps, in October 1925, when pictures

were taken from an aeroplane over Fort Leavenworth, Kansas, developed on the plane, dropped by means of a parachute, and transmitted from Fort Leavenworth to New York, Chicago, and San Francisco, simultaneously. The entire experiment was so successful that army officers in New York City viewed the picture 29½ minutes after the snapping of the camera on the plane at Fort Leavenworth, approximately 1500 miles away by wire. This is an indication of the usefulness of telephotographs for war purposes.

During the year from March 1925 to 1926, a series of tests of radio transmission pictures has been conducted between Carnarvon (Wales), San Francisco, Honolulu, and New York. Specific mention should be made of the pictures sent by radio from Honolulu to New York during the Naval maneuvers of our fleet there in May 1925. As a result of the successful completion of this experimental work, commercial service has been established between England and New York and also between Hawaii and San Francisco.

Inductive Coordination

Last year, the report of the Committee announced the formation of the American Committee on Inductive Coordination, embracing representatives of all wire-using utilities interested in this problem. During the year, the committee has issued a very complete and extensive bibliography of publications bearing on inductive coordination. This bibliography includes not only American, but also foreign references and contains a total of about 900 items. It is expected to be of great value to all concerned with inductive coordination work. Another item of interest in this field is the issuance of a report by the joint, general committee of the National Electric Light Association and the Bell Telephone System, covering the principles and practises adopted by those organizations for the joint use of wood poles by supply and communication companies.

During the year this joint general committee continued its progress in research work on a large number of specific problems in inductive coordination. The study of these problems has been facilitated by the development of improved measuring apparatus and methods particularly adapted to the wave analysis of power-circuit voltages and currents and of induced voltages and currents in telephone circuits.

Two papers dealing with the subject of inductive relations between power-distribution circuits and telephone circuits were presented at the Seattle Convention in September, in connection with a symposium on power-distribution.

Telephone Service for the Deaf

Another interesting telephone development relates to improved service for deaf people. Many partially deaf people, who have difficulty in hearing ordinary conversations, use the telephone with ease. Others, who are somewhat more deaf, however, have not been able heretofore to use the telephone. In order to make the telephone service available in these special cases, apparatus which greatly increases the volume of sound received has been developed for the use of deaf people. Although in cases of extreme deafness, no amplification of sound, however great, makes hearing possible, this new device makes it possible for many people of impaired hearing who would otherwise be unable to use it to obtain telephone service. The apparatus is designed, of course, only for those having impaired hearing.

Characteristics of Speech

The work carried on by telephone research engineers, in the study of the characteristics of speech, has continued to produce important and interesting results which have been described in a number of publications during the year. Of particular interest is the paper published in the A. I. E. E. Journal for March 1926, by Messrs. Maxfield and Harrison entitled "Methods of High Quality Recording in Reproducing of Music and Speech Based on Telephone Research." This paper tells of the application to the improvement of phonographic reproduction of speech of some of the methods developed in the study of the quality of telephone transmission.

Loading of Telephone Circuits

The year 1926 marks the completion of the first 25 years of the application of loading to telephone circuits, in the form of inductance coils inserts in the line at periodic intervals. A paper presented by Shaw and Fondiller at the Midwinter Convention reviewed the progress which has been made in this country, in both the development and application of loading, covering particularly, the last 15 years. The outstanding developments in that period are the compressed-powder iron-dust core material, the loading systems for the long toll cables and the more economical systems for local exchange area trunk circuits. The extent of the application of loading is indicated by the estimate given in that paper, of 1,250,000 loading coils in this country, as of January 1, 1926, and by the expectation that this number will be doubled by 1930.

Fire-Alarm, Police-Signal, and Train-Control Systems

The National Fire Protection Association has continued its work of standardizing and improving emergency signalling systems. At its last annual convention, completely revised "Regulations for Municipal Fire Alarm Systems" and partially revised "Regulations for Protective Signalling Systems" were adopted, and work for the further revision of the latter regulations has been carried on throughout the year.

The International Association of Municipal Electricians has continued the compilation and promulgation of standard specifications for wires and cables for municipal signalling. Important additions were made to these specifications during the past year.

Another important development has been the completion of arrangements by some leading railroad systems for automatic train-control systems. This promises to become a very important field of operation.

The field of police emergency signals and traffic signals is constantly growing in importance. Many cities are now installing an elaborate system for one or both of these. In some cases, the systems include a combination of police-alarm, fire-alarm, and traffic signals, whereby officers on traffic duty may receive due warning of fires and escape of bandits in automobiles, and thus facilitate the movement of fire apparatus in the one case and block all traffic in the other. Further advances have been made also in the installation of extensive modern manual fire-alarm systems in a number of important cities.

Can the University Aid Industry?

BY BENJAMIN F. BAILEY[1]

Fellow, A. I. E. E.

AT first the author was inclined to reverse the title and make it read "Can Industry Aid the University?" There is no doubt in his mind that the engineering professor should have active and continuous contacts with industry. It is generally agreed that it is impossible for a school to teach engineering applications in detail. The field is altogether too broad and the variety of positions which students fill after graduation is so great that any attempt to fit a man to fill a particular position upon graduation must result in failure. The university can and should attempt to give a thorough foundation in the fundamentals underlying engineering and if this is well done it will require easily all the available time.

From this it might seem that if a teacher is well grounded in the fundamentals, he has all the necessary qualifications. To keep the interest of the student, however, and prepare him for his life work, the application of these principles to specific problems must be continually emphasized. If a teacher lacks definite personal knowledge of at least one field of engineering practise, he is seriously handicapped in his attempts to show how the fundamentals of physics, mathematics and economics may be applied to engineering practise. Moreover, the interest and ambition of the student is more easily aroused if he feels that his instructor has personal knowledge of the things about which he is talking. If the proper attitude on the part of the student is secured, the other problems of engineering education will largely take care of themselves.

Another reason for encouraging the teacher to make practical use of his knowledge and experience is that he may increase his income. Everyone knows that the salaries paid university professors are, in many cases, low as compared with the incomes that the same men could earn in industry. Under present circumstances in the colleges if the best teachers are to be secured and held there must be some way for them to earn something outside of their university salaries. Those who have been responsible for the conduct of departments of instruction have many times had the experience of losing their best men when they were offered twice as much salary by industry.

The author believes that there is a growing spirit of cooperation between industry and the universities. This is due to a number of causes. Doubtless the work of college professors during the war had a great deal to do with it. There are numerous instances of supposedly impractical professors who turned out to have the finest kind of executive ability and who were able to apply their theoretical knowledge to practical affairs upon short notice.

The decrease in the relative number of consulting engineers may have helped to foster this cooperation. The fact that the customer can obtain excellent engineering advice free from most of the large electrical companies has tended to deter men from becoming consulting engineers. Many problems, however, come up which cannot well be handled by reference to some manufacturer and if consulting engineers are not available, the work is likely to be turned over to a teacher of engineering.

Relatively, at least, the importance of the individual inventor seems to have decreased. It is coming to be more and more apparent that many problems are of the type best handled by scientists rather than by inventors and again the work is likely to be turned over to a teacher of engineering.

A third reason is the notable work accomplished by the research laboratories established by many of the larger electrical companies. The pronounced commercial success of many of the devices developed in such laboratories has shown the value of scientific services to the smaller manufacturers.

Whatever may be the cause, it seems to be a fact that so much work of a scientific nature is brought to the universities that it may not be long before the handling of this work will constitute a real problem.

For a great many years past, the Engineering Department of the University of Michigan, under the leadership of Dean Cooley, has encouraged the faculty to make contacts with industry. The question as to

1. Professor of Electrical Engineering, University of Michigan, Ann Arbor, Mich.

Presented at the Regional Meeting of District No. 5 of the A. I. E. E., Madison, Wis., May 6-7, 1926.

how far this sort of work should be encouraged was once raised and the regents of the university passed resolutions intended to clarify the situation. These were to the effect that the faculty of the Department of Engineering was encouraged to accept work of the proper character to as great an extent as possible without interfering with their regular work of instruction. They were given permission to use their offices and the laboratory facilities of the university for the carrying on of such work. It was clearly indicated that the work undertaken must be of more than routine character and that the amount and type of such work must meet with the approval of the Dean of the department.

The work offered to the university usually falls in one of three classes.

a. Routine tests of materials and apparatus
b. Engineering advice
c. Research problems

A. Work of the first class has been discouraged, although not entirely prohibited. It frequently happens that a manufacturer wishes a particular test made and no other agency is prepared to do the work as quickly or as economically as the university. Not infrequently the university is asked to undertake work of this character because an absolutely impartial test is desired. With these facts in view, it does not always seem wise to refuse work of this character. When it is possible, however, it is turned over to the younger men to whom the experience is probably of some value.

B. The type of work called *engineering advice* requires a distinctly higher grade of ability. A number of professors have performed notable services in connection with appraisals of railroads, telephone companies and power plants, by acting as expert witnesses in patent suits, by advising with municipalities regarding important bridges, roads and other public works, and by acting as consulting engineers to various manufacturing plants, as well as in numerous other ways. Many of these contacts have resulted in men being enticed away from the university by the offer of large salaries. In some cases these men have been lost permanently to the teaching profession; in other cases "leave of absence" for one or two years has been granted and the man has willingly returned to resume his university duties.

C. A considerable amount of research work has been carried out also; sometimes this is done for pay at the request of some manufacturer, but more often is undertaken merely on account of real interest in the work or with the hope that a good piece of work will result in promotion. Naturally most of us tend to concentrate on work which is paid for in cash as well as reputation, rather than on that which is paid for in reputation only. Nevertheless, some notable work has been done and if time were available, it would be interesting to list some of the papers published, dealing with research work accomplished at the University of Michigan.

Interest in research, particularly in applied research, has been stimulated by the establishment of the Department of Engineering Research in 1920. Some three or four years prior to this time, a group of engineering alumni proposed that the university establish such a department, and this was brought to a head a little later by a request from the Michigan Manufacturers Association. The manufacturers felt very strongly that such a department would be of distinct assistance to the industries of Michigan and other states, and that, in turn, industry might help the university. These concerns pointed to the large sums of money spent in agricultural research and, while admitting that every penny of this was well spent, insisted that money might be spent to equally good advantage to aid industry. The department has had a steady growth and the amount of work done has increased, until this year it is expected that approximately $100,000 will be paid into this department by industry for services rendered.

In establishing this department, a large number of perplexing problems had to be met. One of the first referred to the fees which should be charged for work done. It was universally agreed that the manufacturers requesting services should pay for them. The person doing the work receives a compensation approximately equal to that which he would receive for the same work done for the university. In addition an overhead charge of from 20 to 50 per cent is made to cover, at least partially, the use of laboratories and equipment and the cost of shop service, electricity, gas, air or other sources of energy.

The question of the character of work to be undertaken also demanded serious consideration. The policy of the department is to discourage routine tests as much as possible. If requests for such work come in, the inquirer is advised of the existence of commercial laboratories capable of doing the work requested. If it appears, however, that, fors ome reason or other, the work cannot be so satisfactorily accomplished elsewhere, the Department occasionally accepts such work. The percentage of tests in which no critical judgment is required, however, is very small.

On the other hand, the department fosters work of a research character and work in which judgment and engineering experience is definitely required.

The question of patents has proved to be perhaps the most perplexing of all the problems confronting the department, and the policy to be adopted has not yet been entirely settled. One proposal made was that if, in the course of a research, patentable inventions were made, the patent or patents were to be taken out at the expense of the university and thrown open to the use of the public without charge. To most of the members of the department, this did not appear to be a wise policy. It seemed that the manufacturer who supplied the funds for the investigation and the man who made the invention both deserved some reward. Since it furnished the facilities, the university, was also entitled to consideration. Moreover, if a patent were thrown

open to anyone it is quite likely that no one would use it. The reason, as most engineers know, is that when an invention has been made, the trouble has just started. Almost invariably it is necessary to invest a large sum of money in developing the invention, putting it in form for economical manufacture and educating the public to use the new product. Since proportions and designs cannot be protected by patents (to say nothing of the desire aroused by advertising to possess the new article) a manufacturer might expend large sums in developing an invention and then be at the mercy of anyone who wished to steal the results of his efforts. Under such conditions a meritorious invention might never be put to practical use.

It was considered inadvisable also to allow patents taken out in the course of an investigation to be assigned exclusively to the manufacturer financing the work. An invention made in the course of research would be in the nature of a by-product and, in general, would not be expected when the work was started. It was thought that if some invention of great value should sometime appear, the university might be severely criticized for allowing it to fall into the hands of a single individual or corporation.

The plan tentatively adopted provides that patents may be taken out by the inventor with the consent of the Board of Regents and at the expense of the person financing the investigation. All inventions are to be assigned to the university with the understanding that the manufacturer involved will have first consideration in the case of the sale of the patent or the granting of licenses under it. It is also understood that in case an invention prove valuable, the inventor may expect to profit to some extent. A number of patents have been applied for but in no case has the point been reached where this problem has had to be frankly faced. Under the present scheme the manufacturer is obliged to pay the expenses of taking out the patent and has no definite assurance as to what interest he will have under it. Neither has the inventor any assurance as to what returns he may expect.

The actual work of investigation under the Department of Engineering Research is carried out very largely by the teaching staff of the Engineering Department. There are, however, a few men who devote their entire time to this work. These men hold similar rank to men of the same attainments in the engineering college. The titles used are investigator, associate investigator, assistant investigator, research assistant, and assistant.

One of the first questions of policy to be settled when the Department was organized was whether or not a manufacturer might obtain data for his exclusive benefit. It was definitely determined from the first that the results of all investigations were to be made available ultimately, but publication is necessarily deferred for some time. Within the past year, the department has begun the publication of a bulletin in which the results of investigations are available to anyone interested.

The department is now undertaking the direction of a Meter Testing Laboratory in the Department of Electrical Engineering. This is somewhat of an extension of the original scope of the work of the department since the work of checking meters and instruments can hardly be considered as research. This laboratory was established at the request of the Detroit Edison Company and the Consumers Power Company as a convenience to the Public Utilities of the State. It was thought that the actual administration could most readily be carried out through the Department of Engineering Research. When this laboratory is in operation, the Public Utility Companies will be able to obtain prompt tests upon the accuracy of voltmeters, ammeters, wattmeters, current and potential transformers, and rotating standard watthour meters.

It is believed that the future work of the Department of Engineering Research will lie largely in cooperative research. In Michigan, there are a number of industries each carried on by a large number of manufacturers. Familiar examples are the furniture industry, the beet-sugar industry, the automobile industry, the paper industry and many others. In some of these, very little is done in the way of research, and it would seem that the manufacturers could well afford to cooperate to the extent of financing extensive research work. Some progress has been made in this direction, but naturally it will require time to interest enough manufacturers in each line to make the scheme a success.

The department also plans, as far as its finances will permit, to carry out researches in both pure and applied science upon its own initiative. A number of problems immediately suggest themselves which might well be the basis of extensive work and which promise ample returns for the money invested. In the case of some of these problems no one manufacturer is sufficiently interested to finance the work with the understanding that all results will be public property. Before very much can be done along these lines the department will have to secure more adequate financial support. At present, the State of Michigan spends, yearly, about $250,000 upon agricultural research. Every penny of this is undoubtedly justified. The value of the agricultural products in the State of Michigan is approximately $600,000,000 per year, but the value of the manufactured products is $3,500,000,000, or nearly six times as much. If engineering research received financial support on the same basis as agricultural research may it be seen that there would be approximately $1,500,000 available per year. It is to be hoped that in the near future this work will come somewhere near to securing the support it deserves.

Some mention of several notable investigations already undertaken by the department may be of interest.

Natural Lighting. Work has been going on for about

two years upon the subject of day lighting. Apparently very little had previously been done along this line and the importance of the work is obvious.

Natural Ventilation. A similar investigation was carried on to determine the extent to which ventilation occurs naturally in factory buildings. This is another subject upon which little or no data were available.

Bearing and Gear Noises. Some very interesting work has been done upon the sources of noises in machinery and the methods of measuring noises. A very ingenious device has been developed by which quantitative readings of noise may be made and some advance has been made in locating the source of noises in roller bearings and gears.

Single-Phase Motors. Work has been carried on for about three years upon the subject of single-phase motors, and considerable progress has been made in developing a new type of single-phase motor.

Cutting of Metals. A fundamental research is in progress upon the art of cutting metals with particular reference to milling cutters. A method has been developed for determining accurately the forces involved in action of a single tooth of such a cutter.

Industrial Waste Disposal. This work was undertaken at the request of the City of Flint, where the subject of waste disposal has assumed great importance.

SUMMARY

The writer believes that a distinct advance has been made within the last few years in the relations between the University and Industry. It is hoped and believed that this tendency to cooperate will continue and will be of great advantage to both parties to the transaction.

DUCTILE ARC WELDS

A step forward in the utilization of the heat of electric arcs in the joining of metal parts or the building of metal structures—another step toward the day when the pounding, noisy riveter will resign in favor of the quiet electric welder for most work—has been taken in the development of two methods of producing ductile welds. The one was developed by Dr. Irving Langmuir in the Schenectady research laboratory of the General Electric Company; the other almost simultaneously in the Thompson research laboratory of the company at Lynn, Massachusetts, by Peter Alexander.

In both processes, while the welding is being done, air is excluded from the metal at the joint by means of a bath of hydrogen or other suitable gas. The formation of oxides and nitrides which are objectionable, in the weld metal, is thus prevented; the fused metal is as strong and ductile as the original metal.

Dr. Langmuir's study of lamp filaments in hydrogen was a theoretical investigation. Now, fifteen years later, the results have been applied in a different field—in the development of a new and improved method of welding.

Continuing the theoretical investigation, Dr. Langmuir found that more atomic hydrogen was formed by passing a powerful electric arc between tungsten electrodes in hydrogen at atmospheric pressure. By directing a jet of hydrogen from a small tube into the arc, atomic hydrogen could be blown out of the arc, forming an intensely hot flame of atomic hydrogen burning to molecular form and liberating about half again as much heat as does the oxy-hydrogen flame.

By using such a flame of atomic hydrogen, iron can be welded or melted without contamination by carbon, oxygen or nitrogen. Because of the powerful reducing action of the atomic hydrogen, alloys containing chromium, aluminum, silicon or manganese, can be welded without fluxes and without oxidation. The rapidity with which such metals as iron can be melted exceeds that in the oxy-acetylene flame, so that the process promises to be particularly valuable for welding. Either alternating or direct current can be used with this process.

In testing welds made by this process, the welded portions have been twisted and bent double without cracking or otherwise being injured. Such results have not been attained with the ordinary arc weld, since such welds are usually brittle because of the presence of nitrides or a thin film of oxide or scale, avoided in the new process by the presence of the hydrogen.

The process developed in the Lynn laboratory is based on the utilization of the chemical and physical properties of hydrogen and other gases in the molecular state. This process aims primarily at the prevention of the formation of the nitrides and oxides in the arc-deposited metal, which limit the ductility of the usual arc welds.

In this process the arc is struck between the metallic wire or carbon used as one electrode and the plate or work to be welded used as the other electrode. The crater of the arc is always on the work to be welded. The gaseous atmosphere is supplied in the form of a stream around the arc. Pure hydrogen, water gas, hydrogen-nitrogen mixtures, anhydrous ammonia, methanol vapor and some other gases can be used, according to the nature of the work. The process makes arc welding more efficient, and suitable for fields which at present are out of its reach. Low-carbon steel, alloy steels, and most of the non-ferrous alloys can be welded with success by this process in suitable gaseous mixtures.

From *Research Narrative* No. 115.

Abridgment† of

The Use of the Dynamometer Wattmeter for Measuring the Dielectric Power Loss and Power Factor of the Insulation of High-Tension Lead-Covered Cables

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Associate, A. I. E. E.

***Synopsis.**—The use of the dynamometer wattmeter for measuring the dielectric power loss and power factor of cable and capacitor insulation is not new, but dates from about 1890.*

Dynamometer wattmeters as available today are suitable for making these measurements. Care and attention must be given to their application.

The usual methods of application are:

1. Compensated dynamometer wattmeter method, with air capacitor,

2. Inductance variation method (phase-defect compensation method), with air capacitor,

3. Series resistor and wattmeter method,

4. Resonance wattmeter method.

Comparative measurements of dielectric power loss and power factor of cable samples indicate that results are being obtained with the dynamometer wattmeter wherein the probable departure from the true value is within from 10 to 20 per cent.

There is need for an effective means of standardizing any measuring equipment. Study of the calorimeter method for this purpose seems desirable.

* * * * *

INTRODUCTION

PRESENT-day purchase specifications for high-tension lead-covered cables contain clauses limiting the values of the dielectric power loss and power factor of the insulation; these properties must therefore be measured either on the factory product in reel lengths, or on samples cut therefrom, or on both as may be specified. The dielectric power loss is the total power consumed in the insulation, and is expressed in watts. The power factor of the insulation is the ratio of the dielectric power loss to the product of the voltage across the insulation in volts and the resulting total current in amperes. The measurement of the dielectric power loss and power factor of the insulation therefore involves either (1) the measurement of the power, voltage, and current from which the power factor may be calculated; (2) the measurement of the power factor, voltage, and current from which the power may be calculated; or (3) the measurement of the power and reactive volt-amperes from which the power factor may be calculated.

The range of the values to be measured for present-day, single-conductor cables up to 43-kv. rating, conductor to sheath, (75-kv. between lines, three-phase), and three-conductor cables up to 33-kv. rating between treated paper-insulated conductors, is shown in the following:

Values for samples, 10 ft. of lead

Range of Impressed Voltage, 5 to 100 kv.
Range of Temperature, 20 to 100 deg. cent.
Dielectric Power Loss, 0.05 to 25 watts
Leading Current Power Factor, 0.002 to 0.10
Charging Current, 1.5 to 20 mil-amperes

For factory lengths which frequently extend up to 750 ft., the values of dielectric power loss and charging current are proportionately greater for the same voltage. The values of power factor remain the same.

The measurement of such low values of power and and power factor over a relatively wide range of voltages extending to high values is not simple, but requires special equipment. The instruments available for such measurements are the dynamometer wattmeter, the electrostatic wattmeter, and a-c. bridges. It is the object of this paper to discuss particularly the use of the dynamometer wattmeter in making these measurements.

THE DYNAMOMETER WATTMETER

A dynamometer wattmeter is one which depends for its action upon the electromagnetic interaction between sets of fixed and moving coils, one set being traversed by the circuit current (or a current proportional to the circuit current) and the other set by a current proportional to the circuit potential. The external resistor is usually considered as an integral part of the instrument potential circuit. Most present-day wattmeters for switchboard and portable use are of the dynamometer type, the moving coils being supported between jeweled bearings. For measurements of dielectric power loss in cable insulation where the power to be measured is of very low value, a sensitive dynamometer wattmeter is used in which the moving coils are delicately suspended by a fine filament. The deflections are read from a scale set at some distance from the instrument and traversed by a light beam reflected from a small mirror carried on the moving system. There are usually two complete elements connected in series, one element being mounted above the other, the upper and lower elements being of opposite polarity thus making the

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instrument astatic so as to eliminate errors due to external magnetic fields. Such an instrument is called an astatic reflecting electrodynamometer wattmeter, but it is usually referred to in connection with cable testing as a dynamometer wattmeter. A commercial form of an astatic reflecting electrodynamometer wattmeter is shown in Figs. 1 and 2.

Use of the Dynamometer Wattmeter

The use of the dynamometer wattmeter is not new, but on the contrary is quite old. Its introduction is generally attributed to Professors Ayrton and Perry in 1881. In 1899, Rosa and Smith[1] published results of their measurements of dielectric power loss and power factor of capacitors using a resonance wattmeter method and using a calorimeter method, and following these in 1904 Dr. Rosa[2] published his further work in measurements made upon capacitors and circuits of low power factor using a dynamometer wattmeter with different methods of application, some of which are employed today in measuring dielectric power loss and power factor of cables. In 1901, Dr. C. V. Drysdale[3] described a dynamometer wattmeter of his own design, and at that time wrote the theory of

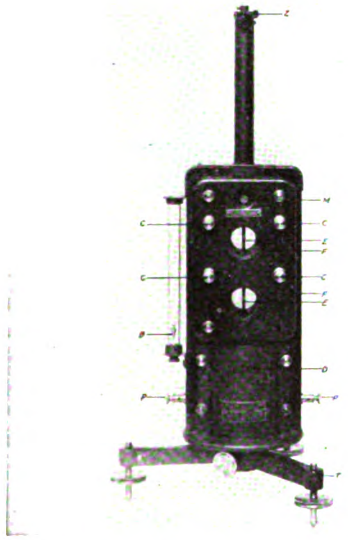

Fig. 1—Astatic Reflecting Electrodynamometer Wattmeter

B Plumb bob
C, C, C, C Current terminals
D Damping chamber
E, E Moving coils
F, F Fixed coils (Field coils)
M Mirror
P, P Potential terminals
T Tripod
Z Zero Setter

the a-c. wattmeter which is still in use today. In the same year Dr. Drysdale[4] described the results of his measurements, using his dynamometer wattmeter to determine the dielectric power losses in capacitors and cables. At about this same time, instruments such as shown in Figs. 1 and 2 were developed and have been improved with the progress of the art.

From these early days to the present it is possible to trace the use of the dynamometer wattmeter for measuring dielectric power losses in capacitor and cable insulation through the writings of such men as Heinke[5], Potts[6], Mordey[7], Apt and Mauritius[8], Semenza[9], Humann[10], Hochstaedter[11], Shanklin[12,13], Farmer[14], Renneson[15], Frigon[16], Barbagelata and Emanuele[17], Granier[18], Marbury[20], and Bruckman[21], and still this list is quite incomplete. The work by Carrol[19] and others in measuring corona losses in high-voltage transmission lines deserves mention in this regard.

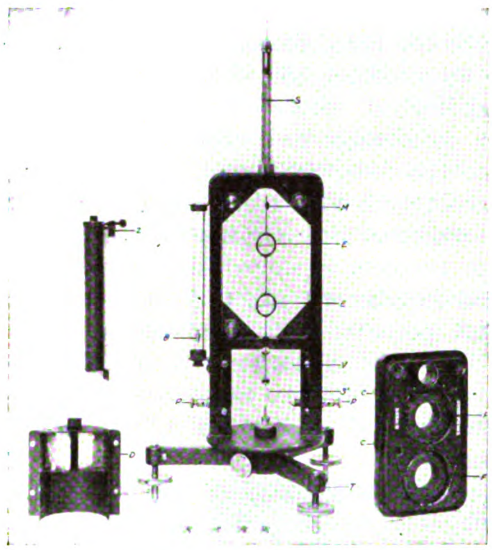

Fig. 2—Parts of Astatic Reflecting Electrodynamometer Wattmeter

B Plumb bob
C, C Current terminals
D Damping chamber
E, E Moving coils
F, F Fixed coils (Field coils)
M Mirror
P, P Potential terminals
S Suspension
S' Spiral
T Tripod
V Damping vanes
Z Zero setter

The use of the dynamometer wattmeter for these measurements is thus seen to be quite firmly established. The theory of the instrument has been adequately stated by several writers[27,28,29]. Instruments are commercially available in which the inherent errors have been reduced to the minimum consistent with good instrument design. The problem in connection with measurements of dielectric power loss and power factor of cable insulation becomes, therefore, mainly a problem of correct application.

Application of the Dynamometer Wattmeter

In applying the dynamometer wattmeter to the measurement of dielectric power loss and power factor of cable insulation, means must be provided for supplying current to the current circuit of the dynamometer and potential to the potential circuit of the dynamometer, so that these will represent the cable-circuit current and potential in known proportionate value and in phase. Dynamometer wattmeters are usually supplied with a current circuit of suitable rating for direct connection into the cable circuit. If this condition is

1. For all references see Bibliography attached to original paper.

not satisfied and a shunt is required, then compensation must be made for any difference that may exist between the phase angles of the shunt and the current circuit of the dynamometer in addition to the usual compensation for differences in temperature coefficients. On the basis that it is desirable to eliminate cause for compensation wherever possible, it would appear that the use of a directly-connected current circuit was preferable.

The potential circuit of the dynamometer wattmeter with the usual external resistor is adapted for voltages up to about 150 volts, so that for measurements at higher voltage it becomes immediately necessary to arrange for properly applying the high voltage to the potential circuit of the dynamometer wattmeter in such a way that the power in the high-voltage circuit can be accurately determined. Though this same problem is solved simply and universally in general instrument practise today by means of instrument potential transformers[22], the application of these alone to measurements of dielectric power loss is not so satisfactory because of the phase-angle correction involved at the low power factor of the measurement[23].

In this connection Table I is of interest, for it shows the maximum allowable departure in phase angle from the true value for different percentage errors for different values of power factor. Since values of phase angle for instrument potential transformers are usually certified to as being correct within from 3 to 5 minutes, it is reasonable to assume that a departure in phase angle of at least 2 minutes from the true value may exist. For this condition it is seen that measurements to within an error of one per cent are not obtainable practically, to within five per cent are not obtainable for values of power factor 0.01 and less, and to within 10 per cent are not obtainable for values of power factor 0.005 and less. It follows, therefore, from the standpoint of phase angle alone that for the majority of these measurements the least error that can be reasonably expected will be in the order of 10 per cent.

TABLE I

Power Factor cos θ	θ	Maximum Allowable Departure in Phase Angle for an Error of					
		1%	5%	10%	25%	50%	100%
		Minutes					
0.002	89°53′	0	0.3	0.6	1.6	3.3	7
0.005	89°43′	0	1	2	4	9	17
0.01	89°26′	0	2	4	8	17	35
0.02	88°51′	0.5	4	8	17	35	70
0.03	88°17′	1	5	11			
0.05	87° 8′	2	8				
0.10	84°16′	4	19				

An additional correction must be made for the phase angle of the potential circuit of the dynamometer wattmeter. Unless the potential circuit is accurately shielded, the phase angle is difficult to calculate and may introduce an additional error in excess of those shown in Table I. For these reasons, the practise of correcting by calculation has been generally abandoned.

Use of the Air Capacitor Compensated Dynamometer Wattmeter Method

The errors resulting from calculating corrections and from those causes not readily susceptible to calculation can be almost entirely eliminated by the use of a high-voltage capacitor so designed as to have a negligible loss [12, 24, 25, 31], and across which the high voltage of the circuit may be directly impressed. Such a capacitor is usually one with air as a dielectric though capacitors with CO_2 gas under pressure have been used. If the loss in the capacitor is zero, then when the current circuit of the dynamometer wattmeter is connected into the capacitor circuit and voltage is impressed across the potential circuit of the wattmeter such as by instrument potential trans-

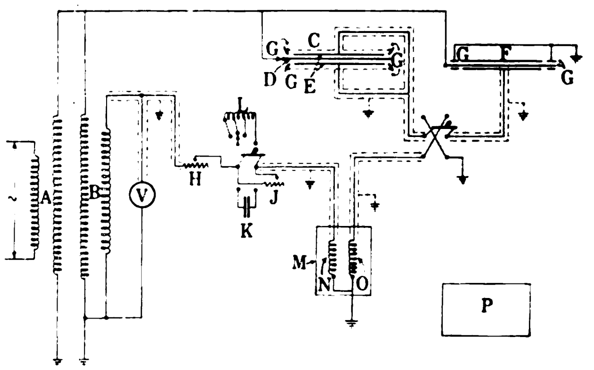

Fig. 3—Diagram of Connections for Compensated Dynamometer Wattmeter Method of Measuring Dielectric Power Losses in Cable Samples

A Power transformer
B Instrument potential transformer
C Air capacitor
D High-voltage plate of air capacitor
E Low-voltage plates of air capacitor
F Cable sample
G Guard rings
H External resistor
J Auxiliary series resistor
K Compensating capacitor
L Compensating inductor
M Dynamometer wattmeter
N Potential coils of dynamometer wattmeter
O Current coils of dynamometer wattmeter
P Potentiometer for calibrating dynamometer wattmeter

Dotted lines indicate grounded shielding

former, the dynamometer wattmeter should indicate zero assuming no loss in the current circuit. It probably will not do so because of the combined phase angle of the instrument potential transformer and the potential circuit of the dynamometer wattmeter, but it may be made to do so by changing the reactance of the potential circuit until such a result is obtained. The dynamometer wattmeter is thus correctly compensated for existing phase-angle differences. The capacitor may now be replaced with the cable sample of the same capacitance, and the resulting deflection read on the scale of the dynamometer wattmeter. The capacitor and the cable sample are connected to the circuit at all times. The power in watts is then directly calculated from the deflection and the watt-constant as obtained with direct current. This method is usually referred to as the Compensated Dyna-

mometer Wattmeter Method, and since first described by Shanklin[12] in 1916 has been found to give reliable results.[26] The circuit diagram for this method is shown in Fig. 3, in which diagram are shown the shields and ground connections necessary to be provided to eliminate errors due to electrostatic and electromagnetic induction.

By this method the manipulation and corrections are reduced to simple form. The dynamometer wattmeter can be calibrated in position at any time by

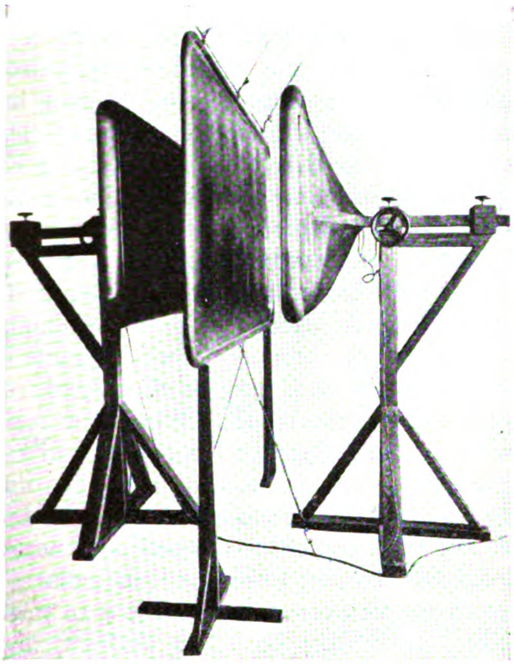

FIG. 4—AIR CAPACITOR. THREE-PLATE VARIABLE-CAPACITANCE TYPE

The middle plate is the high-voltage plate and is 9 ft. long and 5 ft. wide. The low-voltage plates are each 7 ½ ft. long and 3 ½ ft. wide. The capacitance range is from 0.0001 to 0.002 microfarad. The maximum voltage is 100 kv.

taking reversed readings on direct current, reading the values with a potentiometer. This assures accuracy of watt calibration. Losses in the current circuit can be calculated and corrected for if necessary. All phase-angle differences are corrected for by the compensation of the potential circuit.

The use of the air capacitor is quite prevalent in the art today and its use greatly facilitates measurements made with the dynamometer wattmeter. Two commercial forms of such capacitors are shown in Figs. 4 and 5, being of the variable and fixed-capacitance types, respectively. The suitability of any given capacitor of this type can be determined from a consideration of the design and from tests such as those described[12]. Though the loss is not absolutely zero, it is possible to determine its negligibility within satisfactory limits. A value of phase angle of 0.5 minute is considered possible of attainment, and the design must be such as to provide this attainment if the advantages of the method are to be realized. The error introduced by phase angle of the air capacitor is to make the final reading of power to be lower than the true value.

For best results the capacitance of the air capacitor should be equal to that of the sample being measured so that circuit conditions are maintained as nearly identical as possible during compensation and during measurements. Such a condition can be obtained without undue difficulty for 10-ft.-of-lead samples of present-day cables. For long factory lengths, however, this condition is practically prohibitive. It is therefore necessary either to compensate on a current coil of low-current rating and make the measurement on a current coil of high rating, or use a shunt. Either of these methods introduces corrections which may be uncertain. Bridge methods are apparently more susceptible to accurate results for such measurements as these[26].

The sensitivity of the dynamometer wattmeter varies with the design, and is in the order of from 10^{-4} to 10^{-5} watts per millimeter deflection at 110 volts when the scale is set at the conventional distance of one meter from the instrument. This is also the

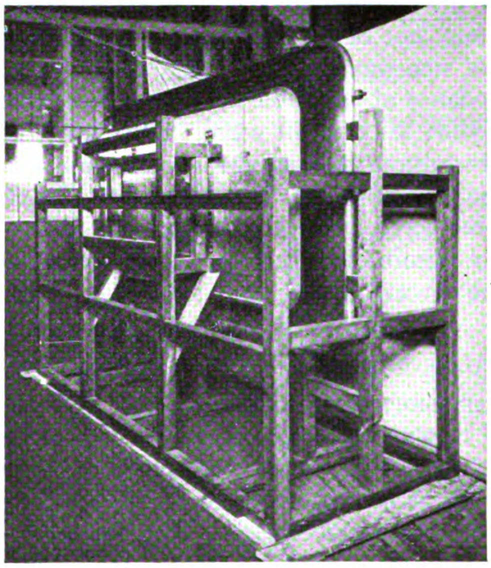

FIG. 5—AIR CAPACITOR. THREE-PLATE FIXED-CAPACITANCE TYPE

The plates are the same size as those shown in Fig. 4. Capacitance 0.0004 microfarad. Maximum voltage 100 kv. This type of capacitor used especially in high-voltage bridge.

order of the lowest values of dielectric power loss to be measured (at the wattmeter terminals) in cable samples (10 ft. of lead) so that for such values the reading error alone may be in the order of 20 per cent since the deflection may be only a few millimeters accurately read to from 0.3 to 0.5 millimeter. For higher values of power the reading error expressed as a percentage value becomes proportionately less.

The choice of means of voltage transformation is pertinent. A set of instrument potential transformers for different voltage ranges is undoubtedly the best,

and these are commercially available up to 132 kilovolts. Ratio transformations obtained with these are independent of the current in the high-voltage circuit. The use of transformer voltmeter coil, though convenient, requires compensation for every measurement, since the transformation is affected by the current in the high-voltage circuit. The same applies to the practise of taking the potential from the low-voltage side of the testing transformer.

The effect of the earth's field is eliminated by making the dynamometer wattmeter astatic, although this is hardly necessary when measuring alternating power. Strong external alternating fields such as from high-current circuits or reactors nearby may, however, seriously affect the dynamometer wattmeter of the reflecting astatic type. Hence, it is quite essential to see that such external fields are eliminated when the dynamometer wattmeter is in use.

The dynamometer wattmeter accurately summates the power due to the like frequencies in voltage and current, and therefore should give the true power regardless of wave form. For cable testing, however, where the current circuit of the dynamometer wattmeter is in the cable circuit, and where the potential circuit of the dynamometer is supplied by means which may or may not be affected by the cable capacitance, the use of sine wave is highly desirable because of the low impedance of the cable to higher harmonics which act to distort the current wave. Also, from the standpoint of voltage measurement, the applied voltage should be of sine-wave form. The prevalence of the use of sine-wave generators today for cable testing is largely eliminating the need for worry regarding errors due to wave form[26].

Inductance Variation Method
Phase-Defect Compensation Method

Another somewhat similar application of the dynamometer wattmeter and air capacitor is used whereby with the capacitor in the circuit the dynamometer reading is brought to zero by means of inductance in the potential circuit. The cable sample of same capacitance is then substituted in the dynamometer wattmeter current circuit for the capacitor and the dynamometer reading is again brought to zero by means of the inductance in the potential circuit. From the change in inductance and the resistance of the potential circuit, the power factor is calculated.[2] This is frequently referred to as the inductance variation method, or the phase-defect compensation method.

Series Resistor and Wattmeter Method

A series resistor may be used with the dynamometer wattmeter in either of two ways. First, it may be used as a substitute for the transformer, the air capacitor still being retained for use in compensating the dynamometer wattmeter. In this case the conditions of use and possible results would be somewhat similar to those when the transformer is used. A series resistor has also been used instead of the transformer and air capacitor, connecting the resistor directly across the high-voltage circuit with the potential circuit of the wattmeter connected either in series with it, or in parallel with a portion of it. Such a resistor must be of fixed value, wherein the leakage to ground and the reactance are so extremely small as to be negligible. For the higher voltages such a resistor is necessarily large and quite expensive, and the problem of shielding is quite complicated. Barbagelata and Emanueli[17] speak of a suitable series resistor for such measurements as being costly and cumbersome, and state that it may have a phase-angle correction larger than those being measured.

The use of a water-column series resistor is being employed in these and similar measurements by some observers[17, 19]. As used by Barbagelata and Emanueli[17] the power factor of the cable insulation being measured is obtained by calculation from circuit constants, one of which is the resistance of the water column. A measurement of this value is therefore required under each condition of use, except at extremely high voltages such as 100 kv. and more, where, under certain conditions, the value of R may be eliminated from the equation expressing the result. Where the resistance of the water column changes frequently and requires frequent measurement as in most of the work in our country today, and where circuit constants enter into the calculation of the result, this method does not appear to be altogether without objection, particularly if the error due to capacitance of the resistor to ground is considerable, as it may be. The authors, however, describe a form of water-column resistor which is claimed to be free from capacitance error.

In this particular regard the work being done under the direction of Professor Ryan[19] in measuring corona losses at high voltages merits consideration, in that a method is given for shielding the water-column resistor and adjusting it to eliminate errors due to capacitance. This result is obtained by varying the resistance of the water-column resistor by varying the water flow and thus its temperature, the capacitance remaining constant. By taking readings of the wattmeter for different resistances, the shielding can be adjusted to give a zero error.

Some comparative measurements have been made with this method and with the compensated dynamometer wattmeter method the results of which are shown in Figs. 6, 7, 8 and 9. The dynamometer wattmeter with water-column resistor was set up as first described[19] by Clark and Miller although the instrument was connected into the ground side of the circuit and the pail was replaced with a continuous hose connection from the point of high potential down nearly to the drain. This hose was banded at intervals and the bands connected to similar bands on the resistor hose to distribute the potential properly. Under these conditions agreement was obtained with

measurements of power factor made with the compensated dynamometer method to within 0.004 on the cable sample, Figs. 6 and 7, and within 0.005 on the experimental capacitor, Figs. 8 and 9, except at the lowest voltage. These departures represent differences from the results obtained with a compensated dynamometer wattmeter method in the order of from 20 per cent to 80 per cent.

The later work as reported by Carrol[19] wherein a

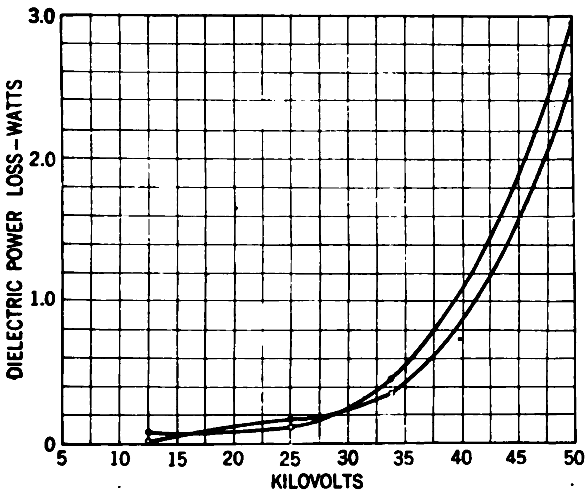

Fig. 6—Comparative Measurements of Dielectric Power Loss in Length of Experimental Three-Conductor Cable, Measuring from Single-Phase Supply with One Conductor "High" and the Other Two Conductors Grounded to Sheath

• By shielded water column series—resistor and dynamometer wattmeter method
⊙ By compensated dynamometer wattmeter method

salt solution under controlled circulation is used to obtain the necessary control of the resistance of the potential circuit would also have to be utilized if this

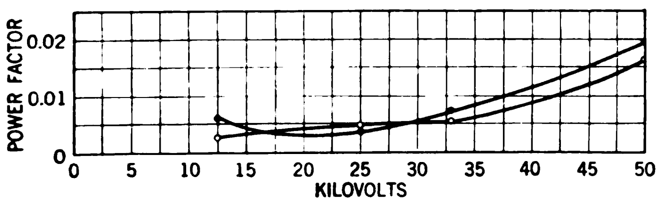

Fig. 7—Comparative Measurements of Power Factor of Length of Experimental Three-Conductor Cable, Measuring Dielectric Power Losses from Single-Phase Supply with One Conductor "High" and the Other Two Conductors Grounded to Sheath. Same Cable as in Fig. 6

• By shielded water column series resistor and dynamometer, wattmeter method
⊙ By compensated dynamometer wattmeter method

method were used for measuring dielectric power losses in cable insulation. In making these tests the need for greater control of the resistance of the potential circuit was evident. Short-circuiting one turn of the water-column resistor was tried to obtain the desired range, but the resulting values obtained as shown in Figs. 8 and 9 show that error was introduced thereby.

While the use of the water-column resistor in measurements of dielectric power loss and power factor of

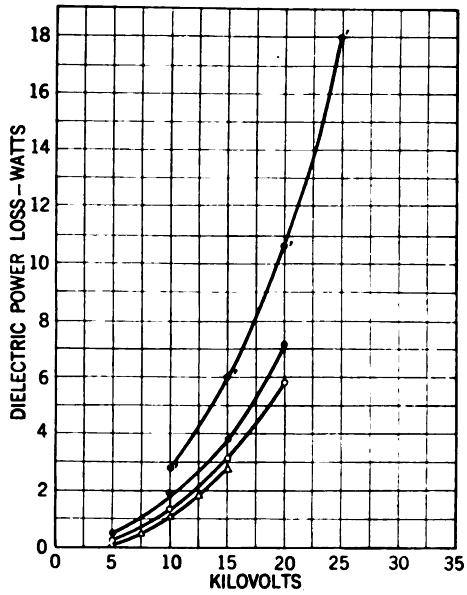

Fig. 8—Comparative Measurements of Dielectric Power Loss in an Experimental Capacitor

○ By compensated dynamometer wattmeter method
Δ By Shering bridge method
•' By shielded water column series resistor and dynamometer wattmeter method
By shielded water column series resistor and dynamometer wattmeter method, with one turn of series—resistor short-circuited

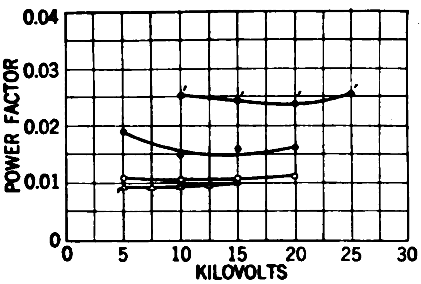

Fig. 9—Comparative Measurements of Power Factor of an Experimental Capacitor. Same Capacitor as in Fig. 8

○ By compensated dynamometer wattmeter method
Δ By Shering bridge method
• By shielded water column series resistor and dynamometer wattmeter method
•' By shielded water column series resistor and dynamometer method, with one turn of series- resistor short-circuited

cables doubtless has merit and warrants further investigation, it does not appear to be inherently more accurate than the present established methods, such as the use of the instrument potential transformer and air capacitor.

Resonance Wattmeter Method

The resonance wattmeter method as early described by Rosa[1] and as used recently by Marbury[20] for measuring dielectric power losses and power factor in capacitors has merit, but would doubtless be some-

what difficult of application to cables because of the wide range of capacitance of samples of different rating and cables of different lengths. The accurate determination of the losses in the inductance to be subtracted from the wattmeter reading for the various conditions of measurement would entail the use of detailed equipment which would not simplify the measurements.

Measurement of Voltage and Current

In all of the above methods, the voltage and current must be measured, since the dielectric power loss is a function of the voltage and since the power factor is calculated from the value of dielectric power loss, applied voltage, and resulting current.

Values of voltage may be read with sufficient accuracy with a portable direct-reading voltmeter, the high voltage being transformed either by instrument potential transformer or by transformer-volt coil.

The current, usually of low value, is best read with a reflecting astatic dynamometer ammeter, which may be a separate instrument or may be the dynamometer wattmeter used for the measurement of dielectric power loss, connecting the potential circuit, with a suitable shunt, in series with the current circuit.

Measurements on Three-Conductor Cables

The discussion thus far has been confined to the dynamometer wattmeter itself and to its application in a single-phase circuit. The measurement of dielectric power loss and power factor of three-conductor cables presents more difficulties. In general, two methods are used at the present time (1) direct measurement from three-phase supply[14] and (2) calculation of the three-phase results from tests made from single-phase supply[13, 26].

Probably the simplest method suggested for making the dielectric power loss measurements from three-phase supply is to measure the power input to the transformers from the low-voltage side with the cable sample connected to the high-voltage side and then disconnected therefrom, the difference of these readings giving the value of dielectric power loss in the cable insulation. Unfortunately, the latter is too small to be accurately measured by this method except at the higher temperatures. Even under these conditions, the final result is the difference of two comparatively large values differing by only a small amount which is not highly accurate.

It thus becomes necessary to make the measurements on the high-voltage side. Although the principle of compensating the dynamometer wattmeter for circuit effects is still applicable, as in the single-phase circuit, it cannot be applied directly to each phase because the current circuit of the dynamometer wattmeter must be connected into the cable circuit between the grounded neutral point and the high-voltage winding of each transformer separately. Thus, the current due to capacitance to ground of the high-voltage winding, and between high-voltage and low-voltage windings, traverses the current coil of the dynamometer wattmeter but not the cable sample or the air capacitor. In a small transformer, error due to this cause may not be large. In a large transformer, shielding is absolutely necessary between the high-voltage and low-voltage winding. Fig. 10 shows the difference in power factor of a cable as measured with a shielded and an unshielded transformer of 100-kv-a. rating at 100 kv., the transformers being similar in other respects, the current coil of the dynamometer being connected between ground and the high-voltage winding. Other sources of error largely indeterminable are also present to varying degree, such as voltage unbalance and interphase effects which are not susceptible to correction, thus rendering the result somewhat uncertain.

Farmer[14] has described and used a method employing the dynamometer wattmeter in a three-phase circuit, later modifying the set-up to provide for compensation with an air capacitor, shifting the instrument from phase to phase, measuring both the dielectric power loss and the reactive volt amperes, the power factor being determined from the ratio of the two.

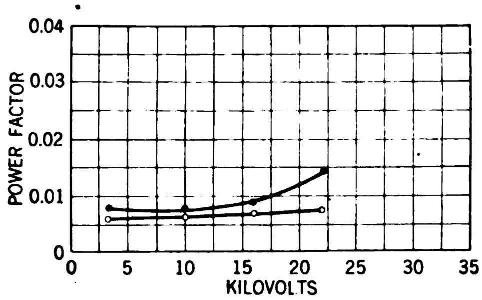

Fig. 10—Comparison of Values of Power Factor of a Three-Conductor Cable Sample When Measured with Current Coil of Dynamometer Wattmeter Connected Between "Ground" and High-Voltage Winding of Transformer, as in a Three-Phase Circuit

Rating of transformers 100 kv-a. at 100 kv. One transformer shielded between high- and low-voltage winding; the other transformer unshielded. Transformers identical in other respects. Note that measurements are at comparatively low voltage, and that differences are increasing considerably with voltage increase

• Unshielded transformer

○ Shielded transformer

The method of calculating the dielectric power loss from measurements made from single-phase supply[13, 26] has the advantage of employing the simpler single-phase measurement which is subject to greater accuracy and certainty in final result. It has the disadvantage of the uncertainty of the calculations embodying the resulting phenomena in the cable exactly. Check measurements between those made from three-phase supply and single-phase supply in general show good agreement, neither method giving consistently

lower or high values. Farmer[14] states that the measured value is frequently considerably lower than the calculated value. Figs. 11 and 12 show comparative results in this regard, obtained in two different laboratories on two different samples of cables cut from the same length. Agreement of power-factor values is within from 0.002 to 0.004. The per cent of difference from the mean is 20 per cent over the entire range of values. Figs. 13 and 14 show results of similar measurements made on the same sample of cable in the same two laboratories. Agreement of power-factor values is within 0.002. The maximum per cent difference from the mean is 20 per cent; remaining values show closer agreement, and at some points actual agreement. On the assumption that the different methods give values subject to approximately the same errors, these results indicate the departure from the true result for both methods to be in the order of from 10 to 20 per cent.

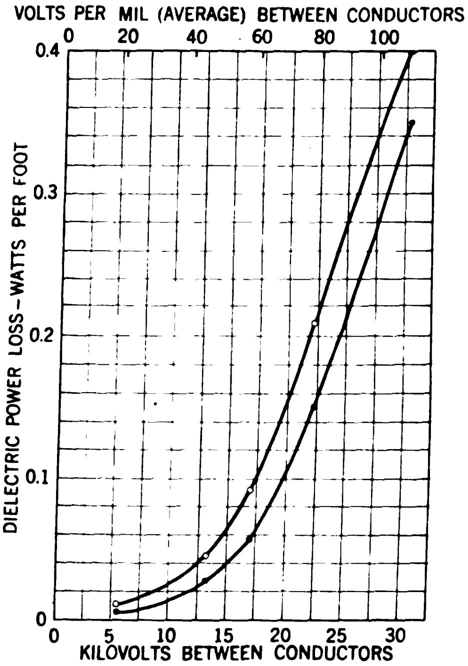

FIG. 11—COMPARATIVE MEASUREMENTS IN TWO DIFFERENT LABORATORIES OF DIELECTRIC POWER LOSS IN TWO DIFFERENT CABLE SAMPLES CUT FROM THE SAME LENGTH OF CABLE

Cable rated three-conductor, 500,000-cm., 9/16-in. x 5/64-in. treated-paper insulation, lead-covered

• Laboratory A. Sample No. 1. Results calculated from measurements made from single-phase power supply by compensated dynamometer wattmeter method

O Laboratory B. Sample No. 2. Results obtained by measurement with dynamometer wattmeter in a three-phase circuit

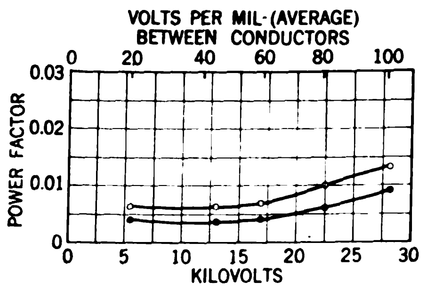

FIG. 12—COMPARATIVE MEASUREMENTS IN TWO DIFFERENT LABORATORIES OF POWER FACTOR OF TWO DIFFERENT CABLE SAMPLES CUT FROM THE SAME LENGTH OF CABLE—SAME CABLE AS IN FIG. 11

• Laboratory A. Sample No. 1. Results calculated from measurements made from single-phase power supply by compensated dynamometer wattmeter method

O Laboratory B. Sample No. 2. Results obtained by measurement with dynamometer wattmeter in a three-phase circuit

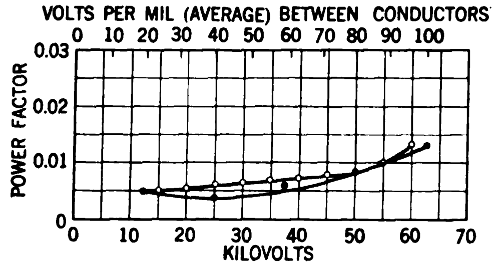

FIG. 13—COMPARATIVE MEASUREMETTS IN TWO DIFFERENT LABORATORIES OF DIELECTRIC POWER LOSS IN THE SAME CABLE SAMPLE

Cable rated three-conductor, 350,000-cm., sector, 10/32-in. x 5/32-in. treated-paper insulation, lead-covered

• Laboratory A. Results calculated from measurements made from single-phase power supply by compensated dynamometer wattmeter method

O Laboratory B. Results obtained by measurement with dynamometer wattmeter in a three-phase circuit

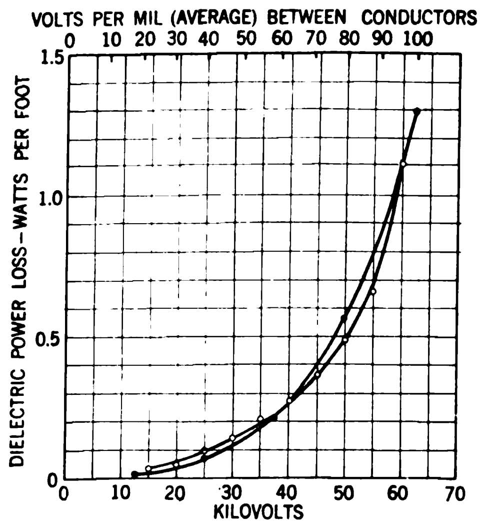

FIG. 14—COMPARATIVE MEASUREMENTS IN TWO DIFFERENT LABORATORIES OF POWER FACTOR OF THE SAME CABLE SAMPLE—SAME CABLE AS IN FIG. 13

• Laboratory A. Results calculated from measurements made from single-phase power supply by compensated dynamometer wattmeter method

O Laboratory B. Results obtained by measurement with dynamometer wattmeter in a three-phase circuit

ACCURACY OF MEASUREMENT

In the absence of known means for definite comparison, the accuracy of these measurements must be determined in other ways. Comparison of measurements made by independent methods is helpful.

It has been shown[26] that for single-conductor cables measured by compensated dynamometer wattmeter method, and by Schering Bridge method that agreement in power factor has been obtained within 0.002. This is at a value of power factor in the order of 0.005, thus the resulting departure from the average value by the two methods is about 20 per cent. Note that the percentage error may seem somewhat high, but this is characteristic of this means of expression where the base values are small. However, the agreement in absolute value is very good.

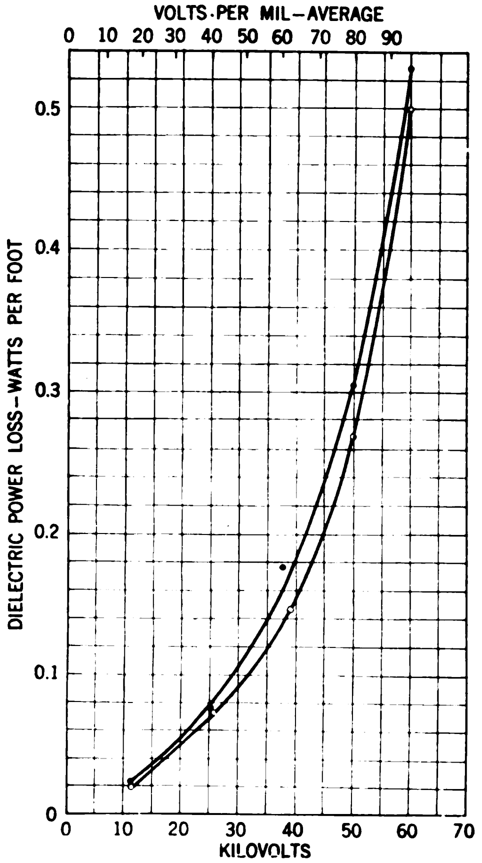

Fig. 15—Comparative Measurements in Two Different Laboratories of Dielectric Power Loss in the Same Cable Sample—Cable Rated Single-Conductor. 500,000-cm., Round, 5/8-In. Treated-Paper Insulation, Lead-Covered

• Laboratory A. Compensated dynamometer wattmeter method
O Laboratory B. Phase-defect compensation dynamometer wattmeter method

Figs. 15 and 16 show results of measurements made on the same sample of single-conductor cable in two different laboratories using the compensated dynamometer wattmeter method and the inductance variation dynamometer wattmeter method (phase-defect compensation method) respectively. Agreement is within 0.02 watt in 0.1 watt for dielectric power loss, and within a power factor of 0.001 at a value of power factor in the order of 0.005. This indicates departure from the average value for the two measurements to be in the order of 10 per cent. The curves of Figs. 11 to 14 show similar results for two methods of measuring three-conductor cables where the departure from the average value for the two methods is in the order of from 10 to 20 per cent.

Conclusion

An appeal has been made for greater attention to the question of making these measurements, large differences—as much as 100 per cent—on a percentage basis having been reported.[30] The discussion given above shows that these measurements are now being regularly made with dynamometer wattmeter methods giving results wherein the probable departure from the true value is within from 10 to 20 per cent in percentage value. Such results are not obtainable with ease, but only after intense application and using available intercomparisons as a means of eliminating possible unknown errors.

In this regard a usable means of definite comparison is quite desirable. Much thought has been placed on

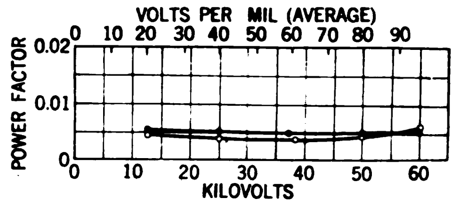

Fig. 16—Comparative Measurements in Two Different Laboratories of Power Factor of the Same Cable Sample—Same Cable as in Fig. 15

• Laboratory A. Compensated dynamometer wattmeter method
O Laboratory B. Phase-defect compensation dynamometer wattmeter method

procuring a suitable comparator which could be used for standardizing any measuring outfit for dielectric power loss and power factor. No satisfactory means has yet been made applicable.

As far as the author knows no attention has been paid to the calorimeter method as being useful for such a comparator. Such a method was used early in the the art in connection with measurements on capacitors and has since been successfully applied with satisfying results. Though the difficulties of such a measurement with cable samples are more severe than with capacitors, nevertheless it is felt that there is a field for such a measurement and for which definite specifications could be drawn up as a comparator, which would enable different measuring equipments to be adequately standardized. The possibilities of development work in this regard are quite worth the effort.

THE EFFECT OF GOOD LIGHT

The effect of good light on factory output was demonstrated last winter in a ball-bearing plant. Without the knowledge of the workmen, illumination was raised from five-ft. candles to 20-ft. candles. Production increased 12.5 per cent. Lighting cost per hour in that section of the factory under test was increased 28 cents and the hourly saving to the company through increased production was $1.47.

Circulation of Harmonics in Transformer Circuits

BY T. C. LENNOX[1]

Associate, A. I. E. E.

Synopsis.—The paper describes the manner in which certain series of harmonic currents may be permitted to flow within a transformer network. In particular it is shown how the fifth and seventh harmonics of transformer exciting current may be eliminated from transmission lines. The extent to which the harmonic currents generated in a rectifier may be eliminated from the a-c. lines by means of phase multiplication is also indicated.

* * * * *

THE action of a third harmonic of current or voltage in three-phase a-c. transformers has become familiar to engineers. Very exhaustive studies of the third harmonic of transformer magnetizing current, in particular, have been necessary, due to the excessive voltages that may result in Y-connected, three-phase circuits where the harmonic of current cannot flow, and to excessive interference with telephone circuits when it flows in a grounded neutral circuit.

It has not been so generally appreciated that this is but one of many similar phenomena that may be encountered if other harmonics than the third and other connections than the simple three-phase, Y, or delta are studied.

The case of the third harmonic of magnetizing current in three-phase transformer circuits is reviewed briefly. Here, it is usual to have three transformers or phases of similar characteristics so that the wave form of the magnetizing current is the same in each phase. Consequently, the third harmonic of current will be the same magnitude in each phase and have the same relation to the fundamental wave.

Bearing this in mind, we may take the case of a three-phase bank, connected in delta on one side and with excitation applied to this winding. Examining, then, the condition at one corner of the delta, it is found that the fundamental waves of exciting current of the two phases differ in phase by 60 deg. The third harmonics of current having three times the frequency of their fundamentals will differ in phase by three times 60 deg., or 180 deg. In other words, they will be equal and opposite and no third harmonic of current will flow from the supply circuit.

Next considering the Y connection, it is found that whereas at the neutral the fundamental waves are 120 deg. apart in phase, and consequently add up algebraically to zero, the third harmonics are three times 120 deg., or 360 deg. apart; or, in other words, are all in the same phase position and consequently add up to three times their average value and must flow into the neutral line. If no neutral is provided, no third harmonic of current can flow and consequently a third harmonic of voltage will appear from line to neutral in each phase.

The exciting current of a transformer contains higher odd harmonics,—the fifth, in particular, being quite prominent although smaller than the third. The seventh and some higher harmonics, although present, are of negligible amount. Considering these harmonics at a corner of the delta, the fifth harmonics will differ in phase five times 60 deg., or 300 deg. and will consequently have a resultant 1.73 times their average value, which must flow in the supply line. Similarly the seventh harmonics differ in phase 420 deg. or, subtracting 360 deg., 60 deg. and have a resultant in the line 1.73 times their average value. Similarly, the eleventh, thirteenth, and other odd harmonics not multiples of three must flow in the line, whereas the ninth, fifteenth, and others which are multiples of three, will equalize in the same manner as the third.

At the neutral of a Y connection, the fifth harmonics will differ in phase five times 120 = 600 deg. or 240 deg., and consequently will add up to zero the same as the fundamental. Similarly the seventh, eleventh, and other odd harmonics, not multiples of three, will equalize and may, therefore, flow in such a circuit without a neutral line. On the other hand, the ninth, fifteenth, and other harmonics which are multiples of three cannot flow.

Consider next the case of a Y-connected bank placed in multiple with a delta-connected bank, Fig. 1, in which all the phases are identical in characteristics, being different only in the turn ratio as necessary to obtain Y or delta connection. At each corner of the delta, three currents converge, so that the fundamental waves add to a resultant of twice the value of that in the Y-connected phase and in phase with it.

The third harmonic cannot flow in the Y connection and will equalize to zero between the two phases of the delta. A third harmonic of voltage exists from line to neutral in the Y-connected units, but if they have delta-connected, secondary windings, the voltage will result in a triple-frequency current in the delta which will reduce the voltage to a practically negligible value dependent on the impedance of the windings.

As the fifth harmonic can flow in the Y connection, there will be a fifth harmonic in each of the three phases converging at the corner of the delta. The delta phases being 30 deg. each way from the Y phase, their fifth harmonics will be 150 deg. out of phase with the fifth in the Y phase. This will result in the three adding up to zero with no fifth harmonic flowing in the line. Similarly with the seventh harmonic, the 30 deg. is multiplied to 210 deg. and the three equalized to zero. The ninth will act similarly to the third, flowing in the delta, and in the secondary delta of the Y-connected phases.

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Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

For the eleventh harmonic, the 30 deg. becomes 330 deg. and the three phases have a relation identical with that applying to the fundamental, so that the full value of the eleventh harmonic must flow in the line. Similarly for the thirteenth harmonic the 30 deg. becomes 390 deg. and the full value of this harmonic must flow in the line.

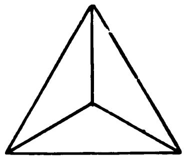

Fig. 1

Continuing the process, we find that all the odd harmonics except the eleventh, thirteenth, twenty-third, twenty-fifth, thirty-fifth, thirty-seventh, and others of that series will equalize within the network.

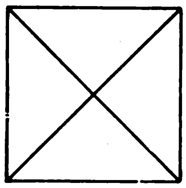

Fig. 2

This is of some practical interest in connection with power transformers or shunt reactors in cases where the fifth harmonic of exciting current may be thought to have some bearing on telephonic interferences.

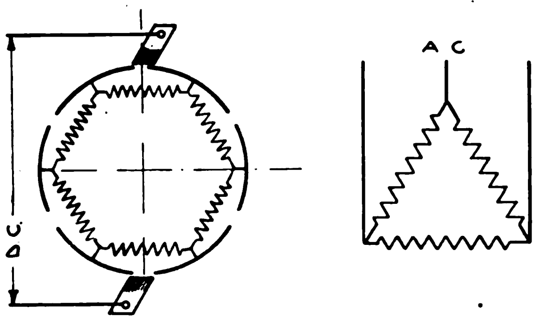

Fig. 3

By suitably arranging the banks so as to balance delta banks against Y banks, the fifth and seventh harmonics of exciting current may be largely eliminated from the lines.

If an analogous connection on a quarter-phase system consisting of a cross-square connection is taken, as in Fig. 2, it is found that the harmonics of the series 3, 5, 11, 13, 19, 21, 27, 29, etc., are equalized while those of the series 7, 9, 15, 17, 23, 25, etc., must flow in the line. A secondary square in the cross bank is not needed unless it is wished to eliminate even harmonics, in which case the second, sixth, tenth, and so on would flow in the squares.

An interesting case in this connection is a polyphase rectifier circuit such as is suitable for use for changing alternating current to direct current. Such a rectifier tends to draw current from the a-c. system having a wave form approximating the rectangular in shape. This wave consists of a series of odd harmonics the magnitude of which is in inverse ratio to their order, that is, in the familiar Fourier series.

Considering a six-phase ring, Fig. 3, with commutator and brushes or their equivalent arranged to operate in synchronism with the alternating voltage, the current in the ring will approximate the form shown in Fig. 4.

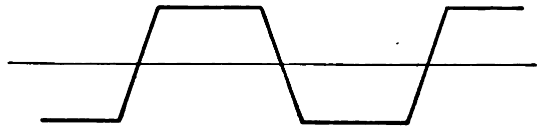

Fig. 4

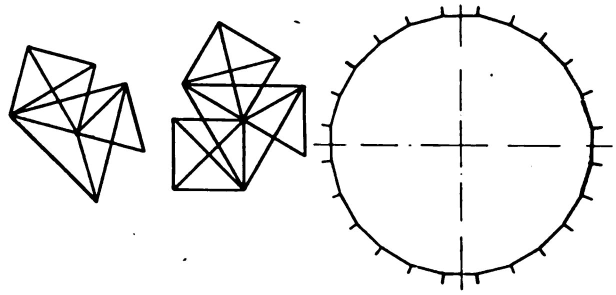

Fig. 5

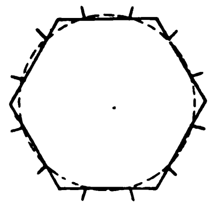

Fig. 6

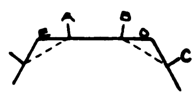

Fig. 7

The current in each phase has to reverse while the phase is short-circuited by the brush. This requires a definite time and explains the slanted sides in place of the vertical sides of a rectangular wave. A series of odd harmonics somewhat similar to that in a rectangular wave will, nevertheless, be present. If the primary of the transformer is connected in delta, the third and other harmonics which are multiples of three will equalize at the corners and the line current will consequently have only the fundamental and the remaining harmonics.

If the number of sides in the polygon is increased to eight by the use of four separate transformers or phases with the necessary number of windings for this arrangement and the primaries are connected cross-square (Fig. 2), the harmonics of the series 3, 5, 11, 13, 19, 21, etc., are eliminated, leaving the remaining ones in the line.

If a twelve-sided polygon is used by means of six single-phase transformers or two three-phase transformers and Y-delta primaries are used with additional delta in the Y phases, all the harmonics except the 11th, 13th, 23d, 25th, and others of that series are eliminated.

For a still larger number of phases in a polygon obtained by the use of separate transformers or core legs, we cannot obtain a simple primary connection of the kind used above. However, for 24 phases using either 12 single-phase or four three-phase transformers, a set of compensating windings placed on the same cores as shown in Fig. 5 could be connected. Here, we have the necessary Y deltas and cross squares to carry all the harmonics except the 23d, 25th, 47th, 49th, 73d, 75th, and others of that series. The three-phase, a-c. connection to such an outfit would be made at any three points equally spaced around the polygon. In any of these polygons, it is possible to double the number of symmetrical phases by tapping out the leads as shown in Fig. 6, so as to have all the connection points fall on a circle intersecting the polygon at equal intervals. Here, the primary or compensating winding will eliminate only the same series of harmonics as for the smaller number of phases. However, some of the remaining harmonics are cancelled within the polygon

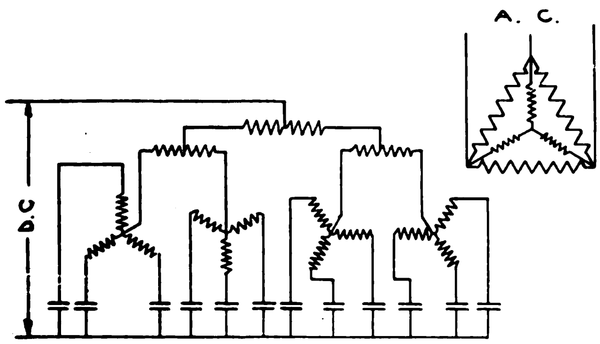

Fig. 8

itself, as for instance, in Fig. 7 which shows a part of a 12-phase connection from a six-phase ring. The current in *B C* is 150 deg. from that in *B A* but flows in coils *B D* on the same core. The fifth harmonic will be 750 deg. or 30 deg. from that in *B A* and, together with that in *A E*, will have a resultant equal and opposite to the fifth in *A B*. Similarly the seventh harmonics will be 330 deg. out of phase and will neutralize.

As a result, no current of these frequencies will be required of the primary coils or line and the residue of harmonics to be taken from the line will be the same as for a polygon having the full number of separate phases.

Table I shows the magnitude of the minimum residue of odd harmonics for polygons of different numbers of phases, in per cent of the fundamental, for a rectangular wave in the polygon. From this it is evident that the minimum ripple resulting in the a-c. lines in such cases is composed of a series of odd harmonics comprising the numbers adjacent to the number of phases in the polygon and its multiples.

The extent to which this ideal condition may be approximated in the case of actual designs will depend principally upon the reactance of the circuits through which the harmonic currents are required to flow. In the arrangements outlined above the primary windings or compensating windings if used, must have small leakage reactance between them and the polygon if more than a few of the lower harmonics are to flow in appreciable amount.

TABLE I
HARMONICS NOT ELIMINATED

	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	— — —	47	49	— — —
Square	100	33.3	20	14.3	11.1	9.1	7.7	6.67	5.88	5.26	4.76	4.35	4.0	3.7	3.45	3.23	3.03	2.86	2.7	— — —	2.12	2.08	— — —
Hexagon	100		20	14.3		9.1	7.7		5.88	5.26		4.35	4.0		3.45	3.23		2.86	2.7	— — —	2.12	2.08	— — —
Octogon	100			14.3	11.1			6.67	5.88			4.35	4.0			3.23	3.03			— — —	2.12	2.08	— — —
12-Phase	100					9.1	7.7					4.35	4.0					2.86	2.7	— — —	2.12	2.08	— — —
16-Phase	100							6.67	5.88							3.23	3.03			— — —	2.12	2.08	— — —
24-Phase	100											4.35	4.0							— — —	2.12	2.08	— — —
48-Phase	100																			— — —	2.12	2.08	— — —

Transformers for tube rectification are frequently connected in star rather than in a polygon. If there are

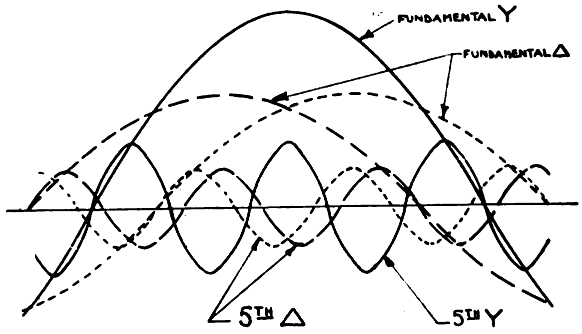

Fig. 9

an even number of phases with this arrangement all even harmonics will cancel. A series of odd harmonics will remain as in the polygon connection and will be eliminated in the same manner and to the same extent. The use of separate Y-connected banks, connected together by inter-phase transformers, as shown in Fig. 8, will not greatly alter the conditions, the minimum residue of harmonics from the 12-phase system shown being the 11th, 13th, 23d, 25th, etc., series. The wave forms to be expected in tube rectifiers are described in some detail by D. C. Prince, in the General Electric *Review* of September, 1924.

To illustrate more clearly the action of the harmonic currents, Fig. 9 shows the fundamental and fifth harmonics at the corner of a Y-delta connection when the harmonic is in phase with the fundamental at its crest.

The Cosmic Harness of Moving Electricity
President's Address

BY M. I. PUPIN

Fellow, A. I. E. E.

Moving Electricity the Mother of Electrical Engineering

The Annual Convention brings us together for the purpose of advancing our knowledge of each other and of the ideals of our Society. We believe that our ideals are in harmony with the ideals of American science and American engineering, and, moreover, we believe that we have a place of honor among those whose mission is the cultivation and amplification of these ideals. They furnished the motive power for the rapid advancement of the science and the art of electrical engineering during the last hundred years. The advancement has been very rapid, but, nevertheless, no other art has a scientific foundation which is so deep, so broad, and so firm as the foundation of electrical engineering. In no other department of human knowledge are science and art so closely welded together. These statements, I know, many will consider as somewhat too bold. I shall try to justify them by referring briefly to the outstanding events in the history of the art of electrical engineering and of the science to which it is welded.

The very meaning of the word engineering implies an art which guides the activities of physical forces into channels of useful service. When the Galileo-Newton philosophy had disclosed the laws of motion of terrestrial as well as of celestial bodies, a new universe was revealed to man, a universe of orderly motion of matter in obedience to forces acting in accordance with laws of child-like simplicity. This philosophy suggested to the engineer new sources of power and service, and to the natural philosopher a new and apparently most comprehensive view of physical phenomena. Some philosophers, thrilled by the beauty of the new knowledge, believed that the whole future history of the universe could be foretold by the Galileo-Newton philosophy if we only knew at any given moment the configuration, the state of motion of every one of its parts and of the forces acting between these parts. That was the mechanistic view of the universe which flourished soon after the triumph of Newton's great achievements. These achievements, however, misled some enthusiasts into the belief that all physical phenomena are reducible to orderly motions of matter under the action of gravitational forces. But as soon as man had discovered that other processes, not expressible in terms of motion of matter, formed an essential part of physical phenomena, that belief was abandoned.

Among these processes, the motion of electricity stands foremost. The new universe revealed by our knowledge of the motions of electricity appeals to our imagination so strongly today that many would not hesitate to rewrite the first sentence of the book of Genesis as follows: "In the beginning God said, 'Let electricity move, and the embryo of the Universe began to form.'" Perhaps in a hundred years from now such a glorification of the motion of electricity will appear just as extravagant as the old mechanistic view of the universe. There is no doubt, however, that the nineteenth, and the first quarter of the twentieth century, will long be remembered as the epoch which revealed to us the hidden powers of electrical motions and their exalted position in our present knowledge of the universe. Who could have foretold all this when Stephen Gray, less than two hundred years ago, modestly announced that electricity can move any distance over conductors and that it does move with enormous rapidity? The world paid small attention to Gray's great discovery, and it might have continued its indifference if Franklin, instructed by his Leyden jar discharges, had not inferred that lightning is a motion of electricity. Gray's modest terrestrial experiment received from Franklin a celestial illustration which commanded attention, although it was ridiculed by some learned members of the Royal Society. The motion of electricity which, in Gray's experiment, was detected by a tiny electroscope assumed a sublime aspect when its flash in the heavens blinded the eye, deafened the ear, and shattered many stable structures of man.

Franklin's discovery of the electrical character of lightning was a great stimulus to the study of the motion of electricity. One may compare it to the stimulus which the Copernicus-Kepler revelation concerning the motion of the planets gave to the study of the motions of terrestrial bodies which Galileo inaugurated. Just as Copernicus and Kepler gave us a Galileo and a Newton, so Gray and Franklin were destined to be succeeded by an Oersted and a Faraday. But it required a Volta to introduce Oersted; it required large electrical motions to reveal the magnetic forces of moving electricity which Oersted discovered.

Prior to Oersted, the engineer moved material bodies and guided their motions into channels of useful service by providing a material connection between the driving and the driven body. Oersted showed that a material body which is the seat of electrical motions can make other bodies move without a material connection between them. The magnetic flux is the invisible coupling. Oersted's discovery of the magnetic field which accompanies electrical motions promised, therefore, to give birth to a new type of engineering, employing a new type of coupling. This promise was

Delivered at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 22, 1926.

one of the great incentives to the advancement of the new knowledge. The mechanical action of an electrically charged body upon other bodies gave a similar promise, but it failed, and it was destined to fail to make that promise good. The promise of the Oersted discovery blossomed out into a reality more beautiful than the fairest dream which prompted that promise. Electricity in motion offered to the engineer a moving force which proved much more powerful than that offered by electricity at rest. The lifting power of Henry's electromagnets was immeasurably greater than the lifting power of the gravitational action of the material out of which his electromagnets were made. One can imagine today what an impression that new fact must have made upon the mind of the engineer of a hundred years ago. Today one can say that electrical engineering is the science and the art which tell us how to make material bodies move by employing an invisible harness hitching up these bodies to moving electricity. It was born when Oersted made his discovery, but its growth was destined to be slow as long as the Voltaic battery was the only powerful means of generating and sustaining electrical motions. To Faraday belongs the glory of discovering a new and much more powerful instrument than the Voltaic battery. It was his clear vision which prophesied a reciprocal relation between moving electricity and moving magnetism. The prophesy was probably the offspring of the intuition which suggested that since moving electricity moves magnets, it is reasonable to expect that moving magnets will move electricity. This expectation proved correct, and it offered to the engineer an ideally simple and powerful method of setting electricity in motion. The promise of Oersted's discovery to the engineer assumed a new meaning after Faraday's discovery, and electrical engineering began its career which placed it in the exalted position it has today among the engineering sciences. The efforts of the electrical engineer to render useful service by hitching up material bodies to moving electricity resulted in the creation of the dynamo, the motor, the transformer, the telegraph, the telephone, and other epoch-making devices which have revolutionized the material conditions of human life. Grateful mankind responded with a generous support of the science which gave birth to and nursed the young art of electrical engineering and, like a wise mother, gave it its exalted ideals. These ideals are the bond of union between electrical engineering of today and its trusty guide, the electrical science. The progress of one brings quickly an equal progress of the other, because hand in hand they always walk together with equal step. One cannot contemplate their stately walk without recalling to mind the well-known line from one of the odes of Horace:

"O matre pulchra, filia pulchrior!".

The Harness of Moving Electricity

The enormous lifting power of electromagnets was the great scientific sensation of a hundred years ago. It excited the lively imagination of Joseph Henry, at that time a young engineer, and he was the first to give it a novel service when he designed the first electromagnetic telegraph which gave the first real job to the electrical engineer of a hundred years ago. The enormous lifting power of the electromagnet furnished also a new job to the natural philosopher when it forced upon him the question: What is the invisible coupling through which this force is transmitted from the stationary to the movable part of the electromagnet? Faraday was the first to suggest an answer to this question. His discoveries and visions detected what one may call an invisible electromagnetic harness to which all material bodies in the universe are attached and which is always available to be employed by moving electricity in useful service. Faraday and Maxwell taught us that this harness is woven out of the electrical and magnetic tubes of force. Change the electrical elements of this cosmic harness in any part of space and its magnetic elements will also be changed in accordance with Maxwell's extension of Ampère's law. Change its magnetic elements and its electrical elements will be changed in accordance with Maxwell's extension of Faraday's law of electromagnetic induction. It is by these changes that an action is transmitted from one part of free space to another. A more complete and, at the same time, ideally simple description of the operation of the invisible harness than that given by Maxwell was unthinkable sixty-one years ago. It became the foundation of the electrical science as well as of the electrical art, that is, of electrical engineering; it welded the two to each other. Faraday and Maxwell performed the welding process. Their mode of thought appealed to the engineer because it expressed the motion of energy from one part of space to another in terms of the action of the invisible coupling between them, furnished by the tubes of force. No elaborate mathematical process was required to aid our understanding of this action and yet the Faraday-Maxwell electromagnetic theory was often accused of being too mathematical, because its fundamental laws, mentioned above, when expressed mathematically were called Maxwell's equations. This conveyed the idea that the theory is a mathematical apparatus which cannot be operated by the mathematical skill of an ordinary electrical engineer and therefore of no use to him. Nothing can be more erroneous than this notion. Nothing is more concrete and simple than the Faraday-Maxwell electric and magnetic flux and nothing is more extensively used by the electrical engineer than these fluxes and the simple laws which govern their activity. No elaborate mathematical apparatus is necessary in order to understand that the Faraday-Maxwell science revealed to us the most accurate understanding of not only the mode of operation of the invisible coupling in ordinary electrical power generation and transmission, but also in the transmission of radiant energy from the distant stars to our terrestrial globe.

This understanding gave us the first glimpse of that unity of the universe in which the invisible harness, joining every one of its parts to every other part, is always ready to transmit service which moving electricity makes available.

Faraday and Maxwell, however, had not spoken the last word concerning the invisible cosmic coupling. New explorers of the boundless region, revealed by the visions of Faraday and Maxwell, have delivered and are still delivering new messages from this region, unfolding many of its secrets. What are these secrets and how does their unfolding affect the views of the electrical science and its art, electrical engineering?

Franklin was the first to profess the belief that all electricity has its origin in material bodies. Faraday's discovery, that to each atomic valency there is attached a definite electrical charge, gave Franklin's belief a more intelligible form, which appealed to our imagination more and more as the conviction grew stronger, that all chemical reactions are due to the activities of the atomic charges. It was this conviction which suggested the name "electron" to the smallest unit of atomic charges long before its independent individual existence had been demonstrated by actual experiment. Roentgen's discovery of the X-ray suggested the hypothesis that these rays are excited by the impact upon the anode of tiny projectiles, shot forth with enormous velocities from the cathode of a high vacuum tube. Experiment proved that these projectiles are the individual electrons, the existence of which in the atomic structure had been suggested by Faraday's electrochemical discoveries; experiment also determined their electrical charge and inertia. This is the foundation of modern *electron-physics* and it is so broad that it furnishes new support to the foundation of the Faraday-Maxwell electromagnetic theory, to chemistry, astrophysics, meterology, biology, and, above all, to electrical engineering. It has created a new electrical industry and a new type of electrical engineering. It is the busy electron in the amplifying vacuum tube which gives life to the radio broadcasting industry and supplies new problems to the electrical engineer, the so-called radio engineer; it carried conviction to those who were inclined to think that the tiny electron was only a fiction of a supersensitive scientific imagination.

The Electron, the Primordial Unit of Power Generation

The marvelous success of this new electrical industry and of the electrical engineering which guides it, directed our attention to the function of the electron in all electrical power operations. The result is that today the electron and its positive partner, the proton, have become the fundamental concepts in the science of modern physics and in the art of electrical engineering. The tubes of electrical force between them are the primordial electrical flux, the fundamental and the only substance in the web of the cosmic harness. The relative motion of that primordial flux manifests itself as the magnetic flux which measures the momentum of this relative motion. Relative to what? Relative to the observer who is measuring that momentum. A charge moving with the observer has no momentum relative to the observer and is not accompanied by a magnetic field which the observer can detect.

Electron-physics made a fundamental contribution to the achievements of Oersted, Faraday and Maxwell when it demonstrated the individual existance of the electron and the proton and pointed out that the electrical flux, which unites the two, is the primordial flux, the cosmic bond of union between all electronic granules in the universe. This is the invisible harness to which all parts of the cosmic space are hitched up. To the electrical engineer who is a disciple of the Faraday school of thought the electronic granules are unintelligible except as local convergencies of the primordial flux. It is the activity of the flux which tells him the story of energy movement from one part of space to another and without this energy transference, the motion of the isolated electronic granules would have but a very small interest for him. He is, it is true, interested in the cosmic processes by which heavier atoms are evolved out of lighter atoms by a suitable grouping of the electronic granules, but that which interests him incomparably more is the energy liberation in these processes and the invisible harness along which the liberated energy is transmitted, destined to perform some useful service in some distant part of space. He is also interested in the energy which is stored up in the formation of the atomic nucleus, and how much of it can be made available when the structure of the nucleus is changed as in radioactivity.

Electron-Physics interpreted in terms of Faraday's visions and Maxwell's quantitative formulation of them suggests to the electrical engineer a universe which reminds him of a power distribution system in which there are an endless number of power stations all interconnected by the primordial flux. Material bodies, from the smallest atoms to the biggest stars, are, according to this picture of the universe, local aggregations of electronic centers in the all-embracing, primordial flux. This cosmic structure, however, is not a static but a dynamic one. Every one of its electronic centers is in a state of activity, receiving energy from its busy neighbors and giving it out without cessation or rest. It is pulled by or is pulling at the cosmic harness to which it is inseparably attached. It is doing its share of service in the evolving universe, and how much of this service is to benefit man depends upon the man himself; upon his science and art of electrical engineering. It is the problem of the electrical engineer to transform the activity of the infinitely numerous, but infinitely small, electronic toilers in the cosmic power stations into orderly service for the uplift of the life of man. He is the coordinator of the restless activity of

these toilers; they follow his bidding as if guided by the magic wand which Faraday and Maxwell and their disciples gave him; they are his obedient servants. Here, they heat an electrical furnace and there, they guide chemical reactions; here they drive the propellers of a battleship, and there they turn the busy wheels of an industrial plant; here, they speedily carry the weary industrial toiler to his home and there, they make it cozy and comfortable by their light-giving service; here, they record the cheerless figures of the stock exchange ticker and there, they carry sweet melodies and soul stirring language to the millions of eager listeners on this hopeful continent.

It is a master mind, indeed, that can thus control the activity of an infinitely numerous army of toilers. No vulgar rule of the thumb can find a lasting place in the logic of such a mind; its art, is an exact science and its science is supported by an art the experience of which, through many generations, has been tested by methods of measurement of astronomical precision. No vague and hazy notions obscure the lucidity of the electrical engineer's operations. The enormous electrical efforts of his million-kilowatt power station are just as lucid to him as the feeble efforts of the tiny electrical power which brings us the wireless message from distant Australia. Both of these efforts are huge in comparison with the efforts of a single electronic toiler in terms of which the electrical engineer can express every electrical effort. He knows the numerical value of the labor of these tiny workers and he also knows that it is their toil by which the lily, without toiling or spinning, arrays itself in beauty which far surpasses Solomon in all his glory. It is their toil which promises to the civilization of man a beauty and glory which will far surpass the beauty of the lily. The mission of the electrical engineer is to make this promise good. In the performance of this mission, he will keep always in mind the words of St. Luke who glorified the blessedness of the indolent lily. The apostle said:

"And seek not ye what ye shall eat, or what ye shall drink, neither be ye of doubtful mind."

"But rather seek ye the kingdom of God; and all these things shall be added unto you."

The men who made the science and the art of electrical engineering did not seek what they should eat or drink. But in their thirst and hunger for the eternal truth they did seek and find, in part at least, the kingdom of God, which resides in the beauty of their science and its art, and in the beauty of the universe which they reveal. That science and its art are the creation of a new philosophy which we call the philosophy of idealism in science. It is the simplest philosophy ever constructed by the mind of man and represents the essence of scientific experience of centuries; an experience which was always guided by a definite motive, a definite mental attitude, and a definite method of work. The motive was the unselfish longing for God's eternal truth; the mental attitude always demanded an open minded and unprejudiced interpretation of nature's language; the method of work is that by which our patron saints Gray, Franklin, Volta, Oersted, Ampère, Faraday, Maxwell, Roentgen and their disciples created the science and the art of electrical engineering. This motive, mental attitude, and method of work is the firmest foundation of the scientific idealism which is the idealism of our profession and we have always been the leaders in the propagation of its gospel. We were the earliest apostles who converted the American industries, so that today they worship at the altar of the Idealism of Science. We must impress that idealism upon all phases of our national life, in order to assist our nation in the solution of the many complex problems of modern democracy.

OIL ENGINES RECLAIM THE DESERT

In the waterless desert, where natural power does not exist, oil engines are developing profitable industry by generating accessible power. A striking example of this may be found at Gerlach, Nevada. Here, in the granite mountains, a rich deposit of rock gypsum was discovered. It was ten miles from the nearest railroad and, being in the heart of the desert, coal was not obtainable. There was neither power, nor water, and there were no housing facilities. Added to these obstacles, the climate in the region covers an unusually wide range of temperature—from as low as 40 deg. below zero in winter to 115 deg. in summer.

The corporation quarrying the gypsum to make plaster of various kinds has overcome all these difficulties. A great mill has been erected and is running full blast, a five-mile aerial conveyor has been provided, a plant railroad has been built, an attractive village for the workmen has been constructed, and also, a large power house from which emanates electric power for manifold purposes. Where once the desert lay silent and untouched, engineering skill has created a busy hive of production—manufacturing one of the greatest industrial necessities, plaster. The machinery about the mill is driven by electric motors, the power being generated by three 8-cylinder 800-h. p. engines, each connected to an electric generator. Owing to the climate, special open-air construction was used to facilitate the radiation of heat from the conductors. These 800-h. p. engines use heavy fuel oil and employ the same principles of fuel injection as the engines used in the oil-electric locomotives which are attracting so much attention from railroad executives on account of their economical fuel consumption. Oil engines such as these, utilizing a minimum amount of precious water, are an available asset in the Nevada desert. The same economy in water applies also to the oil-electric locomotives.

Marine Work

Annual Report of Committee on Application to Marine Work*

L. C. BROOKS, Chairman

To the Board of Directors:

The work of the Committee on Application to Marine Work for this year has been very largely a continuation of the work of the last year, in connection with the compiling of the Revised Rules, which we hope will be ready for publication during the present summer.

As has been the case in the past several years, the work of this committee has been divided into sections, each in charge of a subcommittee, including propulsion, power apparatus, interior communication, fixtures and fittings, wire and cable, radio, historical, and editing. Each subcommittee prepared revisions of the Marine Rules applicable to their work, which revisions were discussed and approved by the main committee, and afterwards turned over to the editing committee for final compiling.

The work of these subcommittees is to be commended, especially from the fact that there are many avenues of thought which needed to be correlated into a unified final decision by the main committee. The entire revision is now in the hands of the editing committee, and it is anticipated that it will be ready for publication very shortly.

At the present time the marine industry is not active, of course, but due to the fact of more stringent requirements of insurance, it is very important that these Revised Rules may be issued as soon as practicable, in order that the United States may have some definite standard as a basis.

A. I. E. E. Marine Rules are now accepted as standard, as far as applicable, by the American Bureau of Shipping, and nearly all of the naval architects and shipbuilding companies.

In addition to the work on the Marine Rules as above mentioned, there were several committees consisting of other lines of thought that were allied with the marine work, as follows:

Personnel Committee, working in conjunction with the Department of Commerce and new commanding officer in charge of the steamboat inspection service; also working in conjunction with the law officer of the Shipping Board. There is considerable optimism that some definite results will be obtained in connection with the proper recognition of electrical engineers on board ships.

This committee has also given assistance in connection with the Department of Commerce, which is endeavoring to establish a uniform practise in fire alarm laws, which is a very important subject in connection with marine navigation. This phase of the question will include also electrical systems or devices in the form of automatic steering arrangements, navigating instruments, sounding machines, etc.

In connection with the committee as a whole, it is with regret that we chronicle the death of W. F. Meschenmoser of the Russell & Stoll Company. Mr. Meschenmoser has been for many years an active member of this committee and chairman of the subcommittee on fixtures and fittings; his work will be greatly missed in future activities and meetings of this committee.

Also, it is reported with keen regret that Mr. Maxwell W. Day, who has been a member of this committee since its inception has found it necessary to retire from all business connections, and resigned from the committee early in the year. Mr. Day's personality and valuable technical experience has been a great asset to this committee through its entire life, and he has been greatly missed.

During the past year one paper has been presented at the Pacific Coast meeting, on the subject of electric propulsion. No doubt the coming year will see other papers prepared for presentation at some of the Regional meetings.

As to the work of the future, it is believed that the work of this committee will be very important in keeping these rules up to date, to conform to changes that develop with the advance of time and the development of the art. This will apply especially to interior communication apparatus, wire and cable, and personnel. It is also believed that considerable work is possible and desirable in connection with standard approval of fittings.

A very important factor in connection with the work of this committee is the cooperation between the work of this committee and other committees covering the manufacture of apparatus and appliances. The application to marine work requires certain refinements and rigid construction not necessary in ordinary apparatus, and for that reason the work of the Marine Committee must of necessity cover construction details more than is ordinarily considered the function of other industrial committees.

In conclusion, the chairman wishes to thank the committee as a whole, and the chairman of the subcommittees in particular, for their good work during past year, and the results which they have obtained.

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*Committee on Applications to Marine Work:
L. C. Brooks, Chairman
H. F. Harvey, Jr., Vice-Chairman
J. S. Jones, Secretary

R. A. Beekman,	A. Kennedy, Jr.	H. M. Southgate,
J. F. Clinton,	M. A. Libbey,	W. E. Thau,
C. S. Gillette,	E. B. Merriam,	C. P. Turner,
William Hetherington, Jr.	W. F. Meschenmoser,	A. E. Waller,
H. L. Hibbard,	I. H. Osborne,	J. L. Wilson,
Edward C. Jones,	Arthur Parker,	R. L. Witham.
	G. A. Pierce,	

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, W. Va., June 21-25, 1926.

Discussion at Midwinter Convention

THE RATINGS OF ELECTRICAL MACHINES AS AFFECTED BY ALTITUDE[1]

(FECHHEIMER)

NEW YORK, N. Y., FEBRUARY 10, 1926

R. E. Doherty: The accompanying Fig. 1 represents a generator. The cooling air enters at a temperature T_1. We are considering some spot, S, on the surface. There is a temperature rise of the cooling air which is occasioned by its passing over the heated surface before it reaches the spot in question. This brings the cooling air, the air to which the surface transfer is made at that spot, up to T_2. Then there is a rise of the surface temperature above that, which is T_3. There is a still further rise of the copper to T_4.

I wish to emphasize that Mr. Fechheimer's equations refer to some particular spot. T_3 is the surface temperature at that spot, and T_4 is the copper temperature. The temperature rise $(T_4 - T_3)$ is not a function of the barometric pressure. The temperature rise $(T_3 - T_2)$ is a function of the pressure, varying, let us say, as the 0.75 power. The rise $(T_2 - T_1)$ is also a function of the barometric pressure, but not the same function as for $(T_3 - T_2)$. It varies as the 1.0 power instead of 0.75.

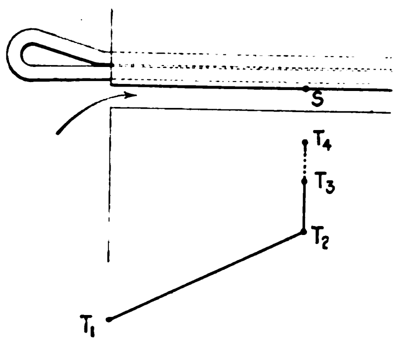


FIG. 1

The temperature rise of the surface spot, S, will depend upon the heat dissipated from it. Mr. Fechheimer's factor k, which corresponds to the factor a in the paper[2] presented by Mr. Carter and myself in 1924, is the fraction of the loss dissipated from the spot or surface which is due to $I^2 R$ loss. It should be observed that this is not the ratio of the copper loss in the machine to the total losses. There may be spots from which there is practically no heat due to $I^2 R$ loss, and others where all of it is due to $I^2 R$ loss. Hence, the table for k in Appendix II is without meaning until it is specified to what surface the values apply.

The author brings out the fact that there are two view-points from which this problem may be treated, which I should state as follows: One may take the temperature rise at sea level for a given load, and calculate the increase in temperature rise *for the same load and losses* when the machine is operated at altitude. The other is to calculate what reduction in load, and, therefore, losses, is necessary to give the same temperature rise as at sea level. The author takes the latter view-point; our paper in 1924 took the former. If correctly done, either gives adequate data for rules. I found the problem difficult enough without having to worry about the redistribution of losses and the necessary additional and very questionable assumptions required thereby. Since, however, the author's results check with those we obtained the other way, I naturally endorse it on the grounds of Dr. Kennelly's philosophy. If it is a convenient form of representation, and fits the facts, it is a perfectly good thing to do.

Now as to what Mr. Fechheimer says about my paper: "In the paper by Doherty and Carter, the exponent for forced convection was found to be 0.73 and to simplify calculations, they used 0.75. This seems to be correct for the machines for which they give data in their paper. As we understand their results, the exponent 0.75 takes account of the air rise as well as the surface transfer. It is felt, however, that their tests are too limited to warrant us to draw conclusions." He adds also that the results were of too complicated a nature to be used as a basis of engineering rules.

Our paper covered the general case. Convection, which is the only factor considered by Mr. Fechheimer, is not the total means by which heat is dissipated. Radiation may be a dominating factor. There are all grades between predominating radiation and predominating convection. Certain tests which I made, gave this figure 0.75, which checked with results on machines so far as they were available at the time. I still think it is about right. We took the rise $(T_3 - T_2)$ into account in a term which we called y. The rise $(T_2 - T_1)$ was accounted for in the term z. We properly combined the two results and called that x. We did not lump them, as Mr. Fechheimer has done, into one factor varying as, say, 0.9 power. It depends upon other factors.

Mr. Fechheimer says that our expressions are too complicated. The phenomenon itself is complicated of course, when the general case is considered. But after obtaining the equation for the general case, the specific data applying to a special case, such as Mr. Fechheimer has treated, may be substituted, and the resulting forms are extremely simple. Our paper gave these simple forms for various special cases, and the relation for the present case was a linear relation as simple as Ohm's law; and Mr. Fechheimer's numerical results, as shown in his Fig. 2, are in substantial agreement with ours.

So, his first point that the exponent 0.75 was taken as applying to both temperature rise, $(T_3 - T_2)$ and $(T_2 - T_1)$, isn't correct. They were not lumped together but were treated separately, and then logically combined.

Now, as to the point that results given were too limited for the drawing of conclusions: there may be justification of statement that they are too limited to draw *broad* conclusions, but I question his justification in saying they are too limited to draw *any* conclusions. We set up a logical theory under definite assumptions and then justified the conclusions by experiment. That is sound engineering. If it satisfies all the facts as they are known, it is reasonable to take the results as applicable within the limit of those facts and assumptions. That is just what we did. A rational theory was set up, taking into account not merely the condition of forced convection, but also the general case where part is radiation and part convection which takes into account the other details which may be thrown out or left in, as conditions may demand.

Then we made certain tests which checked up points on which existing data were insufficient, and applied that theory to actual machines under the conditions of pressure below atmosphere. The results agreed. Other tests were made on an actual machine in the field, first at sea level, then at high altitude. The data obtained on the machine were not complete, but such as were complete were in satisfactory agreement. So upon that basis I venture to suggest that our results are competent within the limits we specify.

I wish to say just a word about the several statements that equations are too complicated for A. I. E. E. rules. Of course they are. An investigation, which of course involves equations to determine a basis for framing simple rules, is one thing, but

1. A. I. E. E. JOURNAL, February, 1926, p. 124.

2. Effect of Altitude on Temperature Rise, by R. E. Dougherty and E. S. Carter, TRANS., A. I. E. E., 1924, p. 824.

making those simple rules is quite another. The present paper, covering one case, and our paper in 1924, which covers many, including that one, are such investigations. Mr. Paxton's proposal represents such simple rules. Therefore don't throw out results because there is an equation in them; otherwise you won't have anything upon which to build a simple rule.

P. L. Alger: An amateur reading Mr. Fechheimer's paper would probably be left with the impression that the effect of altitude on rating is greater than it actually is. For instance, Fig. 6 indicates that a very large reduction of rating may occur at high altitudes. But actual machines, designed for use at high altitudes, would be made with reduced flux densities and lower no-load losses than standard machines. Thus, it is more representative of normal conditions to take the total losses as proportional to the kv-a. rating than as a constant plus K times the square of the load. With this assumption, the effect of altitude on rating is reduced to that shown in Figs. 2 and 3 of the paper.

In the second place, the normal ambient temperature falls about 5.5 deg. cent. for each thousand-meters increase in altitude, or by nearly the same amount as the increase in full-load temperature rise of a normal machine due to the reduction of atmospheric pressure for the same increase in altitude. Therefore, if the cooling air is taken from outside the station, there is practically no change in rating required by change in altitude in the average case. Only when open machines designed for use in heated stations are considered is it necessary to allow for any reduction of rating. And even in these cases the maximum ambient temperature to be expected is certainly less than the maximum ambient temperature that may be met in sea-level operation, so that here, too, the reduction in rating need not be as great as that indicated by Figs. 2 and 3.

E. B. Paxton: I think we should thank Mr. Fechheimer for pointing out quite clearly the different ways in which the altitude correction may be taken into account provided there is sufficient information to do so. As he has said, the present A. I. E. E. rule takes into account only the case where the temperature rise is limited in a test near sea level by the amount of the correction for installation at a higher altitude. For this condition, the results that he obtains check, fairly closely, the results obtained previously by Mr. Doherty, as well as the present A. I. E. E. rule.

I think the present A. I. E. E. rule is faulty principally in that it takes care of that one condition only. It is my opinion that in a great many cases, a correction is made where it is unnecessary, and that, as Mr. Alger has pointed out, the ambient temperature will be sufficiently low to offset the correction necessary for the altitude.

This matter of correction for altitude would seem to be a relatively unimportant matter considering the many other conditions that affect the design and installation of a machine. For that very reason, we should be just as sure that any rule which is standardized does not require corrections unnecessarily as we are to cover the necessary cases.

Along this line, about a year and a half ago, I proposed a rule for inclusion in the A. I. E. E. Standards which is, I believe, an improvement on the present A. I. E. E. rule, in that it does take advantage of a reduction in ambient temperature at the higher altitudes and covers one of the cases which Mr. Fechheimer mentions in his paper. I think we must regard two kinds of applications: first, that of a standard machine, and we should make rules which will allow its application under all conditions where it may safely be used; second, we must recognize that there are conditions where it is necessary to use a special machine. I should like to see the present A. I. E. E. rule extended to allow the use of machines of standard temperature rise at high altitudes, provided the ambient temperature is low enough to compensate for the increased temperature rise. I am convinced that there are many cases where standard machines may be used safely at the higher altitudes without any correction.

W. F. Dawson: First of all, I want to suggest the probability of the ambient temperatures at high altitudes not necessarily being lower than at sea level. I have a record of certain tests on a 2550-h. p., 3600-rev. per. min., synchronous motor which I designed and tested some four years ago at our factory in Lynn, Mass., and repeat tests that were made in the Andes Mountains at an altitude of 14,000 ft. The ambient temperature during the mountain test in January was 21.5 deg. cent., which compares approximately with that in this vicinity. Of course, had that 14,000-ft. altitude been in the Canadian Rockies, the situation would have been different, but one must not forget that high altitudes exist also in tropical countries.

It seems to me that the crux of the situation is all ambient temperature. If the density of the cooling air, due to greater elevation, is lower than standard, its thermal capacity for a given volume is proportionately less. The average temperature difference between inlet and outlet air on self-ventilated turbine alternators at sea level will be between 15 deg. cent. and 30 deg. cent.

At the end of the test of the machine to which I have just referred, inlet air was 28.7 deg. cent. and outlet air 45.8 deg. cent., a difference of 17.1 deg. cent.

According to the formula used in Mr. Fechheimer's paper, the reference-air density was about 0.6 atmosphere which would mean that, at the 14,000-ft. station, the temperature rise of the air after passing through the motor would be 17.1 deg. divided by 0.6, or 28.5 deg., an increase of 11.4 deg., and that is slightly more than the temperature differences we ordinarily expect. It is unfortunate that, while we used temperature indicators at the factory, they were not available at the high elevation; but we did get a very good check on the field in spite of the fact that it was run at the higher current.

In turbine alternators, (and this synchronous motor is a turbine alternator fitted with a starting winding), one of the major losses of the machine is the windage loss. Windage loss will be from 0.3 to 0.5 of the total. In this particular case, at sea level the total loss passed through the machine at its rating, that is, the loss handled by the air, was 57.3 kw. Of that amount, 19.8 kw. was windage. What happened at the higher altitude? The 19.8 must be multiplied by 0.6 because the volume is the same at higher altitude as at the lower altitude, and the windage loss is in proportion to the density of the air, so 8 kw. of that loss are saved at the higher altitude. That is one of the credits of the problem.

The heating by increase in resistance of that field with 93.5 amperes at sea level was 40.8 deg. cent., of which 12.7 deg. was due to windage loss alone, leaving 28.1 deg. attributable to $I^2 R$. The test at higher elevation was run at 100 amperes. If we multiply that 28.1 by $\left(\frac{100^2}{93.5}\right)$, we obtain 32.3 deg. That will be the temperature rise due to copper loss, but the total temperature rise must allow also for the air friction. This will be no longer 12.7 deg. but 0.6 of 12.7 deg. = 7.6 deg. Adding this to 32.3 gives 39.9 deg. as the estimated field rise for the higher altitude. The value reported from Peru was 40.3 deg. cent.

My feeling is that the problem does not involve much of mathematics, but judgment combined with experience, and that it probably reaches its greatest simplicity in turbine alternators and similar machines where the air paths are systematically directed. The principal difference in temperature rise will be due to the fact that the ventilating air, because of lower density, will have a higher average temperature at the air-gap and where the windings are to be cooled; hence their temperature will be correspondingly greater.

The fact that the low-density air has a correspondingly less windage loss must not be overlooked. The full-load efficiency of the motor I have just been discussing was 96.45 per cent at sea level. About 8 kw. of windage loss was saved due to rarefied air at 14,000 ft. altitude, thus bringing the efficiency up to 96.84 per cent.

Sometimes it has been possible to apply the principal of the supercharger to machines which otherwise would have to be derated for operation at high altitudes. It is only necessary to provide special fans which increase the volume of air to correspond with its reduced density and thus insure the same temperature rise ordinarily obtained at sea level.

H. M. Hobart: I am of the opinion that from a standardization standpoint this subject will be best straightened out on the basis that the rating will be the available capacity of the machine at sea level. As Mr. Fechheimer suggested, sometimes you can take more out of the machine at higher altitudes, and sometimes less, according to the prevailing temperatures. That won't change the rating. The rating will be the available capacity at sea level and 40 deg. cent. cooling-air temperature.

G. E. Luke: The present A. I. E. E. rules (1925) for rotating motors and generators, (excepting railway motors), cover altitude limitations as follows:

"Unusual Service Conditions: The use of machines in cooling mediums having temperatures higher than 40 deg. cent. or at altitudes greater than 1000 meters (3300 ft.) should be considered as special."[3]

A similar statement is found for air-blast transformers; however, for self-cooled oil insulated transformers, the correction is 4/10 per cent per 100 meters instead of one per cent. From the wording of the footnote, ("it is provisionally agreed"), it is assumed that this correction was subject to doubt.

Both this paper by Mr. Fechheimer and a previous one by Messrs. Doherty and Carter[2] have brought out the fact that the altitude correction is considerably influenced by the ratio of copper-to-core loss and by the temperature gradient through the insulation. These factors are of considerable importance when temperatures are determined by embedded temperature detectors.

On the basis of certain assumptions, all of these factors can be

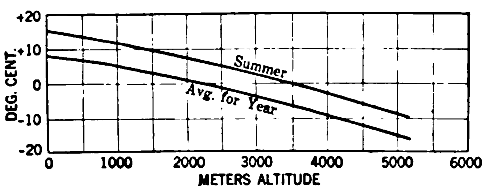


FIG. 2

combined into a group of equations; however, since some of the constants are factors of design, the equations are not in a suitable form for incorporating in the A. I. E. E. Standards.

In the discussion of the Doherty and Carter paper, Mr. E. B. Paxton suggested a plan whereby the maximum ambient temperature for various altitudes could be limited on the basis of a sea-level rating. Mr. F. D. Newbury's modification of this plan, I believe, offers a suitable solution for this unusual service condition. Naturally, such a simple solution is a compromise and is only approximate. It is warranted due to the very small per cent of machines operated at altitudes above 1000 meters (3300 ft.) and also to the average decreasing ambient temperature with increasing altitude. The accompanying Fig. 2 shows the average summer temperature at various altitudes taken near Paris, Brussels, Strassburg, and Munich, as given by the Smithsonian Physical Tables.

Where machines are to be operated indoors at high altitudes with ambient temperatures greater than those specified, the conditions should be regarded as special and the corresponding rating can be specified by the manufacturer as calculated by the method given by Mr. Fechheimer.

C. J. Fechheimer: It would seem that Mr. Doherty has understood me to be critical of the work which he has done. That is far from my purpose, for I appreciate the value of it. As he has pointed out, I have evidently mis-read one statement in his paper. Since he is considering the temperature rise of the surface above the air adjacent to it, and since his results and mine agree, there is no occasion for further discussion on this point; in fact, it is gratifying to note that we are in agreement.

With the simplified equation (36) in his paper, he takes account only of the surface drop and must then add the air temperature rise to it. In general, the air temperature rise is not known, particularly if it is taken from the entrance of the machine up to a particular point. Consequently, the purchaser of a machine is still considerably in doubt as to how to apply the equations. The method which I use, of taking a mean between the exponent, 1, for the air rise, and the exponent of about 0.75 to 0.80 for the surface rise, is not mathematically correct; nor with the possible variations in air temperature rise as compared with the surface drop, is it strictly correct to apply the method which I have used. My purpose was to place this complex subject on such a simple basis that the A. I. E. E. Standards Committee could embody it in its rules. Referring to Fig. 2 in my paper, it will be seen that the influence of the variation from an exponent of 0.75 to 1. is not very great; consequently, taking as an approximation a value of, say, 0.9, the error is not of great magnitude. After all, that is all with which we are concerned. In the present A. I. E. E. rule, as the total temperature rise is considered, it is not broken up into its two components, and in my opinion it will be necessary, in any revised rule, to follow this same practise.

Mr. Doherty refers to the constant k in my paper, which is the fraction of the loss in the core that is proportional to the square of the load at sea-level rating. In making up the tables in Appendix II, I considered that all the $I^2 R$ loss that was in the embedded part was liberated from the core, or from the straight parts of the coils, and that the end windings took care of themselves so far as dissipating their generated heat. That assumption may not be justified, and for accurate solutions, consideration should be given to the longitudinal heat flow along the copper and the transverse heat flow through the insulation. That, however, puts the problem entirely out of the range of a practical solution. Fortunately, this factor k disappears when only the temperature-rise ratios are considered. It appears in the equations when the ratio of ratings is solved for. After all, those solutions for ratings will be of value probably only to the designer and not to the purchaser of the machines, and the designer can approximate the percentage of heat generated in the embedded copper which is transmitted longitudinally or transversely. In the long-core machines, he will not introduce much of error if he considers all of the embedded $I^2 R$ loss to be liberated in the straight part. More of error is introduced in the short-core machine.

I confess that I do not understand how Mr. Doherty has reached the conclusion that I considered only the reduction in load, and not the increase in temperature. Equations (1) and (2) are solutions on the basis of temperature. Equations (3) to (6) are on the basis of ratings.

It is true that I have considered forced convection only. In the majority of machines in which fans or their equivalent are used, radiation may be excluded, and even free convection is of little consequence. My paper is not intended to cover such apparatus as self-cooled transformers or motors which liberate a large percentage of their heat through the outside casing by radiation or free convection. The statement which I made in my paper, to which Mr. Doherty refers, *i. e.*, that the equations in his paper were complicated, was prompted by such equations as (18) and (30), the former covering the general case and the latter the case for forced convection. My whole

3. "For apparatus intended for service at altitudes greater than 1000 meters (3300 ft.) it is provisionally agreed that the permissible temperature rises (to be included in contracts and checked by test at low altitude) shall be less than specified in these standards by 1 per cent of the specified rise for each 100 meters (330 ft.) of altitude in excess of 1000 meters (3300 ft.)."

purpose in writing the paper in the manner as presented was to place it in simple form before the members of the Institute.

Mr. Alger states that by reducing the flux densities, the ratings need not be reduced. That is undoubtedly so, but in many cases, machines with standard windings will be applied at the higher altitudes, chiefly to save the expense of making special machines. The other point that Mr. Alger makes in regard to ambient temperature, would I think, bear further study. While it is true that we have, from the Bureau of Standards, data on ambient temperature, and, as Mr. Luke points out in his discussion, from parts of Europe, a more thorough study of this whole subject could be made by the Standards Committee in order to offer suitable recommendations. Undoubtedly, in many cases the lower ambient temperature will practically off-set the loss in rating that would otherwise be occasioned by the lower density.

Mr. Paxton's comments are largely along the same line of ambient temperature. He previously contributed valuable material in his discussion of Mr. Doherty's paper, and his suggestions are worthy of study by those who will participate in the revision of the rules.

The point that Mr. Dawson makes, that the ambient temperature at 14,000-ft. elevation in January was 21.5 deg., is of considerable interest. However, January is summer in South America, and the particular locality was not far from the equator. The specific machine upon which he had tests made, *i. e.*, a turbo alternator for which the windage loss decreased considerably, is undoubtedly a special case and cannot be treated along with the general cases. While special fans may be added to increase the volume and thereby obtain lower temperature rises at the higher altitude, in general such a scheme is not to be adopted, as it would make the machine so highly specialized that the manufacturers would seldom go to the expense, nor would the customer wish to pay for it.

Since writing the paper, my attention has been called to a rather unusual phenomenon. It is claimed by some of the railway engineers that in a-c. commutator motors, brush-friction loss decreases with increase in current. It is even claimed that some of these commutators run cooler at normal full-load than they do at no-load. I am offering no explanation for the cause of this phenomenon, but, assuming that the statement is correct, the correction for altitude as given for commutators in Appendix IV no longer holds. Not knowing the rate of decrease in brush-friction loss with increase in $I^2 R$ loss, it is impossible for me to suggest a solution to that part of the problem.

One other item of comparatively small importance was not considered in the derivation of the equations. With lower ambient temperature, the air density is increased; with increase in density, both the air-temperature rise and the surface drop decrease. At the higher altitudes, if the ambient temperature is lower, the rating of the machine is not decreased so much as indicated by the equations. It is believed, however, that this additional correction need not be given much consideration.

MOTOR BAND LOSSES[1]

(Spooner)

New York, N. Y., February 10, 1926

G. E. Luke: In particular I remember one experimental machine designed for high-speed railway work that gave considerable trouble due to the bands coming loose. Some attributed this to the high centrifugal stresses; however, later tests proved the trouble to be due to excessive band losses. Careful insulation of these bands reduced the stray losses and no more such trouble was experienced. After Mr. Spooner had completed his first tests on band losses I arranged tests on a 50-h. p. railway motor. Small thermocouples were soldered to the bands and others placed on the winding and core. These couples were brought out to special slip-rings so that the temperature could be determined with the motor running. In this way tests were made with insulated and uninsulated armature bands. An appreciable temperature difference was found between the two tests. In some cases the uninsulated armature had temperatures 10 deg. cent. higher than that armature with insulated bands.

1. A. I. E. E. Journal, January, 1926, p. 14.

Due to the many other losses and factors that must be controlled, work of this nature must be done with a high degree of accuracy and requires considerable patience on the part of the experimenter. Mr. Spooner has also put the data in such form that they can be used in determining the losses on other machines of similar design.

J. C. Lincoln: Some years ago, a case of trouble from bands throwing solder was solved in the following manner: In this particular case the machine was an eight-pole machine and the bands, as is customary, were soldered entirely around the armature. The trouble was corrected by placing four strips for holding the wire of the bands together at 90 deg. around the armature and soldering the bands only where these strips were placed. This left a north pole and a south pole between each of the strips and the bands were not soldered between these strips. The total magnetic induction between the bands was zero.

In other words, between each typing strip there was a north pole and south pole and therefore there was no voltage induced in the bands between each of the tie strips. As the result of this change, the machine which had been throwing solder around the bands and giving trouble was corrected entirely.

P. L. Alger: I should like to ask Mr. Spooner if he has made a study also of the losses in the binding bands on the end conductors of rotating armatures, and, if so, whether such losses are ever large.

Thomas Spooner: Replying to Mr. Alger's questions, we have never investigated systematically the losses occuring in bands which hold the end windings of machines in position. These losses are often appreciable but we have no quantitative data concerning them.

In the case of Fig. 2 of the paper, the losses there given are for the unwound armature. If the armature windings had been in position, as they were for certain later tests, the losses would have been higher, due to eddy currents in the copper.

PROPERTIES OF THE SINGLE CONDUCTOR[1]

(Hering)

New York, N. Y., February 11, 1926

S. L. Quimby: In the classical electromagnetic theory, self-inductance is specifically defined and invariably calculated as a property of a complete electric current circuit. No theory consistent with the facts revealed by experiment has yet been developed to make possible the calculation of the self-inductance of any portion of a circuit.

I now propose to analyze the two experiments described by Dr. Hering and to point out the way in which the energy relations derived by him differ from those which are in accord with the electromagnetic theory.

I shall first consider the second of these experiments. Dr. Hering bases his analysis of this upon a theorem ascribed to Lord Kelvin. This theorem states that if any system of current circuits in which the currents are kept constant by batteries is allowed to alter its configuration, then, of the work done by the batteries in keeping the currents constant, one-half will appear as increased magnetic energy of the system of currents and one-half as mechanical work.

Fixing our attention upon Dr. Hering's apparatus, we imagine that, initially, the weight is locked rigidly in place and furthermore that the whole conductor is perfectly rigid. A current flowing in this conductor now supplies us with a definite system of

1. A. I. E. E. Journal, January, 1926, p. 31.

current circuits, namely, the very large number of filamentary conductors into which the finite conductor may be imagined to be divided. With the weight still locked in place, we now suppose that the conductor is no longer rigid, but elastic. Under the action of the pinch forces, it will shrink, radially. Its self-inductance will therefore increase by an amount ΔL, and the magnetic energy of the system will increase by an amount $1/2 \ . \ \Delta L \ . \ i^2$. At the same time, a certain amount of mechanical energy is stored in the elastically strained conductor. Kelvin's theorem tells us that this energy of elastic strain is precisely equal to the increased magnetic energy. The radial displacement of the material of the conductor accompanying the shrink involves a cutting across the lines of magnetic force in the conductor, and the counter e. m. f. thereby developed accounts for the work done by the battery in supplying the elastic energy.

This is as far as Kelvin's theorem carries us in our analysis, for, if we now release the weight, it will move and this motion will cause the introduction of *new conducting material into the circuit*. We no longer have a definite system of conductors to consider but instead a system which is continually changing through the continual introduction of new conductors. Kelvin's theorem can no more be applied to an analysis of this machine than it could to an analysis of an ordinary d-c. motor, in which, barring resistance, all the energy supplied by the battery appears as mechanical work and the magnetic energy remains practically constant; and this for the same reason, since the commutator on a d-c. motor is merely a device for continually introducing new conducting circuits into the system.

The introduction of new mercury into the conducting system involves a radial flow across the lines of force in the conductor and it is easily shown that the work done by the battery against the counter e. m. f. thereby developed is precisely equal to the mechanical energy acquired by the raised weight.

Dr. Hering's analysis of his first experiment is based upon an assumption which, in the light of the electromagnetic theory, is false. He assumes that if the pinch pressure is allowed to annihilate a fluid-conducting circuit of the type described, then the mean pressure, *i. e.*, the pressure at a distance $R/\sqrt{2}$ from the axis of the conductor, will be constant. This, as the author shows, is equivalent to the assumption that the current will decrease linearly with the radius. Calculations based upon the electromagnetic theory show that under the conditions of the experiment the variation of the current with the radius of the conductor as it collapses would be given by the expression

$$I = [\log (2\, p\, l/R)]^{-1}$$

where

$$1/p = \log^{-1} (3/4),$$

and

l = the length of the conductor.

In conclusion it may be observed first, that the classical electromagnetic theory has never concerned itself with the calculation of the self-inductance of, nor the energy associated with, a unit length or any other portion of a current circuit, and second, that the argument by which the author arrives at his value of these quantities is not consistent with that theory.

A word should be said on behalf of the self-induction formulas supplied by the electromagnetic theory. Where these are calculated for the simple circuits, of whatever size, referred to by the author, they do not necessarily contain approximations, never involve empirical constants, and are never derived by extrapolation.

The author, if I understand him correctly, maintains that the process of evaluating the total magnetic energy in a certain space by integrating the Maxwellian energy density $H^2/8\pi$ throughout that space, is valid only when the magnetic field is uniform in direction. It seems to me that this criticism lacks weight. Consider, for example, a circuit consisting of a straight cylindrical conductor with a return through a concentric cylindrical conducting sheath. I doubt very much whether Dr. Hering will deny that the energy associated with such a current circuit can be obtained correctly by integrating $H^2/8\pi$ throughout the volume enclosed by the sheath. And yet this is precisely the type of field for which he denies the validity of this procedure. The argument which he uses in support of his contention is not, in my opinion, a good one. To adopt one of his own analogies, it is quite true that the pressure at the bottom of a column of bricks cannot be obtained by adding together the pressures at the bottoms of successive strata, but the total potential energy of the column most certainly can be calculated by summing up the separate potential energies of the different strata.

B. A. Behrend (communicated after adjournment): Dr. Hering's paper is a critical review of fundamental electrical principles and an attempt is made to call attention to, and suggest a different attitude toward, certain phenomena and experiments which in the conventional treatment appear distinctly awkward.

It has been known, of course, to the earnest and profound student, that unipolar or homopolar induction and allied phenomena strain somewhat the fundamental simplicity of Faraday's law of induction as given to us in its mathematical form by Maxwell. But Maxwell and his interpreters were aware of this, as was pointed out forty years ago by Oliver Lodge in his "Modern Views of Electricity." I discussed some of these difficulties with Prof. Lodge about 1890 and retain his pencil memoranda on the subject.

Attempts to compare the fundamental phenomena of electromagnetism to related phenomena in hydrodynamics and the theory of elasticity have proved useful. Temperature and electric and magnetic potential and the velocity potential appear as complete mathematical parallels. Lord Kelvin and Professor P. G. Tait have established the identity of mathematical conditions in St. Venant's torsion problem and a hydrokinetic problem.[2] Professor A. E. H. Love has also worked out the hydrodynamical analogy in which the problem of torsion of a twisted prism is compared with that of a frictionless liquid in a rotating cylindrical vessel or with liquid circulating with uniform spin in a fixed cylindrical vessel coinciding with the surface of the twisted prism.[3]

What I propose to point out here is that a similar complete analogy exists between the electromagnetic phenomena cited by Dr. Hering and the phenomena of torsion of prisms as treated by de St. Venant. The value of such analogies lies in creating mental pictures and substituting for unfamiliar problems those to which we have grown accustomed.

So far as I understand the Faraday-Maxwell electromagnetic theory and the ideas recently propounded in several papers before the Franklin Institute and this Institute by Dr. Hering, I daresay that Dr. Hering's views, far from being contradictory of the conventional theory, give an additional physical interpretation and expound some of the obscurities and difficulties of the traditional theory. Guided by his own views, Dr. Hering has made some valuable inventions which in themselves speak well for his point of view, and it seems as though both Bourbon and tyro of our art might well lend an open mind to these papers and to Dr. Hering's interesting and thoughtful experiments.

R. P. Jackson (communicated after adjournment): I was much interested in the statements of Dr. Hering in the February JOURNAL, page 123, concerning comparisons of the inductance of a circular circuit with that of a straight conductor of equal length. Some years ago I made an investigation of similar character and came to approximately the same conclusion.

At that time, I was investigating the requirements of conductors to and from lightning arresters. A great deal has been said about the increased impedance of bends and angles in such conductors and of the necessity of maintaining straight lines or easy curves and avoiding sharp bends. A little investigation

2. Treatise of Natural Philosophy, by Kelvin and Tait, part II, p. 242.

3. A. E. H. Love, Treatise on the Theory of Elasticity, Vol. I, p. 158 et. seq.

demonstrated that as soon as you begin to curve a conductor away from a straight line you begin to reduce its inductance per unit length and that a single-turn loop could not possibly have as much inductance as the same conductor run in a straight line, far from any return circuit.

This conclusion, of course, does not entirely remove the objection to curves and bends in lightning conductors for the simple reason that a straight line is the shortest distance between two points. For that reason, being the shortest conductor, one following a straight line will probably have less inductance than any other conceivable path would afford.

The presence of necessary angles and bends is harmful only in so far as the total length of the conductor is increased and their harmful effect may be much less than ordinarily assumed, providing, however, the conductor itself is of proper section and shape.

It is apparently more important to avoid single, small cylindrical conductors than it is to fear convenient and necessary curves and bends in connection with high frequencies. When there is more than one turn, however, the condition is entirely changed as the same flux threads through the various turns and there is the well known approximation, depending on the relative position of the turns, for the inductance to increase with the square of the number of turns.

(EDITOR'S NOTE: Following the presentation of the paper M. F. Skinker read from an article by Leigh Page, published in the *Journal* of the Franklin Institute for February, 1926, page 245, which article discussed a former article by Dr. Hering in the same *Journal*. Dr. Hering's reply to this is published in the April issue of that *Journal*, page 497.)

A HIGH-FREQUENCY VOLTAGE TEST FOR INSULATION OF ROTATING ELECTRICAL APPARATUS[1]

(RYLANDER)

NEW YORK, N. Y., FEBRUARY 11, 1926

C. T. Weller: About ten years ago we started to investigate the effect of high-frequency discharges through the windings of standard types of current transformers. This investigation led to the development of the by-pass protector. The outfit developed at that time has proved to be very satisfactory for work of this nature. Referring to Fig. 2A in Mr. Rylander's paper, we found the quench-gap to be the most suitable for our purpose, the setting being obtained by varying the number of units in series. We utilize an adjustable air-core reactance in series with the test device to vary the frequency in the oscillation circuit and the voltage across the test device, the total voltage being fixed by the setting of the quench gap. We utilize two crest voltmeters, each consisting of a kenotron and an electrostatic voltmeter for measuring voltage and detecting breakdown. One crest voltmeter is connected across the series reactance and the other across the test device, the test voltage being held on the latter. In case of breakdown, the voltage across the series reactance rises while that across the test device falls. The changes in voltage are accompanied by a change in frequency. The approximate frequency is determined by means of a wave meter coupled inductively to the series reactance. Some difficulty has been encountered in arriving at this determination, however, due to harmonics in the oscillation circuit. However, the frequency is not so important with this outfit since the main reliance is placed on the crest voltmeter. The crest voltmeter has an advantage over a spark-gap in that it will indicate the crest value of the voltage at all times during the test. The outfit described may be used for testing the insulation of the windings of a wide variety of apparatus at high frequency.

V. M. Montsinger: The testing of coils between turns by means of voltage at high frequencies has been practised for years by the company with which the speaker is connected. We have used for that purpose damped oscillations and for detectors we have used a telephone receiver and an ammeter. A diagram of the arrangement for testing with damped oscillations of 20,000 cycles per second is shown in the accompanying illustration.

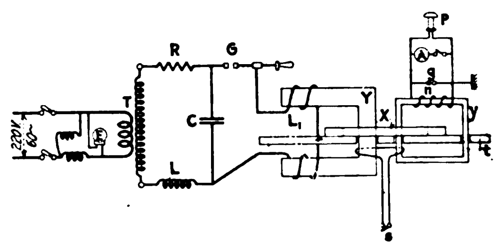
The charging circuit of the condenser C consists of a resistance R, an inductance L, and a step-up transformer T. The transformer T is excited by means of an induction regulator so as to obtain a voltage control of $E = 0$ to 440 volts from a 220-volt, 60-cycle supply.

The discharge circuit of the condenser C consists of a spark-gap G and an inductance L_1 which also serves the purpose of a linking coil, or excitation coil, of the testing yoke, Y. The discharge circuit of the condenser has a natural frequency of about 20,000 cycles per sec.

The coil X to be tested is placed on the table t in such a manner that the coil encircles both the testing yoke Y and the detector yoke y. Both of these yokes are of split construction so that the coil may be inserted. Yoke y carries a coil n of only a few turns connected to a phone receiver P and to a hot-wire ammeter A.

When the spark-gap, G, is arcing, the condenser voltage is discharged across the linking coil L_1 and an oscillating voltage at a frequency of about 20,000 cycles is induced in the coil X under test. When the coil under test is perfect, or when it withstands the induced voltage test, the phone receiver will be silent and the ammeter will indicate zero.

However, the phone receiver will be noisy and the ammeter



ARRANGEMENT FOR TESTING COILS WITH HIGH-FREQUENCY VOLTAGE

will indicate a deflection when the coil under test is defective or when it breaks down during test, because then a short-circuit current in the defective coil will magnetize the detector yoke y and energize its coil n.

A small gap, g, with one terminal grounded is provided for the protection of the indicating instruments.

One auxiliary turn mounted under the table, encircling the testing yoke Y and the detector yoke y, may be short-circuited by the switch s at any time to show whether or not the equipment is operating satisfactorily.

The voltage per turn induced in the coil under test is directly proportional to the voltage E impressed on the transformer, provided that the setting of the spark-gap G is maximum for the discharge voltage of the condenser.

This testing method offers high induced test voltages per turn at the high frequency of about 20,000 cycles per sec. This frequency does not overheat the insulation because each train of damped oscillations, which starts at every half cycle of the supply frequency ($2 \times 60 = 120$ times per sec.), lasts a very short time only and is followed by a comparatively long period of rest.

Experience has demonstrated that this outfit is a practical shop method for inducing high voltage between turns. It does not require an experienced person to operate it and will not only detect weak points of insulation but will give evidence of corona discharges.

E. S. Lee: Mr. Rylander has described a somewhat modified form of a method which, as has been indicated by other speakers,

1. A. I. E. E. JOURNAL, March, 1926, p. 217.

has been variously used during the past eight or ten years. Where it is desired particularly to obtain a high enough voltage between the individual turns of a coil to enable weak spots in the insulation to be broken down, the use of high-frequency voltage is advantageous, as higher voltages are thereby obtainable between turns than with the usual methods employing low-frequency voltage.

It is my understanding that this becomes a comparison method; that is, a coil is selected which is considered a good one and if the reading on the instrument for other coils approximates the reading as given by the good coil, then these coils may be assumed to be suitable and fit for use. If, on the other hand, the reading on the instrument does not closely approach the established reading, there is something wrong with the coil and if the voltage is high enough to cause a breakdown of the insulation, it will be easily detected.

I should like to ask Mr. Rylander how important it is to maintain the relative positions of the coil under test and the tuning coil. If we use this test for more complicated structures, as suggested by Mr. Rylander, how great a factor will be introduced because of the relative difficulty of placing the detector coil in about the same relative position with respect to the coils to be tested, since these may be assembled into stators of different sizes and forms? I believe this condition will have to be taken into account.

Mr. Rylander's paper quite clearly brings out the many defects which may occur in the manufacture of the insulation. If it is found that quite a bit of trouble is arising from these factors, then such a test as has been described is probably necessary. If, however, there are no troubles from these, it is a question whether or not such a test ought to be applied. This is true particularly because it is not altogether simple to determine the exact voltage distribution in the different turns of the coil. Mr. Rylander speaks of this in the paragraph in which he says, "In general, the voltage builds up somewhat on the end coils." Also, in so far as we do not know definitely the conditions that exist in the coils due to surges, we are not absolutely sure that by applying a high-frequency test, we are applying a test that is comparable to service conditions. It may not necessarily have the same characteristics, and we must be sure to have the same characteristics.

I think that this test must be put in the same category with any other test. In the section entitled *Benefits Derived from High-Frequency Testing,* Mr. Rylander states many defects which this test has shown to exist in the coils which he has tested. I think that Mr. Rylander wishes to bring out that this form of testing will show that some defect is present, or, if breakdown occurs, will allow such evidence to remain that the cause of the failure may be ascertained by visual inspection. Although where required, the test as indicated is of value, still of itself it does not show the cause of failure.

G. E. Luke: The A. I. E. E. standardization rules give limits for test voltages between circuits and grounds, but nothing is said concerning test voltages between turns. The reason for this omission is that there has been no standard or established method for conducting this inter-turn dielectric test. This paper and the discussions show that the manufacturing companies recognize the importance of this insulation and are developing means for testing its factor of safety.

In my experience on dielectric tests of windings there have been some puzzling breakdowns between turns; especially do I remember one series of armatures that gave a high percentage of failures between end connectors. Although the clearance was small, the insulation should have withstood a potential of 1000 volts or more, but some failed on a low voltage of from 50 to 100. In this particular case, the trouble was due to insufficient drying of the impregnating varnish or compound. A high-frequency test, such as described, would reveal such a weakness, whereas, without such a test, the machine would be passed as correct. Anything we can do to improve the methods for testing insulation, particularly that between turns, will be of great value to the electrical industry.

J. L. Rylander: Mr. Montsinger has described a method of testing individual coils with induction and the use of high frequency. I wish to point out that that method of test has no similarity in principle to the test described in my paper either as to method of applying the voltage or to the method of detecting failures; and furthermore, it is very limited in its application, as will be explained later. I understand that the test referred to by Mr. Weller and Mr. Lee is the same as that described by Mr. Montsinger as regards the method of applying the voltage; and for detecting breakdown, they use a crest voltmeter instead of the telephone receiver used by Mr. Montsinger.

With the method described by Mr. Montsinger, the voltage is applied to the coil under test by "induction," the coil under test acting as the secondary winding of a transformer. With the method described in my paper the high-frequency high voltage is applied *directly* to the coils or completed windings or other apparatus under test, as shown in Figs. 1 to 8 of the paper.

For the method of detection, Messrs. Weller, Montsinger and Lee use telephone receivers or crest voltmeters instead of the wavemeter shown in Fig. 2B of the paper.

The merits of the directly applied, high-voltage high frequency as compared with the induction method are as follows:

1. It can be applied to completed or partially wound machines as well as to coils of any type or shape, large or small, armature coils, field coils, magnet and other types of coils. The test shown in Mr. Montsinger's diagram is not and cannot be applied to completed a-c. windings; nor can coils be satisfactorily tested if the coils have a very small or a very large opening into which the testing yoke and the detector yoke must pass.

2. Invariably, the cause of any failure can be ascertained. The reason for this is that when a defect occurs, the insulation is burned away only at a small spot between the turns at the defect. With the induction method of test, the result of a defect is that the short-circuited turns are heated to a very high temperature the full length of the turns, so that the insulation is charred the full length of these turns as well as on the adjacent turns; and, as a result, the exact location of the defect cannot be determined; and usually the evidence of the cause is destroyed.

3. This directly-applied test corresponds to service conditions. Current flows in the coils or windings and also voltage is impressed between the turns, and the high-frequency oscillations correspond to the service surge effects upon any particular winding.

4. The wavemeter method of detecting failure, as used with the directly-applied, high-voltage high frequency, is an adequate and most effective method of detecting short circuits and insulation breakdown.

Mr. Lee asked about the importance of the location of the wavemeter tuning coil in respect to the coil or more complicated structure under test. This is a very important feature. Our wavemeter readings consist of the frequency as determined by the inductance and the condenser setting at resonance, and to the intensity and direction of the transmitted electromagnetic field as shown by the ammeter reading and the distance from the wavemeter tuning coil to the apparatus under test. Therefore, the reading for a defective piece of apparatus is different from the reading for the same apparatus without any defects. However, the point should be brought out that even when there is only one piece of apparatus to test, it can be tested and the readings will indicate whether the winding is satisfactory or whether defective. There is no difficulty in placing the tuning coil in the same relative position with respect to the apparatus under test. Mr. Lee stated that my paper "brings out clearly the many defects that may occur in the windings." We have found since we started this method of test that every one of the defects mentioned did occur, although we did not know it before.

Mr. Lee pointed out that it is difficult to determine the exact voltage distribution in the different turns of the coils. When we test a particular type of winding for the first time, we place a crest voltmeter across the end coils or others and measure the voltage on them while the voltage is applied to the leads. We can now estimate very well how it does divide on apparatus which is similar to something we have already tested. It should be pointed out, however, that a knowledge of the approximate voltage distribution in a winding (easily obtainable by this test method) is significant from an operating standpoint rather than from a testing point of view.

In conclusion, it may be stated that, by means of this directly applied high-frequency high-voltage test, the "internal" parts of windings can now be tested as thoroughly as the "external" insulation is tested by the "ground" test.

THE MAGNETIC HYSTERESIS CURVE[1]

(Lippelt)

New York, N. Y., February 11, 1926

S. L. Gokhale: I believe that Mr. Lippelt's analytical conception of reactive and dissipative components of magnetic forces within a magnetic material, if carried to its logical consequence, will eventually do for the magnetic circuit what the conception of "energy component" and "idle component" have done for the electric circuit. Mr. Lippelt also deserves credit for his ingenious method of evolving from an unsymmetrical hypothetic equation another of symmetric form. This method is likely to have a very wide and useful application in other fields.

As to his equation (7) which is one of the two important equations in the paper, I take the liberty of disagreeing with the author. His line of reasoning, as I understand it, is as follows:

a. Near saturation, hysteresis practically disappears, making $R = -H$.

b. Near saturation, the relation of H to β follows the law $H = +K/\gamma$.

c. Therefore, near saturation, the relation of R to β must also be represented by the law $R = -K/\gamma$.

Mr. Lippelt's final equation for the magnetic hysteresis curve de-

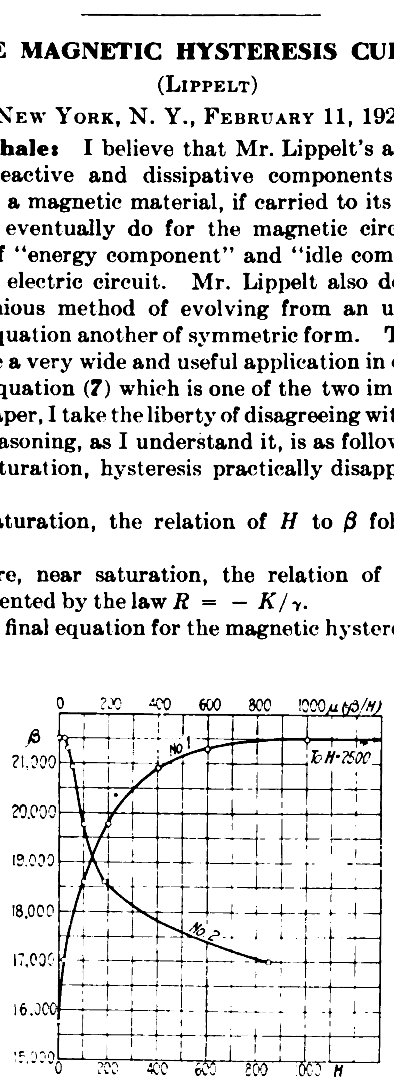


Fig. 1

pends entirely on proposition c, and therefore ultimately upon proposition b, which he accepts as an established and indisputable fact.

At this point I differ from Mr. Lippelt. I have in my hands a few hundred magnetization curves, to demonstrate that the relation of H to β cannot be represented correctly by the equation, $H = K/\gamma$; that relation can be represented much more closely by the equation $\log \gamma = f - g H$, or $H = a - b \log \gamma$. It is not possible to present the full evidence in a brief discussion like this, and I shall therefore limit myself to a single illustration for the present.

Fig. 1 represents the curves for intrinsic induction (Curve No. 1) and permeability (Curve No. 2) for a sample of electrolytic iron. This sample was included in a paper by Dr. Yensen.[2] The sample was tested at the Bureau of Standards, Washington. The material as well as the test data are therefore of the highest possible reliability. A study of Curves 3 and 4 of Fig. 2 shows conclusively that the relation of H to β for this material does not follow the law $H = K/\gamma$, but instead, follows the law $\log \gamma = f \dot{-} g H$. As this material has a remarkably low hysteresis, it follows that near saturation, the hysteresis should be prac-

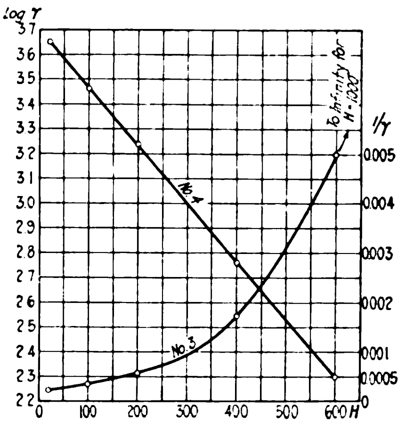


Fig. 2

tically negligible so as to suggest that the true law of reactivity should be $\log \gamma = f + g R$.

If, after a careful study of these and several other curves, Mr. Lippelt decides to revise his views as to the equation of reactivity near saturation, he might have to revise his equation for hysteresis also.

As to the equation for the dissipative component, *viz.*,

$$D = -A/\cosh \theta$$
$$= -A/\cosh \left\{ (c H + f) + q \sqrt{h + (c H + c f)^2} \right\}$$

I notice that the term βh,—that is, the peak value of β for the hysteresis loop,—is conspicuously absent. We all know that hysteresis depends in some way on the peak value of β; any formula for hysteresis in which βh is absent is, therefore, not likely to be the true formula, even approximately. On this point, I believe we need some explanation before we could accept Mr. Lippelt's equation.

In the course of the presentation of his paper, Mr. Lippelt claimed to have established a rational equation for hysteresis; I am unable to follow him at this point. If I understand his argument correctly, he has attempted to formulate a rational equation for R and an empirical equation for D.

In Section VII (Applying the Theory), the author shows that Kennelly's law of reluctivity follows as a corollary from his theory.

Kennelly's law is only another form of Frolich's law. Mr. Lippelt's hypothesis is admittedly a form of Frolich's law, and must necessarily agree with all other forms of that law, including Kennelly's law. Such agreement implies nothing more than this—that any hypothesis in harmony with any other hypothesis will agree with that hypothesis in all its forms. Such an agreement has obviously no evidential value in support of the hypothesis in question.

Mr. Lippelt's hypothesis ($H = K/\gamma$) is analogous to Boyle's law for perfect gases. But in formulating the law on this basis he has to assume that magnetization consists of charging the

1. A. I. E. E. Journal, April, 1926, p. 355.

2. The Magnetic Properties of the Ternary Alloys Fe-Si-C, by T. D. Yensen, Transactions A. I. E. E., 1924, page 145.

molecules with something that is not in the molecules to start with, *viz.*, the magnetic induction β. Such an explanation of the equation would therefore be in agreement with Poisson's theory, but not in agreement with Weber's theory, which is, at present, the generally accepted theory.

TABLE I
MAGNETIZATION TESTS ON ELECTROLYTIC IRON

Test made at the Bureau of Standards—Test No. Tem. 41893. Data for H and B received through courtesy of Dr. T. D. Yensen. The other columns of the table are obtained by computation.

H	B	β	γ	μ $(=\beta/H)$	$1/\gamma$	Log γ
0.2	460					
0.4	4600					
0.5	7300					
1.0	11150					
2.0	14230					
4.0	15770					
20.0	17020	17000	4500	850	0.0002222	3.6530
100.0	18700	18600	2900	186	0.0003450	3.4625
200.0	19960	19760	1740	99	0.0005745	3.2405
400.0	21320	20920	580	52.3	0.001724	2.763
600.0	21900	21300	200	35.5	0.005000	2.310
1000.0	22500	21500	0	21.5	inf.	
1500.0	23000	21500	0	14.3	inf.	
2000.0	23500	21500	0	10.7	inf.	
2500.0	24000	21500	0	8.6	inf.	

Notation: In this table
$\beta = B - H$
$\gamma = S - \beta$ (Where $S = 21500$).
$\mu = \beta/H$ (Intrinsic permeability).

Hans Lippelt: It is obvious that in presenting this paper I did not intend to advance a final and conclusive treatise on magnetism. Of the experimental data which I had on hand, only those appertaining to one magnetic cycle of tungsten steel appeared to be best suited for the study. With such fundamental limitations, it cannot be expected that the results obtained and conclusions drawn will cover all possible cases of magnetization. This state of affairs is reflected in Division 10, under "Conclusions," by the statement that Equation (7) is hypothetical. At the same time it should be noted that this equation is rather plausible and is also rooted in well-known laws of physics. Mr. Gokhale's apprehension that Equation (7) is "indisputable" does not seem to be claimed in the paper.

Mr. Gokhale expresses his disagreement in particular with Equation (7) and rests his point of view on research work of his own and on premises mentioned under a and b and on a conclusion, c.

In deriving Equation (7), use has been made of the relation $R = -\dfrac{K}{\gamma}$, but it has been used merely as a stepping stone for evolving Equation (7), which constitutes the improved form of the relation between R and γ.

The paper in exploiting the test data makes *no use* of Mr. Gokhale's relation c: $R = -\dfrac{K}{\gamma}$, but employs Equation (7) exclusively. The effect will be understood when, for example, both relations are applied to the case of $\beta_h = 13183$, the highest value of magnetization which the tungsten steel attains in its magnetic cycle.

$$\text{Mr. Gokhale's relation (c) } R = -\frac{K}{\gamma} = -\frac{K}{S-\beta}$$

$$= -\frac{0.5682 \times 10^6}{16000 - 13183} = -202 \text{ wrong value}$$

$$\text{As per Eq. (7) of paper, } R = -\frac{2 \times 0.5682 \times 10^6 \times 13183}{16000^2 - 13183^2}$$

$$= -182 \text{ correct value}$$

The difference amounts to 11 per cent of the true value.

Referring now to Curves 1, 2, 3, and 4 submitted by Mr. Gokhale, essential characteristics of those curves, not mentioned yet, should be stated before making further use of them. The equation of Curve 4 is

$$\log \gamma = \log (S - \beta) = 3.6996 - 0.002331 \times H \qquad \textbf{(d)}$$

from which follows (see also Curves Nos. 4 and 1).

for $H = 0$ $\gamma = S - \beta = 5007$ and therefore $\beta = +\beta_0 = +16500$
for $H = 1588$ $\log \gamma = 0$; $\gamma = S - \beta = 1$ $\beta = 21500 - 1$

simultaneously $\left.\begin{matrix} H = 0 \\ \beta = 0 \end{matrix}\right\}$ would make $\gamma_o = S$ and $\log \gamma_o = 4.3324$ which is not situated on the straight line No. 4.

The fact that for $H = 0$ a residual magnetization $\beta_0 = +16500$

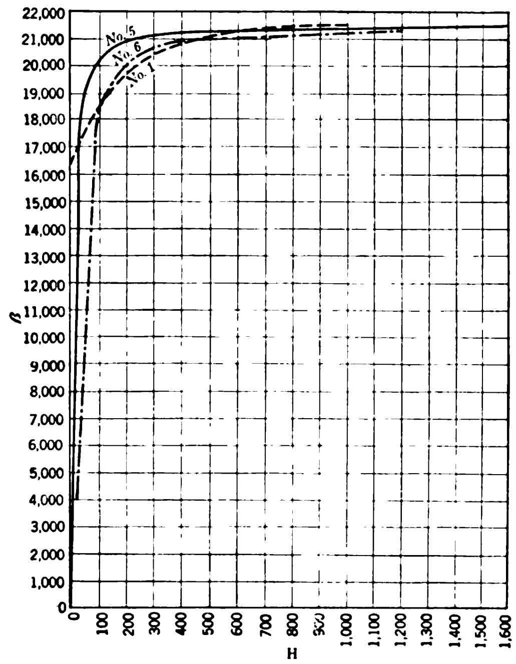


FIG. 3

occurs, renders the cited curves unsuitable for comparison with the hysteresis curve of the paper. Curve 1 looks more like the descending branch of a hysteresis curve, while Table I showing test data indicates that the H-values progressed from $H = 0$ to 2500, characterizing it as an ascending branch.

Due correction should be made, because "Weber's theory" also implies that the magnetizing effect of a field H depends on the configuration of molecules at the beginning of the process.

On the other hand, if the low hysteresis is to be neglected altogether, there should be $\beta = 0$ for $H = 0$.

Fig. 3 herewith has been drawn up to facilitate, as far as possible, comparison between Mr. Gokhale's results of research and the theory of the paper. Curve 1 has been copied from Mr. Gokhale's Fig. 1, and Curve 5 is a magnetization curve computed on the basis of Equation (7), or rather Equation (15), which is another form of Equation (7) of the paper. Numerical values are given in Table II. K as it appears there is a value adapted by mathematical trial to Curve 1.

Now inspecting Fig. 3, if, as called for, Curve 1 were duly corrected to start at the origin of the system, the two curves 1 and 5 would be close together for values of β from 0 to about 18,000 and from 21,000 to saturation. A difference, however,

TABLE II

Comparison of Equation (7) or rather (15) of the paper with Equation (d) of discussion

$-R = H \qquad K = 0.1205 \times 10^6 \qquad S = 21500$

$$\beta = -\frac{K}{H} + \frac{1}{H}\sqrt{K^2 + S^2 \times H^2} = -\frac{0.1205 \times 10^6}{H} + \frac{1}{H}\sqrt{(0.1205 \times 10^6)^2 + 21500^2 \times H^2}$$ corresponding to Equation (15)

$H \quad -R$	20	60	100	200	400	600	1000	1588
β as per above Equation (15)	16303	19586	20331	20906	21200	21300	21380	21424
β as per Equation (d)	17000	17872	18573	19789	20925	21300	21477	21499
Difference	−697	+1714	+1758	+1117	+275	0	−97	−75

is conspicuous for values of β from 18,000 to 21,000. The agreement between the two curves would be better yet, if Curve 1 would start at a residual magnetization $\beta = -\beta_0$, *e.g.*, including that amount of hysteresis which exists in the electrolytic iron under test. In the latter case H would be replaced by $-R$ and a conclusive comparison of the two pertinent Equations (**d**) and (**7**) could be made. If, then, a need for improvement of Equation (**7**) should come into evidence, it might be taken care of by adding an exponent n, possibly thus

$$R_n = -\frac{2K\beta}{(S^2 - \beta^2)^n} = -2\left(\frac{k}{S^2 - \beta^2}\right)^n \times \beta \qquad \textbf{(e)}$$

In this form, the dimensional homogeneity of the equation would be retained. Curve 6 shows the corrective effect of a coefficient $n = 0.949$ upon Curve 5. Further research work along the lines of the new theory, however, should establish a term for R which covers all cases of magnetization.

Such a revision of Equation (**7**), or one similar, should have only a limited effect upon the equation for the dissipative component D, on account of the anticipated near agreement between the curve as per Equation (**7**) and the graph of the improved term.

Since, however, the molecular friction (and hysteresis) depends very much on the material under test, it is to be expected that for different materials the D-curves will have different configurations. The many constants in Equations (**11**) to (**14**) give quite a great latitude in this respect and should accord to Equations (**11**) and (**14**) more than transitional importance.

The quantity β_h does not occur in Equations (**11**) to (**14**), because they relate D to H. β is very much in evidence in Equations (**33**), (**35**), and (**36**), and in calculations of loss in Appendix III.

The empirical character of the Equations for D is admitted, but the Curves D_1 and D_2 are rational inasmuch as they are the outgrowth of rational theory.

Section VII (Applying the Theory) was added to show first, that by reason of functional appertainment, the magnetization curve should be referred to R and not to H, and secondly, that $\tan\tau = \frac{1}{S}$, which was not known before.

Regarding Mr. Gokhale's reference to Weber's theory, according to which the magnetism is resident in the molecules, the gist of that theory will not be much altered by assuming that the molecules are ordinarily devoid of magnetism, but in magnetizable materials they can be polarized in one direction only. When magnetized to the extent of $\beta = H$ (for those molecules the polar axes of which happen to be parallel to H) and to $\beta < H$ (for those molecules the polar axes of which are not parallel to H), they tend and begin to aline their axes parallel to the field H and thereby also deflect the molecules from their original position. In so doing they encounter the friction D. At the same time the flux within them increases in accordance with their "magnetic ability." Each molecule then represents only a link in one of the many parallel chains constituting the magnetic flux of the circuit.

A further refinement of the theory will have to settle the question as to whether the polar axes are rigidly fixed to their respective molecules or whether they permit of a certain shift around them.

As the flux enters the molecules and alignment of the polar axes takes place, a reaction R is encountered. While mathematical terms are given in the paper for D and R, the writer believes himself justified in assigning the cause of those forces R and D to the thermodynamic and mechanical state of the material under test. Such conclusions are drawn from results of research published by J. A. Ewing.[4]

4. Conclusions drawn from references in Magnetic Induction in Iron and other Materials, by J. A. Ewing. Third Edition, 1900, D. Van Nostrand Co., New York.

EFFECT OF HEAT ON MAGNETICS

Page 171, Magnetization of Iron at various temperatures, Fig. 77 with $H = 0$ to 2.5. Fig. 78 $H = 0$ to 50, D decreases with increasing temperature; therefore $\frac{d\beta}{d\epsilon} > 0$ and $\frac{dR}{d\epsilon} \gtreqless 0$. For large H and β, ϵ_m is approached, hence saturation value goes down. Observe that β adds to the elongation when within a certain value. Compare Fig. 126. $H < 280$.

Page 172. Fig. 79, same case, but $H = 0.3$ = constant; $t = 0$ to 800 deg. For low temperatures: $\frac{dD}{d\epsilon} < 0$ = negative, but D remains too large. The weak $H = 0.3 < D$ cannot accomplish a parallel alignment of polar axes. R therefore remains near zero value. Above 700 deg. D is getting so small, ($D = 0$) that under the weak H, alinement of polar axes is accomplished, involving also $\frac{d\beta}{d\epsilon} > 0$ and $H = -R$, which brings about further elongation $\epsilon = F_3(\beta)$, carrying ϵ to critical value ϵ_m, thus reducing β. $\beta = H$.

Page 173. Fig. 80 $H = 4.0$ = constant. Fig. 81 $H = 45$ = const. Same process as in Fig. 79, but quantitatively different, inasmuch as the stronger field overcomes D at lower temperatures.

Page 176. Magnetization of nickel at various temperatures. Fig. 86 $H = 0$ to 80, t held constant at various values t = 13 deg., 245 deg., 284 deg., 298 deg., 308 deg.

D abates with rising temperature, which also entails increasing ϵ. As β grows larger due to the growing field intensity, D is falling off. $\epsilon = F_3(\beta)$ adds to the thermal elongation until the critical value is being approached. The greater the elongation by heat, the less elongation $\epsilon = F_3(\beta)$ is necessary to reach the critical value ϵ_m.

Page 177. Fig. 87, Field kept constant at various values H = 2.5, 10, 30, 50; while temperature varies from 0 to 310 deg. Explanations are similar to those for Fig. 79.

Page 183. Fig. 89. Bar magnet subjected to heat cycle 8-160-10 deg. Curve shows the abatement of β with separation of molecules by thermal expansion. Such separation also permits better alinement of axes of molecules, which is reflected in higher β values when the magnet cools off.

The recurrence of β and its stored magnetic energy leaves no other interpretation than that heat has been transformed into magnetism directly. This experiment should be repeated with a winding around the magnet and connected to a suitable galvanometer for checking the flow of Coulombs in and out. In that form the outfit would be an apparatus adapted to change heat into electricity.

EFFECT OF MECHANICAL STRESS UPON MAGNETS

Page 204. Fig. 98, Nickel under compression. H varies from 0 to 160; while compressive stress is held constant at various values, *e. g.*, 0, 1.9, 3.5, 6.8, 10, 13.8, 19.8 kg/mm^2. Rate of magnetization increases with compression, *e. g.*, with mutual approachment of molecules.

$$\frac{d\beta}{d(-\epsilon)} > 0 \text{ and } \frac{H_R}{(-\epsilon)} \text{ numerically larger than } \frac{D}{(-\epsilon)}.$$

Residual magnetism $+\beta_0$ increases with pressure, therefore we have $\frac{dD}{d(-\epsilon)} > 0$.

Tension applied to nickel has the opposite effect (ϵ = positive). Compare Fig. 95 on page 200.

Pages 197, 224, Villary effect:—In iron, when subjected to a weak field, a

Fig. 4 (herewith) shows the development along its axis and a cross section through a rod of magnetizable material. Certain notations are also given which are necessary for further explanations.

The outstanding feature of the aforesaid conclusions is that magnetic reaction R, magnetic friction D, and, as a sequel, β, depend very much on the relative distance between the molecules. There are various forces affecting that distance.

Briefly stated

$$R = F_1 (\epsilon, \alpha) \tag{f}$$

$$D = F_2 (\epsilon, \alpha) \tag{g}$$

In general, *e. g.*, if not counteracted otherwise,

Separation of molecules ($\Delta l = + \epsilon l$ = positive) by expansion lowers D, β, R.

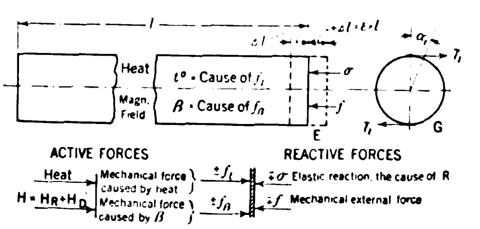


FIG. 4

Mutual approach of molecules ($\Delta l = \epsilon l$ = negative) by compression increases D, β, R, each at its own rate.

If counteraction does take place, as, for instance, when mechanical pressure opposes thermal expansion, the effect upon β depends upon

$$\frac{d D}{d \epsilon} \gtreqless \frac{d R}{d \epsilon} \text{ or } \gtreqless \frac{d \beta}{d \epsilon} \tag{h}$$

$$\frac{d D}{d \alpha} \gtreqless \frac{d R}{d \alpha} \text{ or } \gtreqless \frac{d \beta}{d \alpha} \tag{j}$$

For ϵ, a critical maximum value ϵ_m exists. When ϵ_m is exceeded, the effect is similar to that of a large air-gap or a broken magnetic chain.

To augment the above equations (**f** and **j**), the following two well-known relations should be cited:

$$\epsilon = F_3 (t_o, \beta, \sigma, f) \tag{k}$$

$$\alpha_1 = F_4 (t_o, l_1) \tag{l}$$

Observing now that $\epsilon = \sigma E$ and $\alpha_1 = \tau_1 G$, it is obvious that R and D depend on the elastic quality of the material.

It is understood, of course, that the two fundamental laws of thermodynamics also apply. They must be referred to, for instance, when explaining the change of magnetization through heat in a permanent magnet. Here they force the conclusion that heat energy is transformed into magnetic energy.

---

mechanical tension will cause β to rise; when in a strong field and put under tension, β will decrease.

This Villari effect in iron seems to indicate that in iron a negative maximum for ϵ exists. The neutral point between $(- \epsilon_m)$ and $(+ \epsilon_m)$ occurs when a certain external load is applied.

Page 243. Fig. 121. Nickel under tension and torsion. Tension alone (Curve *c c*) separates the molecules and therefore holds β low. Torsion added brings about lateral compression and a mutual approachment of molecules, and also an increase of D, the molecular friction. As soon as H has reached a value (12 in Fig. 121) to overcome this larger D, alinement of polar axes of molecules takes place "en masse," accompanied by a large increase in β. The molecules remain then in alinement for the descending branch, owing to the high value of D, and a high residual magnetism is the result.

Page 208. Fig. 102. Nickel in (successive) constant fields. H = 6.9, 21.8, 53.5, 118. Pull = 0 to 12 $\times$ 2.75 $k\,g/m\,m^2$. Separation of molecules lowers β and stored magnetic energy. Removal of tension brings back β and its energy. Case is similar to bar magnet under influence of heat, page 183.

CORRESPONDENCE

TRANSMISSION LINE SAG CALCULATIONS

To the Editor:

Referring to the paper on *Transmission Line Design*, abstracted in the A. I. E. E. JOURNAL of December 1925, p. 1352, I wish to call attention to an important omission by the author.

When there is wind pressure, the cable of a transmission line span lies in an oblique plane and not in a vertical one. It still has the shape of a catenary, and deflections in the direction of the resultant force are in the oblique plane. If one support is a distance b higher than the other, the dimension b does not lie in the oblique plane, but in a vertical one.

A new dimension $q = b/\cos \theta$ should be taken, which is the difference between the distances of the two supports from the horizontal line through the lowest part of the cable. The dimension q lies in the oblique plane. The angle θ is the angle between the oblique plane and the vertical.

This matter is not a minor correction, but it makes a large difference. For instance, in the problem with cable loaded, Table VII, of Mr. Smith's paper, b = 179 feet and the lowest point of the cable is given as 91.2 feet from the lower support, and between the two supports. If the obliqueness of the plane is allowed for, q = 197 feet and the lowest point of the extended catenary is outside of the two supports, and 34.5 feet from the lower support. The calculated sag is very materially changed.

Since the span is first calculated with a wind load, the above error affects the succeeding calculations.

It is not necessary to use an approximate calculation, as used by Mr. Smith, for the deflection from the line joining the supports, since a simple calculation depending directly on the catenary formula can be employed. See the paper on sag calculations by the writer, A. I. E. E. JOURNAL for June 1926, page 564.

H. B. DWIGHT.

To the Editor:

Mr. Dwight's letter calls attention to an important point, and one which should have been mentioned in the paper.

The reason for not taking into account the angle θ, due to the wind load, was not stated in this paper, but will be found in the previous paper on *Transmission Line Design*, by F. K. Kirsten, A. I. E. E. TRANSACTIONS, 1917. In each of these papers the maximum load at freezing temperature was considered in the vertical plane with no wind, but with the assumption that the snow accumulation might then result in a loading at least as great as the loading computed for the inclined plane with wind. Since this condition is one of the two possible maximum sag conditions, it would determine the minimum clearance to ground. This assumption, if justified, gives an added factor of safety.

If the assumption is not permissible, Mr. Dwight's suggestion must be considered. In any case a complete investigation might require the consideration of the inclined position for clearances between cables.

G. S. SMITH.

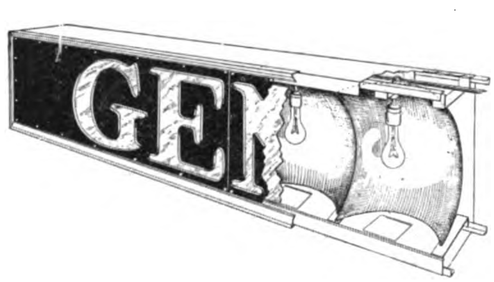
ILLUMINATION ITEMS

By Committee on Production and Application of Light

A DAYLIGHT ELECTRIC SIGN

Multiplies the Effective Hours of Electrical Advertising

Perhaps the major reason for the popularity of electrical advertising is its enormous "brightness" contrasts—its letters of fire drawn out against the dark night sky. Its use and maximum effectiveness have been confined chiefly to those hours when there is a dark night sky; and the time clocks, turning the signs off after the people are abed, are set to turn them on again only at dusk the next day. While it is true that during the evening hours advertising is most effective—when people are most receptive—yet there are daylight hours when advertisers clamor for attention. The theater, with its matinee performances, has empty seats to fill. The real-estate development, where brightest days are best for trade, finds everyone vying for attention. The shopping district stores entice the midday throngs—with as keen competition for the attention of all, those who walk or those who ride,—as at any other time. Yet, at these hours, the signs brilliant at night become mere painted messages dependent upon such secondary agencies as beauty, grace, and color to catch and hold the eye. For the filament of the incandescent lamp, although very bright, is small in size, and against the light daytime backgrounds, there is insufficient area of brightness to command attention.



DAYLIGHT SIGN

It is a simple matter, optically, to build up the area of brightness and lay images of the brilliant filament side by side so that, for example, the entire surface of a letter is given the brightness of the filament itself. Then the brilliant area is large and will attract. The traffic signal and the familiar stop signal of the motor car are examples of such building up of the area of brightness to a size at which it competes successfully with the light of day. And in the "daylight" sign, a large reflector directs an image of the filament to every point on the surface of a glass letter, giving it the brightness of a line of fire *by day*.

In obtaining this brightness, the light has been concentrated into a relatively narrow angle; hence, within this angle only is its effectiveness at a maximum. Therefore, such a sign is of greatest value when the circulation is massed within a relatively narrow viewing angle, and where people approach the sign nearly "head on" for a considerable distance. There are many such locations,—atop the marquee projecting over the sidewalk, at a dead-end street, on a highway curve,—where the new sign might well be used to give a daytime punch.

At night, the sign is effective if dimmed to a much lower brightness. The brightness used by day would fuzz and blur the letters and make them indistinguishable, even at short distances; in fact the glare would be intolerable. Dimming at night may be easily accomplished by a time clock that switches to a lower voltage transformer tap or cuts in a series resistance if in the direct-current district. Often it will be satisfactory to wire the lamps in two circuits of equal numbers and wattage, the time clock connecting the halves in series at a predetermined hour.

The use of color, preferably in the glass letter itself, improves both day and night effect. The lighter colors should be employed in order not to sacrifice the high brightness that compels attention.

The first installation of the "daylight" sign was made on Central Pier, Atlantic City. Here it is so situated and the direction of the boardwalk is such that the letters are visible to people approaching from afar and over a considerable stretch of boardwalk. It was desired to compel the attention of the passerby in an inescapable manner, even on the brightest day, and high brightness is an unfailing means to this end. Hence the "daylight" sign was used. Rippled alabaster glass, with a slightly opalescent case, smooths out streaks and striations without too great a diffusion of the concentrated beam. Back of each letter is a large, polished, parabolic reflector, with a 200-watt, Mazda C lamp so placed that the filament is at the focus of the reflector. The reflectors are turned at a slight angle so that they aim down the boardwalk approach. The necessary dimming at night is accomplished by connecting two groups of lamps of equal wattage, in series, so that each lamp in the letters receives half voltage at night.

When approaching the store from afar down the boardwalk, the effect is striking; even on the brightest days of ocean sunshine, with the white, glittering beach nearby, the more brilliant, sparkling letters of the "daylight" sign stand out beyond all surroundings and compel attention.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Pacific Coast Convention, Salt Lake City

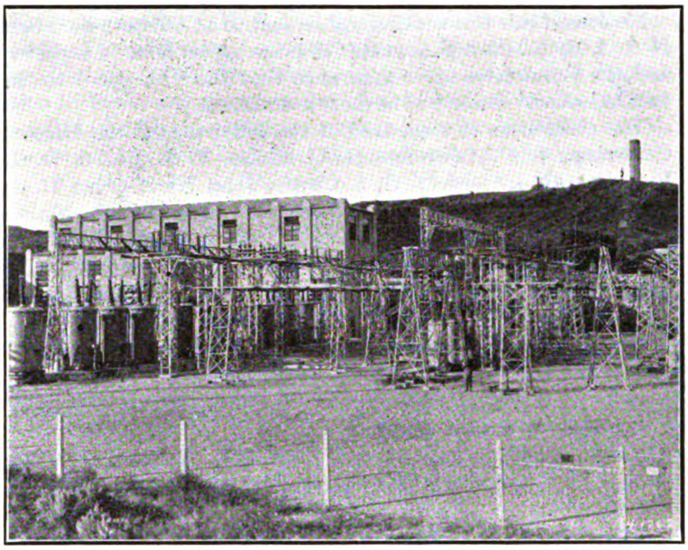
SEPTEMBER 6-9

Arrangements are being completed for the 1926 Pacific Coast Convention of the Institute which will be held in Salt Lake City, September 6, 7, 8 and 9, 1926. A special technical program is being prepared and the Convention Committee is arranging a series of events for the entertainment of those who will be in attendance. The convention meetings will be held at Hotel Utah, which will also be the headquarters for all other convention activities.

Among the wide variety of subjects covered in the technical papers will be high-voltage transmission, corona, surge recorders, vacuum switching, fire protection for generators, stability of alternators, protecting oil tanks against lightning, telephony, mining applications, education, etc. A tentative list of papers is given below.

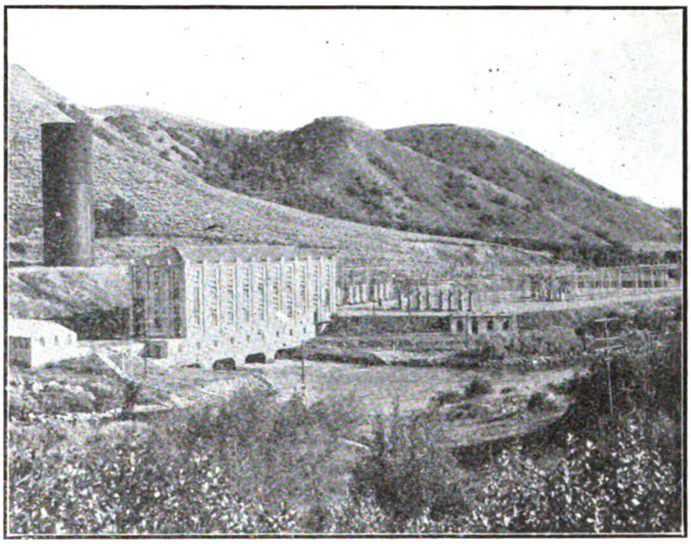
A visit to Utah at any time of the year is most delightful, and it is particularly so during the early part of September. It is planned to hold technical sessions during the forenoons, with afternoons devoted to sightseeing trips to such places as Utah Copper Company open-pit mine at Bingham, where immense tonnage of copper ore is mined with electric shovels; to the Utah Copper Company mills at Magna and Arthur, where from 30,000 to 40,000 tons of ore per day are milled and where large quantities of electric power are used; to the beautiful Saltair resort which is located on Great Salt Lake; to the numerous canyons surrounding the city, and to the many notable places of historic interest in and about Salt Lake City.

Immediately following the Convention, arrangements will be made for those interested to visit the various properties which comprise the hydroelectric development of Utah Power & Light Company. One trip of three days' duration will cover the Bear Lake-Bear River system which is one of the most highly developed hydroelectric projects in the world. Bear Lake, a natural reservoir about 30 miles long and 9 miles wide, serves as a storage and equalizing reservoir for the entire Bear River system. The



GRACE HYDROELECTRIC PLANT, UTAH POWER & LIGHT CO.

flow of Bear River, below Bear Lake, is maintained practically constant throughout the entire year for power purposes and to the great benefit of irrigation projects located along the river. At Bear Lake, a pumping plant is installed to insure water in the river even during periods of low precipitation and run-off. For those who cannot afford the three days necessary to cover the Bear Lake-Bear River System, an excursion of one day is planned



ONEIDA HYDROELECTRIC PLANT, UTAH POWER & LIGHT CO.

to the new 30,000-kw. Cutler Generating Station which will be placed in operation during the latter part of 1926 and which will be in excellent condition for inspection and study during the early part of September.

One item of interest to all electrical engineers will be the ceremony in connection with the presentation of the A. I. E. E. Edison Medal to Dr. Harris J. Ryan, Past-President of the In-

stitute and Professor of Electrical Engineering at Stanford University.

The time of the Salt Lake Convention has been planned to fit in with the convention of the Rocky Mountain Coal Mining Institute which is to be held in Glenwood Springs immediately following the Salt Lake Convention, and also the Annual Meeting of the Colorado Railway Light and Power Association, which is to be held in Colorado Springs during the week following the Salt Lake Convention.

Notices of this Convention will be sent to all Western members of A. I. E. E., during August. A large attendance is expected and the Committee gives assurance that the time spent at the Salt Lake Convention will be most profitable.

The committee is composed of the following: C. R. Higson, Chairman; P. P. Ashworth, H. G. Baker, V. L. Board, D. L. Brundige, R. J. Corfield, G. S. Covey, John Harisberger, R. A. Hopkins, C. P. Kahler, J. A. Kahn, E. A. Loew, C. A. Malinowski, J. F. Merrill, E. B. Meyer, H. T. Plumb, R. C. Powell, C. C. Pratt, Paul Ranson, L. W. Ross, John Salberg, H. H. Schoolfield, M. M. Steck, A. Vilstrup, H. B. Waters and B. C. J. Wheatlake.

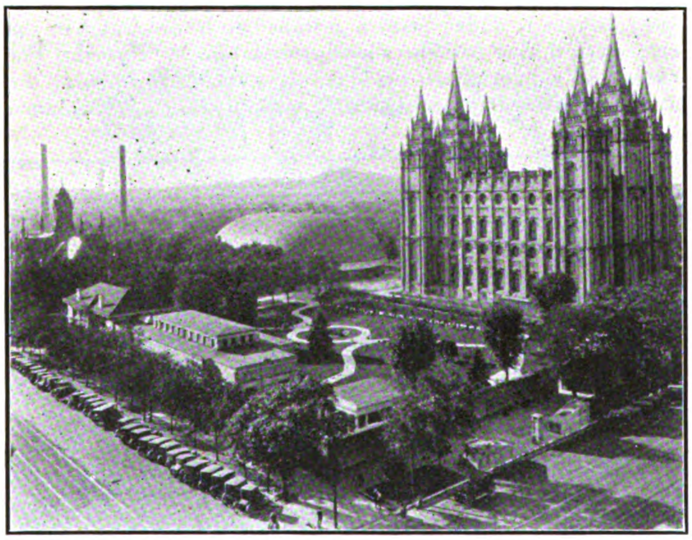
TENTATIVE LIST OF PAPERS FOR PACIFIC COAST CONVENTION

A New 220-Kv. Transmission Line, C. B. Carlson and H. Michener, Southern California Edison Co.

Effect of Unbalanced Tension in a Long-Span Transmission Line, by E. S. Healy and A. J. Wright, Electric Bond and Share Co.

110-Kv. Transmission-Line Construction of The Washington Water Power Company, by L. R. Gamble, Washington Water Power Co.

The Circle Diagram of a Transmission Network, by F. E. Terman, Stanford University.



Mormon Temple Block, Salt Lake City

The Space Charge That Surrounds a Conductor in Corona, by H. J. Ryan and J. S. Carroll, Stanford University.

Calibration of Lichtenberg Figures, by K. B. McEachron, General Electric Co.

Vacuum-Switching Experiments at California Institute of Technology, by R. W. Sorensen and H. E. Mendenhall, California Institute of Technology.

Temperature of a Contact and Related Current-Interruption Problems, by Joseph Slepian, Westinghouse Electric & Mfg. Co.

Fire Protection of A-C. Generators, by J. A. Johnson, Niagara Falls Power Co., and E. J. Burnham, General Electric Co.

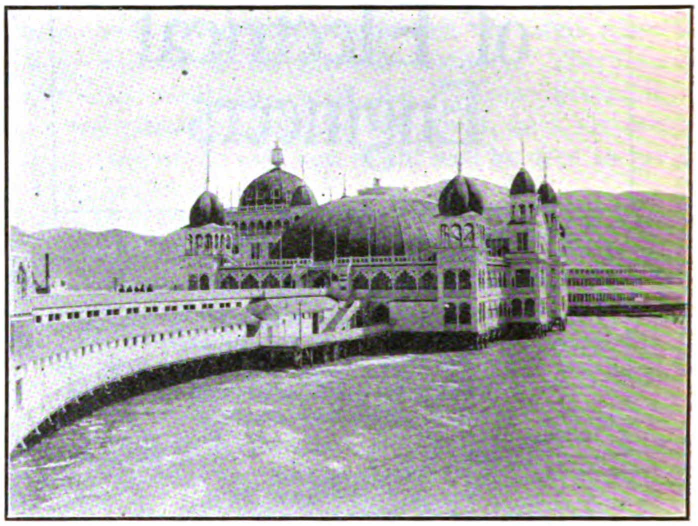
Stability Characteristics of Alternators, by O. E. Shirley, General Electric Co.

Synchronizing Power in Synchronous Machines, by H. V. Putman, Westinghouse Electric & Mfg. Co.

Protection of Oil Tanks Against Lightning, by F. W. Peek, Jr., General Electric Co.

Protecting Oil Tanks Against Lightning, by E. R. Schaeffer, Johns-Manville, Inc. (Informal presentation).

Engineering Education—Its History and Prospects, by H. H. Henline, Stanford University.



New Saltair Pavilion, Great Salt Lake

Transcontinental Telephony, by O. B. Jacobs and H. H. Nance, American Telephone and Telegraph Co.

Carrier-Current Communication on Submarine Cables, by H. W. Hitchcock, Pacific Telephone and Telegraph Co.

Controlling Insulation Difficulties in the Vicinity of Great Salt Lake, by B. F. Howard, Mountain States Telephone Co.

Electrical Practise in Lead-Silver Mines in Utah, by Leonard Wilson, Consulting Engineer.

Variable-Voltage Equipment for Electric Power Shovels, by R. W. McNeill, Westinghouse Electric & Manufacturing Co.

The White Sulphur Springs Convention

The forty-second Annual Convention of the A. I. E. E. convened at the Greenbrier Hotel, White Sulphur Springs, W. Va., President M. I. Pupin presiding. About 350 members and guests were in attendance and while it was numerically smaller than many of the previous conventions it was of the utmost technical interest because of the number of excellent papers and committee reports. The hotel and its surroundings left nothing to be desired in the way of entertainments and sports. Following the usual custom at Summer Conventions, the technical sessions were confined entirely to the mornings, leaving the balance of the day open for recreation and social purposes.

Conference of Section Delegates

The first event of the Annual Convention was the regular annual Conference of Section Delegates held under the auspices of the Sections Committee at morning and afternoon sessions on Monday, June 21.

Forty-three of the fifty-one Sections were represented by officially appointed delegates. Five of the Geographical Districts were also officially represented by their Secretaries or alternates, and there was also present a number of Counsellors of Student Branches.

The conference, which was also attended by a considerable number of officers and officers-elect and other interested members,

was presided over by Chairman Harold B. Smith of the Sections Committee. The program, which had been prepared in advance by a special committee and mailed to all the delegates, was considered in detail as follows:

1. Announcements by Professor H. B. Smith, Chairman, Sections Committee.
2. Remarks by President Pupin.
3. Remarks by President-elect Chesney.
4. Report by National Secretary Hutchinson on results of previous Sections conferences.
5. Public Relations:
   (a) Affiliation with Sections of other engineering societies and with other local organizations.
   (b) District and National speakers bureau.
   (c) The relations and service of Secticns to the community.
6. Regional Meetings.
7. Other new business.

The latter part of the conference related to organization and activities of Student Branches and was presided over by Dean C. E. Magnusson of the University of Washington, Seattle, in his capacity as Chairman of the Committee on Student Branches.

Recommendations were adopted as follows:

That a national committee be appointed to study the question of better public relations.

That the speakers bureau be strengthened or extended principally on the side of popular interpretation of scientific and engineering subjects.

That provision be made, if possible, in the budget for the coming year to pay traveling expenses for Student Branch Counsellors and incoming Student chairmen of all Branches to a District meeting each year; also to pay similar expenses for one delegate from each of the Districts to the national convention each year.

That a joint meeting of the Counsellors and incoming Student chairmen of all Branches in the two Pacific Coast Districts be held during the Pacific Coast Convention at Salt Lake City, commencing Monday, Sept. 6, 1926.

At the meeting of the Board of Directors held at the Convention on June 23, these recommendations were considered and action favorable to the objects desired was taken.

An abstract of the proceedings of the entire conference, which included discussion upon many other topics in addition to those referred to above, is being prepared and will be printed in pamphlet form and mailed to all delegates in attendance and to all officers of Sections, Branches, and the national body. Any Institute member who is interested may obtain a copy of the pamphlet without charge upon application to Institute headquarters, New York.

Tuesday, June 22

Immediately after opening the session on Tuesday morning President M. I. Pupin presented his president's address. In his address he pictured the relations of the great fundamental theories and discoveries of the science of electricity, closing with a plea for more thorough study of the marvelous properties of electricity which we are just now beginning to understand, the behavior of the electron. Dr. Pupin's address is published on page 758 of this Journal.

Following the President's address, Cummings C. Chesney, President-Elect, was introduced and he spoke briefly of his appreciation of being chosen for the presidency and of his hopes for carrying on another successful year of the Institute.

President Pupin then announced the winners of the Institute prizes for papers presented during the year 1925 and presented to the winning authors their certificates of award and cash prizes. These authors were R. W. Wieseman who won the First-Paper Prize and J. H. Cox and J. W. Legg who won the Transmission Prize. A complete account of the awards was published in the July issue of the Journal, page 685.

Following the presentation of prizes, Dr. Pupin introduced Mr. E. B. Meyer who took the chair and proceeded with the reading of the reports of the Technical Committees six of which were presented at this session. In the absence of Dr. Whitehead, Chairman, Dr. Kouwenhoven presented the report of the Research Committee. This was followed by the report of the Standards Committee which was presented by Mr. C. E. Skinner. The report of the Instruments and Measurements Committee was presented by Mr. J. R. Craighead in the absence of Chairman Knowlton, and Mr. H. P. Charlesworth followed with the report of the Committee on Communication. The final report of this session, that of the Committee on the Production and Application of light, was presented by Chairman P. S. Millar. Chairman Meyer then declared the reports open for discussion and the following members took part in the discussion which ensued:—W. E. Beaty, S. L. Gokhale, P. S. Millar, H. Goodwin, Jr., H. M. Hobart, and Dr. H. B. Dwight. At the close of the discussion the technical session adjourned until Wednesday morning.

Tuesday afternoon was devoted to golf, tennis, and other outdoor recreations as were all the afternoons during the convention. On Tuesday evening an informal reception was held in the Ball Room of the hotel. In the receiving line were President Pupin, President-Elect Chesney, and several other distinguished members of the Institute including officers past, present, and elect, together with many lady guests. Following the reception dancing was enjoyed with music by a most pleasing orchestra. Incidentally, there was dancing on every evening of the convention following the other scheduled events.

Wednesday, June 23rd

Two technical sessions were held on Wednesday morning, Session A being held in the Ball Room of the hotel. Mr. E. B. Meyer called the session to order and introduced Mr. H. M. Hobart, Chairman of the Electrical Machinery Committee, who took the chair. Three papers were presented at this session as follows:—*Synchronous Machines*, presented in part by R. E. Doherty and continued by C. A. Nickle. The discussion of this paper followed immediately on its presentation and the following men participated: C. A. Adams, P. L. Alger, M. I. Pupin, R. W. Wieseman, R. D. Evans, and H. B. Dwight, with closure by R. E. Doherty. The next paper on the program, *Graphical Solution of A-C. Circuits*, by F. W. Lee, was presented by Dr. Kouwenhoven in the absence of the author. Discussion followed by M. I. Pupin, W. P. Dobson, C. A. Adams, D. C. Prince, Harold Pender, R. E. Doherty, and C. W. Bates. The title of the third paper on the program was *Multiplex Windings for D-C Machines* and was written by C. C. Nelson. As the author was not present the paper was read by Mr. H. B. Dwight and was discussed by W. B. Kouwenhoven, H. B. Dwight, J. L. Burnham, and C. A. Adams.

Session B on Wednesday morning was held in the Tudor Room of the hotel and was presided over by Mr. F. L. Hunt. The first paper to be presented was entitled *Remotely Controlled Substations* and was abstracted by its author, W. C. Blackwood. This was discussed by C. M. Gilt, F. B. Johnson, C. Lichtenberg, E. K. Huntington, G. O. Brown, with closure by Mr. Blackwood. The next paper of the session was entitled *The High-Speed Circuit Breaker in Railway Feeder Networks*, by J. W. McNairy who presented it in abstract, following which a written discussion by R. J. Wensley was presented by title. Verbal discussion followed by J. J. Linebaugh and C. Lichtenberg. The final paper was by Alfred Bredenberg, Jr., and was entitled *Regenerative Braking for D-C Locomotives*. This was abstracted by the author. As there was no discussion of this paper the meeting adjourned.

Two of the entertainment features which the ladies particularly enjoyed were the auto drive on Wednesday afternoon and the card tournaments on Thursday evening.

In the drive on Wednesday, automobiles took a large party through some of the most beautiful mountain and valley scenery, a stop being made at Lewiston for tea.

On Thursday evening both bridge and hearts were played by a large number of ladies and men. The winner at each table received a salad bowl as a prize.

Standardizing Organizations Discussed

On Wednesday evening the relations between the Institute, the American Engineering Council and two major standardizing organizations were outlined by three able speakers. Dr. C. H. Sharp, described the activities of the International Electrotechnical Commission. He mentioned the agreements which have been reached among various nations and suggested the possible formation of an international standards association.

L. W. Wallace, executive secretary of the American Engineering Council, told of the work of that organization, particularly in advocating congressional acts dealing with the Patent Office, Mapping, Muscle Shoals, Salaries of Federal Judges and Radio Broadcasting. The Council has prepared a number of reports on important questions including waste in industry, the twelve-hour shift, commercial aviation and accidents and production.

C. E. Skinner, chairman of the American Engineering Standards Committee, told of the objects and work of that body. He mentioned the rules of procedure for making standards which have been prepared and pointed out the mutual benefits which would result if all standards-making bodies follow these rules as a guide.

The regular meeting of the Board of Directors was held at two-thirty Wednesday afternoon. A resumé of the business transacted by the Board will be found elsewhere in this issue.

Thursday, June 24th

The session on Thursday morning was presided over by Progessor H. B. Smith and like the Tuesday morning session was devoted entirely to the presentation of Technical Committee reports. All of the reports were presented in abstract and were as follows: Report of the Committee on Power Transmission and Distribution, P. H. Thomas, Chairman, presented by P. H. Chase, Vice-Chairman; Report of the Committee on Protective Devices, E. C. Stone, Chairman, presented by F. L. Hunt, Vice-Chairman; Report of the Committee on Applications to Iron and Steel Production, F. B. Crosby, Chairman, presented by A. G. Pierce; Report of the Committee on General Power Application, A. M. MacCutcheon, Chairman, presented by Mr. MacCutcheon; Report of the Committee on Applications to Mining Work, F. L. Stone, Chairman, abstracted by H. A. Winne; Report of the Committee on Applications to Marine Work, L. C. Brooks, Chairman, presented by A. G. Pierce; Report of the Committee on Electrochemistry and Electrometallurgy, G. W. Vinal, Chairman, abstracted by Mr. Vinal; and the Report of the Committee on Power Generation, V. E. Alden, Chairman, presented by Mr. Alden. An extended discussion followed which was participated in by W. S. Lee, W. A. Del Mar, R. D. Evans, H. R. Summerhayes, M. I. Pupin, C. A. Nickle, H. M. Hobart, and R. N. Conwell.

Friday, June 25th

On Friday morning the last two technical sessions of the Convention were held in parallel. Session A was under the chairmanship of W. A. Del Mar and the first paper to be presented was *The Mechanism of Breakdown of Dielectrics*, by P. H. Hoover. This was discussed by W. F. Davidson, P. L. Alger, R. W. Wieseman, and in a written discussion by R. W. Atkinson read by E. Kirschner. The second paper presented in Session A was by D. C. Prince and was entitled *Mercury Arc Rectifiers*. The paper was abstracted by Mr. Prince and discussed by C. P. Osborne, A. H. Mittag, J. A. Cook, D. C. Prince, W. A. Hildebrand, W. F. Davidson, and R. D. Evans, with closure by A. V. Mershon.

Session B on Friday morning was called to order by Mr. L. W. Morrow who called on Mr. Gokhale to abstract his paper on *Law of Magnetization*. It was discussed by J. R. Craighead, H. Lippelt (by letter), W. L. Upson, and J. E. Jackson, with closure by Mr. Gokhale. The next paper was entitled *Surface Heat Transfer in Electric Machines with Forced Air Flow*, and was by G. E. Luke who presented it in abstract. This was discussed by J. L. Burnham with closure by G. E. Luke. The final paper of the session was on *General Theory of the Auto-Transformer* which was presented by the author, W. L. Upson. This was discussed by J. R. Craighead with closure by Mr. Upson. The session then adjourned.

The Golf Tournament

A great many of the men at the meeting participated in the golf tournament and in addition there was a ladies' putting contest. The golf tournament, which was played for the Mershon Trophy, was very closly contested. After all other contestants had been eliminated, Friday afternoon brought a match between the two remaining players, H. C. Don Carlos and W. P. Dobson. Their match however resulted in a tie. Therefore as both of these gentlemen reside in Toronto the committee decided that they should play off the match later on a Toronto course. Subsequently this was done and this time Mr. Don Carlos was victorious by a score of four up and three to go. Accordingly his name will be added to the eleven other names already on the Mershon Cup. He will not have permanent possession of the cup as it is required that a contestant win this annual tournament twice before he may keep the cup. He received, however, as a permanent prize another handsome cup. Mr. Dobson as runner-up also received a cup.

The winners of the other features were as follows: N. M. Garland had the low gross score (79). Farley Osgood had the low net score (63 with 21 handicap). W. S. Lee won the final of the second flight, and R. F. Gheen was runner-up. P. M. Lincoln won the final of the third flight, while W. B. Kirke was the runner-up.

The ladies' putting contest was won by Mrs. N. M. Garland, the prize consisting of a silver vase, and Mrs. H. W. Young won a bronze bowl as second prize.

Tennis Tournaments

Tennis tournaments, both singles and doubles, were played. L. B. Chubbuck won the singles tournament and H. B. Dwight was runner-up. For this Mr. Chubbuck's name will be placed on the Mershon Tennis Trophy and he received a silver cup as a permanent prize. For permanent possession of the Mershon Cup the same player must win the tournament twice.

The doubles tournament was won by H. R. Summerhayes and E. H. Hubert. The runners-up were P. M. Alger and D. C. Prince.

The annual Convention Committee, the efficient management of which insured a most successful convention, consisted of the following: Farley Osgood, Chairman, W. R. Collier, W. S. Lee, E. B. Meyer, W. E. Mitchell, A. M. Schoen, H. B. Smith.

Twentieth Anniversary of Illuminating Engineers

Marking the founding of the Society in 1906, the Twentieth Anniversary Convention of the Illuminating Engineering Society will be held at Spring Lake, New Jersey, September 7th to 10th inclusive, when the great advances and developments which have been made during the past 20 years in this special field of Engineering activity will be fittingly observed. A program of diversified and comprehensive papers on subjects of great practical interest has been arranged by the Committee in charge. One special feature of the program particularly appropriate at this time will be a session devoted to developments in the art of illumination which have taken place during this twenty-year period. Another session will be of interest to central-station

lighting men and devoted to the presentation and discussion of the Lighting Sales Manual, prepared by a joint committee of the Illuminating Engineering Society and the National Electric Light Association. The manual outlines methods found most efficient by some of the leading illuminating engineers of the country in promoting good lighting by central stations. Central-station lighting men from the leading public utilities are to be invited to discuss the manual and promote its adoption and use.

The entertainment features of the program have not been overlooked, and the hotel, with its surroundings admirably adapted to provide the recreational features, will repeat the success of previous meetings; golf, bathing in ocean or pool, tennis, country roads to attract the lover of horseback riding, boulevards for the motorist, broad porches overlooking the ocean are but a few of the many attractions. Special features of entertainment will be provided for the ladies.

World Power Conference Program and Appointments

Topics for discussion at the sectional meeting of the World Power Conference to be held in Basle, Switzerland, August 31 to September 12, 1926, in which the American Committee of the conference will participate, include the utilization of water power, inland navigation, exchange of electrical energy between countries, electricity in agriculture and railway electrification.

This is shown in the technical program of the sectional meeting of the World Power Conference, copies of which have been received by O. C. Merrill, executive secretary of the Federal Power Commission, Washington, D. C., Member of the Institute and general chairman of the American Committee.

Beside Mr. Merrill according to a recent announcement the following American engineers will attend the World Power Conference. Prof. A. E. Kennelly and Prof. Harry E. Clifford, of the Department of Electrical Engineering, Harvard University; John W. Lieb, vice-president, New York Edison Company; Louis Marburg, of Marburg Brothers, Inc.; O. G. Thurlow, chief engineer, Alabama Power Company; Hugh L. Cooper, Consulting Engineer; and David B. Rushmore, formerly consulting engineer, General Electric Company.

Following are some of the papers to be presented by the American delegation Committee:

The Economic Relation Between Electrical Energy Produced Hydraulically and Electrical Energy Produced Thermally: Conditions Under Which the Two Systems Can Work Together to Advantage, by W. E. Mitchell, Vice-President, Alabama Power Company, Birmingham, Ala.

Electricity in Agriculture, by Dr. E. A. White, Director, Committee on the Relation of Electricity to Agriculture, Chicago, Illinois.

Railway Electrification, by W. S. Murray, Consulting Engineer, New York City.

National Aspects of the Study of Water Resources, by Nathan C. Grover and John C. Hoyt, Geological Survey, Department of the Interior.

Utilization of Water Power, and Inland Navigation, by Colonel Hugh L. Cooper, Consulting Engineer, New York City.

Exchange of Electrical Energy Between Countries, by Colonel William Kelly, Director of Engineering, National Electric Light Association (formerly Chief Engineer, Federal Power Commission).

Up to the present time, twenty-nine countries have agreed to take part in the conference and sixty-five reports have been received. A complete list of the authors and titles of the reports, together with the conditions governing them, may be obtained from the Secretary of the World Power Conference, (World Power Conference, Basle). At the close of the conference, a full report, including the discussions, will be published.

The opening meeting of the conference will be held on Tuesday, August 31st. Tuesday afternoon and Wednesday (Sept. 1st) will be given over to the reports on utilization of hydraulic power and inland navigation. Thursday and Friday, September 2nd and 3rd, will be occupied with discussions on railway electrification and electricity in agriculture.

On Saturday and Sunday (Sept. 4th and 5th), a special train, generously provided by the Swiss Federal Railways, will take the party to the Gotthard to inspect the electrification works.

Monday and Tuesday, September 6th and 7th, will be given up to the reports on hydroelectric and thermal power, and the exchange of power between countries. The closing meeting will be held on Wednesday, September 8th.

Following the conference, a number of visits have been arranged to industrial establishments September 8th and 9th, and from the 10th to the 13th, there will be two somewhat longer excursions which will enable the visitors to see something of the wonderful scenery of Switzerland. One will be to the Engadine, with Buchs as the objective, whence opportunities will be offered for further excursions to Austria, Germany, Czecho-Slovakia, Hungary, Norway and Sweden. These will be organized by the National Committees of the countries concerned. The other excursion will include the Bernese Oberland and the West of Switzerland with the possibility of extended trips to Italy, France, Belgium and Holland.

Further details regarding the program of the conference and the excursions may be obtained from the Secretary of the World Power Conference.

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the Greenbrier Hotel, White Sulphur Springs, W. Va., on Wednesday, June 23, 1926, during the Annual Convention of the Institute.

There were present: President M. I. Pupin, New York; Past-President Farley Osgood, New York; Vice-Presidents Harold B. Smith, Worcester, Mass.; Edward Bennett, Madison, Wis.; Arthur G. Pierce, Cleveland; W. P. Dobson, Toronto; Managers H. M. Hobart, Schenectady; G. L. Knight, Brooklyn, N. Y.; J. M. Bryant, Austin, Tex.; M. M. Fowler, Chicago; H. A. Kidder, New York; H. P. Charlesworth, New York; National Secretary F. L. Hutchinson, New York. Also, by invitation, C. H. Sharp, C. E. Skinner (representatives of Standards Committee), and G. O. Brown (representing Vice-President-Elect A. E. Bettis).

The minutes of the Directors' meeting of May 21, 1926, were approved as previously circulated.

A report of a meeting of the Board of Examiners held June 11, was presented and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 61 Students were ordered enrolled; 342 applicants were elected to the grade of Associate; 11 applicants were elected to the grade of Member; 38 applicants were transferred to the grade of Member; 9 applicants were transferred to the grade of Fellow.

The Board ratified the action of the Finance Committee in approving for payment, monthly bills amounting to $28,743.86.

The Finance Committee called attention to the fact that, under the by-laws, traveling expenses are paid for Section delegates to the Annual Convention covering actual transportation expenses both ways, including Pullman and meals enroute, but that other traveling expenses have been authorized on the basis of ten cents per mile one way. The committee recommended that all traveling expenses be placed upon the uniform basis of ten cents per mile one way from the place of residence to the meeting place, excepting that in the case of members, who are appointed to represent the Institute upon special occasions, actual traveling and hotel expenses shall be paid, upon application. The Board

voted that the recommendation be adopted, and directed that Section 46 of the Institute By-laws be amended accordingly.

The Finance Committee called attention to Section 22 of the Institute constitution, which provides that "upon application, the Board of Directors shall exempt from future annual dues, any Fellow, Member, or Associate who has paid dues for thirty-five years, or who shall have reached the age of seventy after having paid dues for thirty years," and recommended that such members be designated "Members for Life" (in distinction from the present "Life Membership" list, which includes those who commute their future dues by payment of a single sum as provided in the by-laws). The Board voted that applications for permanent exemption from further payment of dues received hereafter under Section 22 of the constitution, be referred to the Finance Committee, with power; also that all members so exempted in future shall be designated in the Institute records as "Members for Life."

The Committee on Coordination of Institute Activities reported that it is desirable to schedule all important meetings of the Institute much further in advance than heretofore, some of the reasons being the desirability of reserving the necessary meeting rooms, hotel accommodations, etc., and of avoiding conflicts with the meeting dates of other organizations as far as possible. Upon the recommendation of the committee, the following schedule of meetings was approved (the first two meetings had previously been approved by the Board): Pacific Coast Convention, Salt Lake City, September 6-9, 1926; New York Regional Meeting, November 11-12, 1926; Midwinter Convention, New York City, beginning Monday, February 7, 1927; North Eastern District Regional Meeting, April or May 1927 (place to be determined later—Pittsfield, Mass., and other places under consideration); Annual Convention, Detroit Section territory, beginning Monday, June 20, 1927; Pacific Coast Convention 1927 (place and date to be decided upon later by the Pacific Coast membership).

The Committee on Coordination of Institute Activities also recommended that, inasmuch as several annual conventions are now held, the use of the expression "Annual Convention of the Institute" be discontinued and that the three principal annual national conventions be designated as follows: "Winter Convention," "Summer Convention," and "Pacific Coast Convention;" also that the serial numbers applying to the Annual Conventions as held heretofore be continued and applied to the Summer Convention only. This recommendation was approved by the Board.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Prizes for Papers Awarded in Northeastern District

Prizes for papers presented during 1925, in the Northeastern District of the Institute, have been awarded by the Prize Committee of that District.

The committee awarded the Best-Paper Prize to K. B. McEachron and E. J. Wade for their paper *Studies of Time Lag of Needle Gaps.* Each author received a certificate of award, and a cash prize of $25 was divided between them.

Honorable mention was awarded to I. F. Kinnard and H. T. Faus for their paper *Temperature Errors in Induction Watthour Meters*, and to R. F. Franklin, for his paper *Short-Circuit Currents of Synchronous Machines.*

The First-Paper Prize for the District was awarded jointly to R. W. Wieseman, for his paper *A Two-Speed Salient-Pole Synchronous Motor*, and C. A. Nickle, for his paper *An Electro-Mechanical Problem Analyzer.* A certificate was presented to each author and a $25 cash prize was divided between them.

Honorable mention was given to F. M. Clark, for his paper *Effect of Repeated Voltage Application on Fibrous Insulation*, and to E. J. Burnham, for his paper *Overvoltages on Transmission Systems Due to Dropping of Load.*

The District Prize Committee consisted of P. M. Lincoln, chairman; A. C. Stevens, secretary; F. J. Adams, A. E. Knowlton and H. W. Tobey.

Saskatchewan Section Holds Meeting in a Camp

A three-day meeting in a tent camp was held by the Saskatchewan Section on July 8, 9 and 10, at Estevan, Saskatchewan. Twenty-nine tents were erected to accommodate the one hundred members of the Section and the invited Saskatchewan Branches of the Engineering Institute of Canada and the Canadian Institute of Mining and Metallurgy.

Meetings were held in a large marquee erected for the purpose. The following papers were read:

Electrical Development of Southern Saskatchewan, by S. R. Parker.

Industrial Development of Southern Saskatchewan, by W. H. Greene.

Preservative Treatment of Wood, by R. D. Prettie.

Addresses were delivered by Dr. Chas. Cansell, Deputy Minister of Mines, Ottawa; Professor Hall, of the University of Manitoba; Professor Worcester, of the University of Saskatchewan; and Mr. Thorn, Chief of the Natural-Resources Branch of the Canadian Pacific Railway, Calgary.

On Thursday, July 8th, visitors were the guests of the Town of Estevan, at a complimentary banquet.

The large attendance was recorded in spite of heavy rains the day before the meeting opened, which necessitated many of the members driving through mud for distances of two and three hundred miles. One much appreciated feature of the meeting was the low cost of sleeping accommodations, for which each adult was charged two dollars, while children were taken care of without charge. The novelty of camping out was greatly enjoyed and all voted the meeting a great success.

Armour Institute and Northwestern University to Unite

On June 30, Armour Institute of Technology, at Chicago, brought to a successful close a campaign for raising a million dollars as a preliminary move in its affiliation with Northwestern University. Of the million dollars, the alumni subscribed more than one-third, the balance being made up of donations from members of the Armour family, a citizen of Chicago interested in engineering, and several public utility corporations.

A further call for $10,000,000, for endowment and buildings to be erected on the Evanston Campus of Northwestern University and on the McKinlock Campus at Chicago Avenue and the Lake, is being undertaken under the leadership of Samuel Insull, Chairman of the Joint Trustees Committee. The arrangement between the two institutions allows a five-year period in which they shall jointly attempt to raise the capital fund.

A Request for Decision on Radio Law

The failure of Congress to complete radio regulation and the confusing decisions rendered by the Courts on radio laws of 1912 have led the Department of Commerce to request an opinion from the Attorney General on the whole situation of Departmental authority. The most important feature of the matter is in respect to the right to assign, enforce or deny the use of specific wavelengths to individual stations,—the key to the whole regulation.

Since 1923 the Department has been making such assignments in accordance with decision of the Court of Appeals, District of Columbia, rendered during that year, on the assumption that,

by the law of 1912, they were under duty to make such assignments to prevent interference. Recent decision of the Chicago Court, however, cast doubt on this authority. The Attorney General now likewise disagrees with the construction of the Court of Appeals, advising that while each applicant must designate a definite wavelength, outside the band between 600 and 1600 meters, it is still his prerogative to use other wavelengths at will. Persons desiring to construct stations must determine for themselves whether or not there are specific wavelengths available for their use without being subject to interference from other stations. They must simply proceed at their own risk.

University of Pennsylvania Creates New Course

The creation of a new graduate course to prepare men for engineering research or for teaching and which will lead to the degree of Master of Science in Electrical Engineering has been announced by Dr. Harold Pender, Dean of the Moore School of Electrical Engineering of the University of Pennsylvania and Fellow of the Institute.

At the same time, Dean Pender announced that four graduate fellowships, each of which carries with it free tuition and a cash stipend of $500, have been made available to encourage students who are properly qualified to add a fifth year to their university training. Applications for the fellowships may be made to the Dean of the Moore School.

The course will begin with the academic year of 1926-27, and will include the following subjects; introduction to mathematical physics, advanced mathematics for engineers, advanced electric-circuit theory, electron theory and its engineering applications, and a thesis.

Each graduate student will be required to complete an independent and original investigation in some field of electrical engineering. The student will be encouraged to select his own problem and must submit monthly reports on the progress of his investigation.

Applicant must have completed with credit an undergraduate course in electrical engineering substantially equivalent to that given in the Moore School.

A Uniform Electrical Ordinance

A uniform electrical ordinance has been prepared by the Electrical Manufacturers Council, providing that work done in accordance with the regulations as laid down in the two national codes shall be prima facie evidence that it is in conformity with the most approved methods of construction for safety to life and property. As the number of municipalities adopting this ordinance increases, the inspection situation will become simplified accordingly.

This ordinance provides, also, for the adoption of modifications in the codes as they are made, so that it may be possible to keep in step with the progress of the codes without the necessity of a detailed local study of each revision. The only subjects in need of local restudying from time to time are the special local rulings which can either be issued separately in bulletin form or can constitute separate articles of the local ordinance adopting the codes as its basic article.

The inspector has played an important part in formulation and revision. He has eliminated from them much that was undesirable and is constantly suggesting changes to cover either old, unnoticed or new conditions.

There are two ways in which he may assist—as an individual or as a member of an inspectors' organization. One of the most important services to be brought about is the general use of national codes of American standards.

The Committees in charge of the revision of the codes welcome constructive suggestions and criticisms from inspectors as individuals facilitate the acquisition of this knowledge, the National Fire Protection Association, sponsor for the National Electric (Fire) Code, has appointed a field secretary whose business is to keep in personal touch with inspectors and present their views to the Electrical Committee of the Association.

Power Show Reflects Tremendous Advances

Contemplation of the rapidly increasing demand for mechanical power by the industries and homes of the United States reveals the secret for its success and leadership as an industrial and commercial nation. Greater and more economical production at a smaller expenditure of human energy is the reason for its supremacy. Mechanical power as utilized in the automobile and tractor, in the locomotive and steamboat, and as derived from the electric motor in the factory and home, lies at the root of the growth of the country and of the increase in the physical and spiritual well-being of its people. The tremendous advances in the art of generating power to meet the demand are emphasized by the recent announcement by an eastern public utility of the award of a contract for a steam turbine to generate 160,000 kilowatts or more than 210,000 horse power. This gigantic machine is 60 per cent larger than the largest turbine previously constructed. Compared with the turbines of ten years ago, it is considered a miracle of the engineering world. A more interesting contrast is called to mind by the opening of the Exposition in Philadelphia fifty years ago when, after some speech-making, President Grant and the Emperor of Brazil started the giant Corliss Engine, generating 1400 horse power, weighing 700 tons, and requiring sixty-five freight cars to deliver in Philadelphia.

To reflect these enormous strides in the mechanical arts and to make them available to the engineering and industrial public is the important function of the National Exposition of Power and Mechanical Engineering which is held annually in the Grand Central Palace in New York City. The Fifth Exposition will be held from December 6 through 11, 1926, and will fill four floors of the Palace with showings of all types of power and heat generating, distributing, and using equipment. It will include refrigerating, heating and ventilating machinery and machine tools and power transmission devices, in addition to the usual important exhibits of power plant apparatus. Over 450 exhibitors will provide a well-balanced exposition that will have something novel and important for every mechanical engineer and industrial executive.

The exposition is under the management of Fred W. Payne and Charles F. Roth with offices in the Grand Central Palace.

Westinghouse Awards Educational Scholarships

Four scholarships each of which provides for payment of $500 a year to be applied toward an engineering education have been awarded by the Westinghouse Electric and Manufacturing Company. The winners of the awards, based on the 1926 competitive examination given by the Educational Department, are Robert R. Lockwood, an employe of the company and student in the night school of Carnegie Institute of Technology; William J. Morlock, a graduate of the McKeesport (Pa.) High School; Frank M. Redman, graduate of Grant High School, Portland, Oregon; and Harry W. Thiemecke, company employe and student at Carnegie Institute of Technology.

Fifty-two applicants competed for the scholarships which were established by the Westinghouse company as a memorial to those of its employes who served in the World War.

Employes, or sons of employes, are eligible for the examinations, which are held annually. The awards are granted for one year only but will be continued for the full engineering course if the student meets the academic and other standards

of his school. Since the fund was established at the close of the war, 32 Westinghouse Scholarships have been awarded.

Mr. Lockwood will take up Electrical Engineering at Carnegie Institute of Technology, Mr. Morlock at Ohio State University, and Mr. Redman at Leland Stanford University. Mr. Thiemecke will take Ceramic Engineering at Ohio State University.

The committee in charge of the awards consists of L. A. Osborne, chairman, and Walter Cary, vice presidents of the company, and T. P. Gaylord, Acting Vice President.

AMERICAN ENGINEERING COUNCIL

SEEKS SOLUTION OF BROADCASTING PROBLEM

A public service solution of the broadcasting problem is sought by the American Engineering Council, according to announcement made by its president, Dexter S. Kimball, of Cornell University.

A committee of investigation will be appointed to examine the whole situation in an attempt to obviate the "radio chaos" which may affect some 20,000,000 listeners. Dean Kimball asserts that many of the problems are of an engineering nature and that he believes a careful study of them, in an unbiased, broad-minded, and comprehensive way by a special committee chosen for that purpose, will be productive of results beneficial and of convincing form. He states that there are now 540 broadcasting stations, at least 200 of which are giving regular programs of considerable interest to substantial audiences, and approximately 600 additional applicants still remain, to whom broadcasting licenses have not been granted by the Department of Commerce.

PROPOSED LEGISLATION FOR DIVISION OF SAFETY

The House Committee on Labor, on May 21st, 1926, decided to report favorably upon a bill presented by Representative Rathbone, of Illinois, proposing legislation for the creation of a Division of Safety in the Department of Labor.

The duties of such Division will be to collect statistics on industrial situations involving jeopardized safety, with special reference to cause, effect and occupational distribution, and present them to the Department together with coincident recommendations of plans for labor safety and devices for various application to this end.

The bill provides for the cooperation of all other Governmental Departments interested in this work, and a museum exhibit of protective devices for the prevention and control of industrial disease, both mechanical and physical.

RECOMMENDATIONS FOR ORDNANCE RESERVE COMMISSIONS

As a result of the efforts of American Engineering Council and other Engineering Organizations to assist the Ordnance Department in recruiting the Reserve Corps, many recommendations have been received from the field men placed in charge of this work. Local leaders in the engineering profession in many cases have submitted names of prominent engineers who are capable and willing to fill these commissions. These recommendations have been submitted to the Director of Commissioned Personnel in the Office of the Chief of Ordnance who in turn, will submit them to the district officers of the Engineer Corps. The men will then be interviewed preparatory to choosing those best suited for appointment.

Effect of Bus Transportation on Railroads

All common carriers using motor bus transportation have been called upon by the Interstate Commerce Commission to give complete information regarding the operation of their motor bus and motor truck lines including, as far as possible, the effect on railroad traffic or competing motor transportation.

A series of dates have been set for hearings during July, August and September, covering 14 cities. These hearings will be conducted by Commissioners Esch and Aitchison and Examiner Flynn.

International Mid-Continent Engineering Convention

The Minnesota Federation of Architectural and Engineering Societies will hold an International Mid-Continent Engineering Convention in Duluth and on the Mesabi Iron Range, August 12th, 13th and 14th. The program will include papers descriptive of the great iron-mining and transportation industries in northern Minnesota and Wisconsin and visits to mines, docks and mills. There will be a banquet with speakers of national repute, and other entertainment. Special provision will be made for entertaining the ladies. The architects and engineers of Canada and this country are cordially invited. Inquiries should be addressed to W. H. Woodbury, 510 Wolvin Bldg., Duluth, Minn.

The Federation which is planning the convention is composed of a number of engineering and architectural organizations, including the Minnesota Section of the American Institute of Electrical Engineers.

Howard N. Potts Medal Award

Dr. W. D. Coolidge, assistant director of the research laboratory of the General Electric Company and inventor of an X-ray tube which bears his name and which is universally used in hospitals and laboratories, has been awarded the Howard N. Potts gold medal for 1926 by the Franklin Institute of Philadelphia.

The medal, to be formally presented by the institute on October 20, is "in consideration of the originality and ingenuity shown in the development of a vacuum tube that has simplified and revolutionized the production of X-rays," according to the Institute's citation.

In accepting the medal, Dr. Coolidge will present a paper on his new and powerful cathode-ray tube.

PERSONAL MENTION

B. M. Horter, who had been connected with the Philadelphia office of the Cutler-Hammer Mfg. Co., has been appointed manager of that company's Boston office.

Ralph B. Stewart, Associate of the Institute and former member of the United States Patent Office, has opened his own offices in Washington, D. C., as Patent Attorney.

William H. Cahoon, formerly of Ford, Bacon and Davis, Inc., Engineers, is now connected with George F. Hardy, Consulting Engineer, New York City, as electrical engineer.

B. Lester, Assistant to the Industrial Sales Manager of the Westinghouse Electric and Manufacturing Company, and Member of the Institute, recently removed from East Pittsburgh to New York.

David Hall, a Fellow of the Institute, who has been associated with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., as power engineer, has been transferred to Los Angeles, as manager of their engineering division for that district.

F. F. Elznic, previously with Charles Cory & Sons Co., Inc., of this city, has just become president of the Acorn Manufacturing Co. and is doing much to increase the capacity of the organization. The Vice President and General Manager is Mr. S. N. Nead, Jr.

B. Tikhonovitch, connected with the Engineering Department of the New York Edison Company, was recently transferred to the Electrical Engineering Department as assistant to the designing engineer. Mr. Tikhonovitch has served on

the Generating Station Committee and other Committees of the Institute.

JOSEPH N. MAHONEY, Fellow of the Institute and actively prominent in the electrical field since 1898, has formed new affiliations with the American Brown Boveri Electric Corporation of New York City as their manager of engineering. This change was made by Mr. Mahoney last month, prior to which time he had been rendering valuable service as Sales Manager and consulting engineer of the Sperry Gyroscope Company. His scientific labors have embraced work in almost every branch of the engineering profession, for beside joining the Institute in 1917, he is as well an active member of the American Society of Civil Engineers, The American Society of Mechanical Engineers, the American Institute of Mining Engineers, the American Electro-Chemical Society, the Society of Automotive Engineers, and the Brooklyn Chamber of Commerce.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work,

1.—Bernard Bider, 4560 N. Central Park. Ave., Chicago, Ill.
2.—A. F. Buckley, 211 Sherman Ave., New York, N. Y.
3.—E. W. Hoover, 1482 E. Stark St., Portland, Ore.
4.—M. E. Johnson, 133 Ardsley Road, Schenectady, N. Y.
5.—H. A. Katz, 1402 Monadnock Bldg., Chicago, Ill.
6.—D. F. McConnell, 402 N. Highland Ave., Pittsburgh, Pa.
7.—J. F. Wessel, U. G. & E. E. Corp., 111 Broadway, New York, N. Y.

Obituary

Charles E. Scribner, a Fellow of the Institute since 1913, and one of its vice-presidents from 1913 to 1915, died at his summer home in Jericho, Vt., June 25, 1926. Mr. Scribner, who was 68 years of age, had been actively engaged in work in the electrical field for more than forty years.

Born in New York, he removed very early to Toledo, Ohio, where he was educated in the public schools. In 1876 he went to Chicago, taking with him his first invention—an automatic telegraph repeater. A year later he obtained employment with the Western Electric Manufacturing Company, the name of which was afterward changed to the Western Electric Company. Later he became chief engineer of the company. For 22 years he served in that capacity, at the end of which time he was made consulting engineer for the same concern and remained with them until his retirement from active business.

Mr. Scribner was a well-known electrical inventor, having taken out almost 500 patents during the course of his active service. After the death of Steinmetz, he was credited with holding more patents in the electrical field than any other man save his friend, Thomas A. Edison, who said of him:

"I had the greatest admiration for Mr. Scribner's imaginative power and his ability to visualize and anticipate in minute detail the requirements of the vast technique that has been gradually built up in the electrical industry. Mr. Scribner was the most industrious inventor I ever have known. He was apparently indefatigable and his imagination seemed to be boundless."

Most of his inventions related to telephone apparatus. The first multiple switchboards to be used commercially on a large scale were of Mr. Scribner's design. The electrical circuits employed in intercommunication, switchboards, and signalling apparatus, as devised by him, have been adopted not only throughout this country, but in nearly all countries in the world.

Charles A. Coffin, founder and for thirty years head of the General Electric Company as president and chairman of the board of directors, died Wednesday night, July 14, 1926, at his home in Locust Valley, Long Island. He had been an Associate of the Institute since 1887.

Mr. Coffin was born in December, 1844, in Somerset County, Maine, and graduated from Bloomfield (Me.) Academy. His first business was in the shoe and leather industry, but in 1883 he became associated with the Thomson-Houston Electric Company in Lynn, Mass. In 1892 the Thomson-Houston Electric Company and the Edison General Electric Company of New York were consolidated and Mr. Coffin became president of the new General Electric Company. He has been called "the greatest organizing genius of the electrical industry in America" and was recognized as one of the greatest single factors making for the growth and development of the use of electricity in this country.

During the war Mr. Coffin was active in relief and Red Cross work and received the French Legion of Honor and the Belgian order of Leopold II. Yale, Union, and Bowdoin Colleges conferred honorary degrees upon him.

William H. Browne, 3rd, who was elected to the grade of Associate at the April 1926 meeting of the Institute Board of Directors, was killed in a railway accident on the 28th of June. Mr. Browne was the son of one of our Associates, William H. Browne, 2nd, of Raleigh N. C.; he was but twenty-six years of age and an operator for the McCollom Geological Exploration Corp.

Oberlin Smith, a Member of the Institute since 1913, died at his home in Bridgeton, N. J., on the 18th of July. At the time of his death he had been President and principal owner of the Ferracute Machine Company for more than sixty years.

Mr. Smith was born in Cincinnati on March 22, 1840, and was educated at the West Jersey Academy, Bridgeton, N. J., and at the Polytechnic Institute, Philadelphia. At the age of sixteen he became an apprentice at the Cumberland Nail and Iron Works; he next started a small machine shop and from that developed the Ferracute Machine Company.

He invented and patented fifty-two presses and dies, many of them used by the Government and in the Ford automobile plants. He also made the dies from which Chinese money is stamped.

Mr. Smith was formerly President of the American Society of Mechanical Engineers and the National Geographic Society. He was a member of the American Society of Civil Engineers, the Engineers Club of New York, and the Franklin Institute of Philadelphia.

Willis E. Osborne, for several years a resident engineer in the Orient for the Western Electric Company of London, and an Associate of the Institute, died at his home in Corsicana, Texas, on the 4th of July. Mr. Osborne was born in Pennsylvania in 1880 and received his education in that state.

Frank E. Goodnow, an Associate of the Institute since 1917, died in Evanston, Ill., on the 27th of May, after a long illness. He had been connected with the Public Service Company of Northern Illinois since 1909. Mr. Goodnow was a graduate of the Massachusetts Institute of Technology of the class of 1908.

William Yale Avery, electrical engineer for Gibbs Bros., Inc., New York City, and for the past six years a Member of the Institute, died suddenly July 5, 1926. Mr. Avery was born March 30, 1873 and at an early age started his electrical career, studying in the public schools at Providence, R. I., engineering night school, Tufts College and taking a special two years' course at Pratt Institute, Brooklyn in further night school work.

He later returned to Tufts College for another special electrical course. His professional experience embraced a varied and valuable training for later undertakings; draftsman for Brown & Sharp, Corliss Co., the Brooklyn Navy Yards on electrical ship equipment and installation, civilian in charge of electrical division of the Bureau of Equipment, Navy Dept., Washington, D. C., followed by work with the Bureau of Steam Engineering, in connection with ship electrical installations specifications for parts, purchase, etc. From 1919 to 1920 he was electrical engineer for the Electro Dynamic Co., Bayonne, N. J., handling navy, merchant marine and special motors and generators, inclusive of submarine equipment, etc. At one time Mr. Avery was affiliated also with the Cramp Shipbuilding Co. and Harlan & Hollingsworth.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES JUNE 1-30, 1926

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ARCHITECTURAL CONSTRUCTION, v. 2; An Analysis of the Structural Design of American Buildings. Book one: Wood Construction.

By Walter C. Voss and Edward A. Varney. N. Y., John Wiley & Sons, 1926. 224 pp., illus., diagrs., tables, 12 x 6 in., cloth. $6.50.

The aim of the authors is to present the modern practise of structural engineering as applied to architectural construction from the viewpoint of both the engineer and the architect. The present book, the first of several analyzing the structural design of buildings, is devoted to wood construction and deals primarily with mill buildings and the so-called second-class and third-class construction, in which more or less inflammable materials are used structurally.

The chapters discuss the design of beams, of floor construction, of roof construction, of columns and of miscellaneous framing. Each principle of design is analyzed, its relation to the entire building and to those architectural and structural details that control it is studied, and its application shown by illustrative problems.

BEGINNINGS OF THE NEW YORK CENTRAL RAILROAD.

By Frank Walker Stevens. N. Y., G. P. Putnam's Sons, 1926. 408 pp., illus., ports., map, 9 x 6 in., cloth. $4.00. (Gift of the New York Central Railroad Company).

A record of the early problems, trials, successes, failures and growth of the early railroads which were consolidated in 1853 to form the New York Central Railroad. The organization and history of the ten corporations which were consolidated is given, as it has been recovered from their surviving records, contemporary publications and letters, and much of interest is given about early matters of transportation, legislative regulation, and equipment. The book appears in the centennial year of the Mohawk and Hudson, the first of these roads.

CLAY PRODUCTS CYCLOPEDIA AND EQUIPMENT CATALOG. 3rd edition. 1926. Chicago, Industrial Publications, Inc., 1926. 336 pp., illus., 12 x 9 in., cloth. $3.00.

A combination of reference book and catalog of equipment for those engaged in making clay products. The text treats of many phases of manufacture, such as plant construction, power, fuels, conveyors, raw materials, drying, kilns, preparation of clays, molding and glazing. Condensed catalogs of a number of equipment makers are given. The book also contains a list of trade names, statistics, and a list of trade associations.

DIVERGENTE UND KONVERGENTE TURBULENTE STROMUNGEN MIT KLEINEN OFFNUNGSWINKELN.

By Fritz Donch. Ber., V. D. I. Verlag, 1926. (Forschungsarbeiten auf dem gebiete des Ingenieurwesens. Heft 282). 58 pp., diagrs., tables, 10 x 7 in., paper. 7,50 r. m.

This brochure presents the results of another of the series of investigations of fundamental problems in the flow of fluids which are being carried on at the Institute of Applied Mechanics in Gottingen, under Professor Prandtl's direction. Using air and a rectangular pipe with movable walls, the investigator examined the details of turbulent flow, especially convergent and divergent flow, from a unified point of view. Formulas are derived and the experimental results are evaluated.

DIE EDELSTAHLE, Ihre Metallurgische Grundlagen.

By F. Rapatz. Berlin, Julius Springer, 1925. 219 pp., illus., diagrs., tables, 8 x 5 in., boards. 12,-r. m.

This book aims to be an introduction to the study of alloy steels. The author has especially intended to show what properties are necessary for various purposes and what properties the steels now in use have.

After a brief introduction, the author discusses the uses of alloy steels and the demands made of them, the qualities that make for easy working, structure and heat treatment. The various steels are described and the method of manufacture explained. Methods of testing and imperfections are discussed.

ELEKTRISCHE SCHWINGUNGEN, vol. 1.

By Hermann Rohmann. Ber. u. Lpz., Walter de Gruyter & Co., 1926. 132 pp., 6 x 4 in., cloth. 1,50 r. m.

A revised edition of the first volume of a concise text on electric waves. After a brief summary of those matters of general electrical theory which are important in connection with them, the author discusses waves in condenser circuits, the generation of waves and the methods of measuring and investigating them. By using a terse style and confining himself to the bare essentials, the author has attained a very brief text.

ELEMENTARY TREATISE ON STATICALLY INDETERMINATE STRESSES.

By John Ira Parcel and George Alfred Maney. N. Y., John Wiley & Sons, 1926. 368 pp., diagrs., tables, 9 x 6 in., cloth. $5.00.

Aims to present the fundamental methods of attack on the problem of indeterminate stresses as clearly as possible and as fully as is consistent with an elementary treatise, and to illustrate the methods by applying them to some common types of indeterminate structures.

The first three chapters, comprising more than one-third of the book, give an exposition of the theory of elastic deflections and a

broad treatment of the general problem of indeterminate stresses. Chapters four to seven treat specifically the continuous girder, the rigid frame, the elastic arch, and secondary stresses. The final chapter contains a general discussion of statically indeterminate construction, a historical review and a good annotated bibliography.

FEUERVERSICHERUNG UND BRANDSCHADENABSCHATZUNG BEI MASCHINELLEN FABRIKEINRICHTUNGEN.

By Felix Moral. Berlin, V. D. I. Verlag, 1926. 102 pp., 8 x 6 in., paper. 2,80 r. m. (3,80 r. m. bound.)

A concise practical handbook on factory insurance. The author discusses under-insurance and over-insurance, the various kinds of insurance of plant equipment, special clauses for equipment insurance, the appraisal of machinery for insurance and the form of the policy. He also treats of expert appraisal of fire losses and of the determination of damages to machinery by fires.

HIGHWAY CURVES AND EARTHWORK.

By Thomas F. Hickerson. N. Y., McGraw-Hill Book Co., 1926. 382 pp., tables, 7 x 4 in., fabrikoid. $3.50.

A handbook on highway location which lays emphasis on the subject of curves and earthwork, including banking and widening of pavements. Includes a variety of original tables intended to facilitate the laying-out of easement spirals. A useful book for the engineer engaged in the design of modern highways for automobile traffic.

LANDESELEKTRIZITATSWERKE.

By A. Schonberg und E. Glunk, Mün. u. Ber., R. Oldenbourg, 1926. 398 pp., illus., diagrs., maps, 11 x 8 in., paper. 26.-mk.

A thorough, important discussion of the problem of centralized production and distribution of electricity, or, in other words, of superpower systems. The authors pay but little attention to such matters as hydraulic machinery, generating equipment, etc., but discuss thoroughly and in detail the broad technical, economic and legal questions involved in unified systems of generation and distribution. The object throughout is to call attention to correct methods for the economic utilization of natural power resources in the most efficient way.

The principles enunciated are illustrated by descriptions of various large German undertakings carried out by the firm of Oskar von Miller, of which the authors are technical managers.

LEHRGANG DER SCHALTUNGSSCHEMATA ELEKTRISCHER STARKSTROM-ANLAGEN, vol. 2; Schlatungsschemata für Wechselstrom-Anlagen.

By J. Teichmüller. Mün. u. Ber., R. Oldenbourg, 1926. 171 pp., plates in pocket, 13 x 9 in., cloth. 22,-mk.

A systematic presentation of alternating circuits, intended for use by students and engineers. Covers the excitation of alternators, synchronization, transformer circuits, voltage regulation, balancing, converter circuits, meter circuits in single-phase and triphase plants, control devices and over-loads. The second section of the book gives descriptions and diagrams of the wiring of nineteen actual plants selected to illustrate good current practise. The diagrams in the book are unusually satisfactory.

METAL-PLATE WORK; Its Patterns and Their Geometry.

By C. T. Millis. 5th edition. Lond., E. & F. N. Spon; N. Y., Spon & Chamberlain, 1926. 503 pp., diagrs., 8 x 5 in., cloth. 7/6.

Sets forth a system of geometric construction of the patterns for sheet-metal work which has been in use for over forty years. By it, nearly all the patterns required may be laid out on one geometric principle.

The new edition has been rearranged and enlarged.

MOVABLE BRIDGES, vol. 1; Superstructure.

By Otis Ellis Hovey. N. Y., John Wiley & Sons, 1926. 352 pp., illus., diagrs., tables, 9 x 6 in., cloth. $6.00.

The first volume of a treatise on the design of movable bridges and their machinery. This volume, on the superstructure, opens with a brief history of early designs. The author then discusses various types of movable bridges, giving statistical information intended to assist in determining the best type for particular conditions. The simplest and most practical methods of stress analysis are then discussed briefly, followed by a chapter on elastic deflections. Details of design are then discussed and there are chapters on rail joints, counterweights and houses for operators. Appendixes give an analysis of stresses in lenticular discs and a new method for designing tread plates for the supporting and segmental girders of rolling-lift bridges.

PHYSICAL CHEMISTRY FOR COLLEGES.

By E. B. Millard. 2nd edition. N. Y., McGraw-Hill Book Co., 1926. (International chemical series). 458 pp., diagrs., tables, 8 x 6 in., cloth. $3.50.

Aims to bring before the student certain of the more important aspects of physical chemistry, together with accurate data that illustrate the applicability of its laws to the phenomena observed in the laboratory. The new edition has been revised and some portions have been enlarged and rewritten.

PRACTICAL PAPER-MAKING.

By George Clapperton. 3rd edition, revised by R. H. Clapperton. Lond., Crosby & Son; N. Y., D. Van Nostrand Co., 1926. 220 pp., illus., 7 x 5 in., cloth. $2.50.

A concise manual for paper-makers, in which much practical advice is given on present day methods. The new edition follows closely the plan of previous ones, but has been changed by omitting obsolete methods and adding new ones, and by the addition of descriptions of new machinery.

DIE SCHALLTECHNIK.

By Richard Berger. Braunschweig, Friedr. Vieweg & Sohn, 1926. 115 pp., diagrs., 9 x 6 in., paper. 8,-r. m.

A summary of the present state of knowledge of acoustics. The monograph is intended to enable those not deeply informed to orient themselves quickly in this field, and also to point the directions in which research is needed.

STORY OF THE WESTERN RAILROADS.

By Robert Edgar Riegel. N. Y., Macmillan Co., 1926. 345 pp., 8 x 5 in., cloth. $2.50.

While there are many books on various phases of the railroad problem and on particular roads and railroad men, there has been practically no attempt, the author of this work says, to combine these into a general history of the railroads. The present book is an attempt to do this for the western roads.

The treatment is econonic and social and covers the period from 1852 to the early years of the present century when, in the view of the author, the western railroad net was completed. A considerable bibliography is included.

SUPERVISION OF VOCATIONAL EDUCATION OF LESS THAN COLLEGE GRADE.

By J. C. Wright and Charles R. Allen. N. Y., John Wiley & Sons, 1926. 415 pp., 8 x 6 in., cloth. $3.00.

This book, by the Director and the Editor of the Federal Board for Vocational Education, aims to place at the disposal of prospective and novice supervisors such portions of their own experiences as will assist them to improve their work. The topics discussed include the work of administrators and supervisors, qualifications, preparation, and methods of supervision.

UEBER DEN MARTENSIT.

By H. Hanemann and A. Schrader. Düsseldorf, Verlag Stahleisen, 1926. (Mitteilung aus der Metallographischen Abteilung des Eisenhüttenmannischen Laboratoriums der Technischen Hochschule zu Berlin). 25 pp., plates, 11 x 8 in., paper. 6,60 mk.

This brochure presents the results of an investigation of martensite undertaken to determine the soundness of a new hypothesis concerning its structure. Martensite, according to this hypothesis, contains two hitherto unknown phases of the iron-carbon alloys, different from alpha and beta iron. The methods of investigation and the results are given, with a discussion by various experts.

UNTERSUCHUNG UBER DIE GESCHWINDIGKEITSVERTEILUNG IN TURBULENTEN STROMUNGEN.

By J. Nikuradse. Berlin, V. D. I. Verlag, 1926. (Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, Heft 281). 44 pp., illus., diagrs., tables, 11 x 8 in., paper. 6,-r. m.

Although the distribution of the velocities in turbulent flow is of great importance for its understanding and also for its

theoretical investigation, the present research is, the author says, the first undertaken on this point. This work gives the results of experiments on the distribution of velocities in closed channels and also on the surface of open channels.

Part one describes experiments on turbulent flow in pipes with circular, triangular and rectangular sections, giving the apparatus used, the method, and the results. Prandtl's law is derived from the consideration of dimensions, and the degree to which it corresponds with experimental results is shown.

In part two, the distribution of velocities in an open rectangular channel and on its surface is investigated. A comparison of distribution in open and in closed channels ends the work.

Workshop Operations and Lay-outs for Economic Engineering Production.

By Philip Gates. Lond., E. & F. N. Spon; N. Y., Spon & Chamberlain, 1926. 200 pp., illus., diagrs., 8 x 5 in., cloth. 7s 6d.

Aims to assist students and workmen to an understanding of methods for laying out machine-tool operations so as to ensure profitable production. The book deals with both small and heavy work and is illustrated by examples from English or American practise. Practically all the ordinary machine-shop operations are introduced.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Tire Testing by Means of the Sprague Dynamometer, by F. L. Haushalter, B. F. Goodrich Co. The following motion pictures were shown: "The Wizardy of Wireless;" "The King of the Rail" and "The Queen of the Waves." April 23. Attendance 30.

Radio Waves, by Dr. J. H. Dellinger, Bureau of Standards. The following officers were elected: Chairman, A. R. Holden; Secretary-Treasurer, H. L. Steinbach. May 7. Attendance 300.

Cincinnati

Annual Dinner. The following officers were elected: Chairman, W. P. Beattie; Secretary-Treasurer, L. J. Gregory. June 11. Attendance 36.

Cleveland

Mental Attitude, by Dr. M. I. Pupin, National President, A. I. E. E. A dinner preceded the meeting. The following officers were elected: Chairman, H. L. Grant; Secretary-Treasurer, W. E. McFarland. May 18. Attendance 102.

Detroit-Ann Arbor

Standard Distribution Systems, by B. L. Huff, Consumers Power Co., and

A-C. Low-Voltage Networks, by H. P. Seelye, The Detroit Edison Co. May 25. Attendance 125.

Traffic Control, by W. L. Potts, Detroit Police Department. Illustrated with slides. The following officers were elected: Chairman, Harold Cole; Vice-Chairman, A. H. Lovell; Secretary-Treasurer, F. H. Riddle. June 29. Attendance 60.

Fort Wayne

Annual Banquet. The following officers were elected: Chairman, D. W. Merchant; Vice-Chairman, P. O. Noble; Secretary-Treasurer, C. F. Beyer; Vice-Secretary-Treasurer, R. E. Pumphrey. June 3. Attendance 58.

Ithaca

In the Lands of Buddha, by Professor H. B. Smith, Worcester Polytechnic Institute. The following officers were elected: Chairman, R. F. Chamberlain; Secretary-Treasurer, G. F. Bason. May 14. Attendance 50.

Annual Banquet. Address by Dr. M. I. Pupin, National President, A. I. E. E. May 15. Attendance 180.

Lehigh Valley

Japanese Power Systems, by S. Q. Hayes, Westinghouse Electric and Mfg. Co. Illustrated by moving pictures.

"*Super Superior" Remote-Control Systems*, (humorous) by C. F. Crowder, H. N. Crowder, Jr., Company. Illustrated. A dinner preceded the meeting. May 21. Attendance 125.

Mexico

Business Meeting. June 10. Attendance 21.

Milwaukee

Automatic Substations, by Wm. E. Gundlach, The Milwaukee Elec. Ry. & Lt. Co. A motion picture, entitled "The Story of Anaconda," was shown. The following officers were elected: Chairman, H. L. Van Valkenberg; Secretary-Treasurer, P. B. Harwood. June 29. Attendance 55.

Minnesota

Present-Day Conditions in Mexico, by D. K. Lewis, Twin City Rapid Transit Co. The following officers were elected: Chairman, S. B. Hood; Secretary, M. E. Todd. June 16. Attendance 62.

Schenectady

Analysis of Railway Operations, by E. E. Kimball, General Electric Co. Illustrated with slides and moving picture. May 14. Attendance 300.

Social Meeting. May 22. Attendance 100.

Southern Virginia

Industrial Power Plants, by J. L. Jordan, Viscose Corp.;

Economy in Bridge Design, by P. A. Blackwell, Virginia Bridge and Iron Co.;

From Trees to Rayon, by Roy Smith, Viscose Corp., and

Wood Preservation, by J. H. Gibbony, N. & W. Railroad. Joint meeting with A. S. C. E. and A. S. M. E. May 21. Attendance 51.

Spokane

Business Meeting. The following officers were elected: Chairman, Richard McKay; Vice-Chairman, L. R. Gamble; Secretary-Treasurer, J. B. Fisken. May 21. Attendance 21.

Syracuse

Business Meeting. The following officers were elected: Chairman, C. E. Dorr; Secretary, F. E. Verdin. June 14. Attendance 10.

Business Methods Applied to City Government, by Mayor C. G. Hanna, and

Echoes of Life, by Dr. J. L. Davis. Annual Dinner of Technology Club and Affiliated Societies. June 14. Attendance 320.

Worcester

Operation of the New England Power System, by W. S. Cavanaugh, New England Power Co. The following officers were elected: Chairman, C. F. Hood; Vice-Chairman, G. F. Woodward; Secretary-Treasurer, F. B. Crosby. June 15. Attendance 45.

BRANCH MEETINGS

Rhode Island State College

Illumination of New York Central Railroad, by Mr. Hill. May 10. Attendance 14.

Carbon Dioxide as A Fire Extinguisher, by Mr. Barash;

Construction of Electric Welding Machines, by Mr. Penon, and

Applications of the Electric Welding Machine, by Mr. Easterbrooks. May 24. Attendance 12.

Business Meeting. The following officers were elected: Chairman, G. A. Eddy; Secretary, C. Easterbrooks. June 7. Attendance 16.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to **EMPLOYMENT SERVICE, 33 West 39th Street, New York City,** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, with electrical engineering degree and at least three years' design, test or laboratory experience. Heating experience an advantage. Salary, $45-$65 a week. Apply by letter. Location, Middlewest. X-219C.

GRADUATE ELECTRICAL ENGINEER, experienced in small electric motors, to establish sales department with company manufacturing electric appliances. Opportunity. Apply by letter, with full details of age, past employment and salary, and lowest salary to start. Location, Middlewest. X-117.

ENGINEER, experienced, to handle disconnecting switch business for electrical apparatus manufacturer. Man with designing and field erection experience desired. Must be able to conduct correspondence. Opportunity. Apply by letter. Location, Pennsylvania. X-156C.

MEN AVAILABLE

ELECTRICAL GRADUATE, age 24, single, desires permanent position engineering work. One year test, one year carrier-current field engineering with General Electric Company. Familiar with utilities of the South. C-1391.

EXECUTIVE ENGINEER, electric engineer, or maintenance engineer, electrical engineer with fourteen years' central station and engineering experience supplemented by consulting, construction and State public service commission engineering work. Can win and hold the public's confidence and handle others efficiently and quietly. Age 42. United States preferred. C-1509.

ELECTRICAL ENGINEER, 28, married, three years' experience in testing, research and development work on electrical appliances, four years' experience in engineering department of large public utility, desires position in large manufacturing company in connection with design of electrical apparatus and its application to central station systems. Salary $250 a month minimum. Location, Ohio, Pennsylvania, or New York preferred. B-4362.

INSTRUCTOR OF MATHEMATICS—MECHANICAL DRAWING, 24, single. Has tutored in mathematics for three years. Has taught in Friends' School as physical training instructor. Available July 15th. Location, New York City. C-1514.

GRADUATE INDUSTRIAL ELECTRICAL ENGINEER, 27, married, desires position with engineering, manufacturing or construction firm. Seven years' experience in industrial plant engineering. Excellent references from former employers and plants in which I have installed electrical equipment. Location, vicinity of New York. C-1636.

ELECTRICAL ENGINEER, engineering and arts graduate with production, scheduling, budgeting, valuation, some design, operating and construction experience. Available as assistant executive or department head of operating holding or manufacturing company. Nine years' experience, five years utilities and four years industries. Married, age 30. Now with large utility. Available in two months. B-9676.

ELECTRICAL ENGINEER, desires position as operating or distribution engineer. Age 27; married, technical education. Two years G. E. test, three years electrical superintendent of large industrial plant, and two years with utility company serving 12,000 customers as distribution engineer. Salary $225. Available two weeks' notice. B-9390.

SALES ENGINEER, 29, married, desires to represent manufacturer in Chicago and Middlewestern territory. University electrical engineering graduate. Six years' experience selling to dealers, jobbers and manufacturers. C-1651.

ASSISTANT EXECUTIVE B. S. and E. E. degrees, five years' well balanced experience in all phases of distribution and power substations and their commercial aspects, and one year's experience in administrative office of manufacturing company. Three years in supervisory capacity. Desires position with electrical company requiring technical, commercial and executive ability. Minimum salary $3600. Location preferred, lower Great Lakes States. B-7315.

MANAGER, 37, married, redesign machinery and processes, origination new products, installation new departments, purchase new businesses, installation shop control. Sixteen years' experience large and moderate sized manufacturing plants. Graduate engineer. Employed at present as departmental manager. Available on one month's notice. Location, Wisconsin. C-1050.

HYDROELECTRIC DRAFTING, 28, single, graduate electrical engineer class 1924, desires to make a start with hydro-electric engineering firm as draftsman. Can produce specimens of work. Available in ten days. Location preferred Chicago. B-8850.

PROFESSORSHIP in electrical engineering wanted by graduate of Harvard University with thirteen years' university teaching experience, and five years (in addition to numerous summers) in varied practise. Specialist in high voltage transmission research, theory, design and practise. Important experience with both Westinghouse and G. E. Companies. Age 43, married, excellent health, best of references. C-577-2-C-15.

ELECTRICAL ENGINEER AND PHYSICIST, 34, graduate several schools, on instruction staff well known institution for five years. Extensive development experience on apparatus, also patent experience. Position in the development of electrical instruments desired. Thorough practical and theoretical knowledge of electricity. Location preferred, Philadelphia. B-165.

ASSISTANT EXECUTIVE, well balanced experience of thirteen years on cost analysis industrial processing, commercial statistics, advertising, administrative control. Seven years with large company servicing subsidiaries and clients. Public utility experience. Technical graduate, married, age 34. Prefers administrative or commercial to strictly technical. Location, New York, New England. Available reasonable notice. B-9122.

RECENT UNIVERSITY GRADUATE of Marquette University, College of Engineering, holding a Professional Degree in Electrical Engineering, havingt two years of practical experience in large steel foundry and manufacturing plant; also several months of heat-treating and specialty work. After one week's notice, anywhere in the U. S. C-1438.

MANUFACTURER'S AGENT, electrical engineer having ten years' engineering and selling experience in New England desires to represent manufacturer of electrical or allied lines in this territory on minimum salary and commission basis. Now located with internationally known electrical manufacturer. Available two weeks' notice. A-1330.

ELECTRICAL GRADUATE, American born and educated, English descent, desires foreign service with some reputable company. Good personality, good appearance, engineering experience, ambitious, and a willing worker, employed at present. Only foreign service desired, preferably

in Germany, France, Sweden, or some British Possession. C-1658.

TECHNICAL GRADUATE, B. S., (E. E.). Westinghouse Factory training, one year on road as Service Engineer. Three years as Chief Electrician for Reclamation Service, Wyoming Project, completely in charge of Hydro-Installation and Power Lines, Electrification of draglines, shops, etc. Age 28. Mechanic and not office man. Can do all repair work in shop winding bearings, switchboards, etc. Handle men well and have trained crew. Salary not less than $250. Will appreciate correspondnece. C-1680.

INDUSTRIAL ELECTRICAL ENGINEER, technical graduate, 27, completed Westinghouse Engineering graduate student course. Experience in testing and in the industrial engineering department of the Westinghouse Company plus actual experience in the industry. Desires position as industrial sales or efficiency and testing engineer. Possibilities for advancement and where initiative and ability are recognized. Excellent references can be furnished. Available on reasonable notice. B-8918.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1926.

Berthold, W., New York Rapid Transit Corp., Brooklyn, N. Y.
Bricker, G. W., Jr., with H. C. Hopson, Inc., New York, N. Y.
Broome, G. W., Stevens & Wood, Inc., New York, N. Y.
(Applicant for re-election.)
Brummal, J. S., Kansas City Telephone Co., Kansas City, Mo.
Burkhardt, G. E., General Railway Signal Co., Rochester, N. Y.
Chapman, H. N., Jr., Woodward & Tierman Printing Co., St. Louis, Mo.
Cook, H. C., Day & Zimmerman, Saxton, Pa.
Cooke, L. B., Bell Telephone Laboratories, New York, N. Y.
Copeland, W. T., E. H. Faile & Co., New York, N. Y.
Covington, P. M., Electric Light & Water Dept., Red Springs, N. C.
DeConly, J. C., Consulting Engineer, Los Angeles, Calif.
Denney, L. J., Bell Telephone Co. of Western Pa., Pittsburgh, Pa.
Eyton, J., Canadian Westinghouse Co., Ltd., Montreal, Que., Can.
Gardner, W., New York Telephone Co., New York, N. Y.
Gerst, P. E., Commonwealth Edison Co., Chicago, Ill.
Hall, V. E., Elliot Engineering Co., Binghamton, N. Y.
Harris, C. A., Bureau of Reclamation, Emmett, Idaho
Heard, W. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Hill, L. A., Pacific Tel. & Tel. Co., Spokane, Wash.
Huntington, S. A., (Member), The Syracuse Lighting Co., Inc., Syracuse, N. Y.
Jansson, G. E., (Member), Condit Electrical Mfg. Co., Boston, Mass.
Jennens, W. S., (Member), Utah Power & Light Co., Salt Lake City, Utah
Jordan, E. F., City Elec. Inspector, City of Roanoke, Roanoke, Va.
Kegl, Z. J., York Insulated Wire Works, G. E. Co., York, Pa.
Kent, H. G., Binghamton Light, Heat & Power Co., Binghamton, N. Y.
Kirsch, M. J., Petroleum Heat & Power Co., Stamford, Conn.
Lemmon, J. A., Diehl Mfg. Co., Elizabeth, N. J.
Lenehan, C. V., The New York Edison Co., New York, N. Y.
Lessman, G., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Marrison, W. A., Bell Telephone Laboratories, New York, N. Y.
McKenzie, M. T., Savanah Electric & Power Co., Savannah, Ga.
Messenger, T. I., Monitor Controller Co., Cleveland, Ohio
Montgomery, D., Cia. Mexicana Luz y Fuerza Motriz, Mexico, D. F., Mex.
Moulton, F. E., Clyde River Power Co., Richford, Vt.
Nordhaus, C. H., Grigsby-Grunow-Hinds Co., Chicago, Ill.
Odermatt, A., American Brown Boveri & Co., Camden, N. J.
Sanders, W. F., Tallassee Power Co., Badin, N. C.
Shortall, W. J., General Electric Co., Schenectady, N. Y.
Siemers, Frederic W., 9610 38th Ave., Corona, L. I., N. Y.
Smith, G. J., Binghamton Light, Heat & Power Co., Binghamton, N. Y.
Sweet, J. W., Virginia Public Service Co., Roncerverte, W. Va.
Tanton, F. W., Newfoundland Power & Paper Co., Deer Lake, Newfoundland
Tasker, H. G., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Tevonian, H. P., Brooklyn Edison Co., Brooklyn, N. Y.
Turner, E. A., (Member), Appalachian Electric Power Co., Roanoke, Va.
Weiss, H. E., Allis-Chalmers Mfg. Co., Salt Lake City, Utah
(Applicant for re-election.)
Weller, G. L., (Member), The Chesapeake & Potomac Tel. Co. & Associated Companies, Washington, D. C.
Wood, G. W., Stevens & Wood, Inc., New York, N. Y.
(Applicant for re-election.)
Total 44.

Foreign

Ayyar, P. N., (Member), Hydro-Electric Surveys, Chepauk, Madras, India
Baker, M. P., Shanghai Municipal Council, Shanghai, China
de Camargo, F. F., Companía Paulista de Estrada de Ferro, Jundiahy, S. Paulo, Brazil, S. A.
Gladstone, J. W. B., R. Thomas & Sons Co., Liverpool, Ohio; for mail, London, S. E., 23, Eng.
Iyer, K. V., Public Works Dept., Triplicane, Madras, India
Jacobs, E., Elec. Dept., Shanghai Municipal Council, Shanghai, China
Pulham, G. B., (Member), Metropolitan-Vickers Electrical Co., Ltd., Calcutta, India.
Reddi, C. G., Electrical Engineer, Nungambakam, Madras, S. India
Silvester, L. T., "Italcable" Co., Anzio, Roma, Italy
Soga, M., Keihin Electric Railway Co., Ltd., Kawasaki City, Kanagawaken, Japan
Svarup, A., Thomason College, Roorkee, U. P., India
Swann, S. A., Nottingham Electricity Dept., Nottingham, Eng.
Venkateswaran, P. S., Tata Hydro-Elec. Power Supply Co., Bombay, India
Waddell, J. J., (Member), Elec. Engr., Borough of San Fernando, Trinidad, B. W. I.
Welbourn, B., (Member), British Insulated Cables, Ltd., Prescot, Lancashire, Eng.
Total 13.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held May 17, June 11, and July 26, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

BOLSER, M. O., Assistant Electrical Engineer, Department of Water and Power, City of Los Angeles, Calif.
CRAFT, EDWARD B., Executive Vice President, Bell Telephone Laboratories, New York, N. Y.
KELLY, WILL G., Assistant Engineer of Distribution, Commonwealth Edison Co., Chicago, Ill.
MacCUTCHEON, A. M., Engineering Vice President, Reliance Electric and Engineering Co., Cleveland, Ohio.
POWELL, ALVIN L., Manager, Engineering Dept., Edison Lamp Works, Harrison, N. J.
SILVER, ARTHUR E., Consulting Electrical Engineer, Electric Bond & Share Co., New York, N. Y.

To Grade of Member

AMBROSE, FREDERIC B., Engineer, Duquesne Light Co., Pittsburgh, Pa.
BENHAM, C. F., Asst. to General Supt., Great Western Power Co., San Francisco, Calif.
BLACKWELL, EDWARD S., Asst. Supt. of Construction, Div. of Construction & Engineering, Stone & Webster, Inc., Pinehurst, Wash.
BOSTWICK, THOMAS J., Chief Electrical Engineer, Aluminum Company of America, Pittsburgh, Pa.
BURGER, EMMETT E., Electrical Engineer, General Electric Co., Schenectady, N. Y.
CHUBBUCK, L. B., Electric Engineer, Canadian Westinghouse Co., Hamilton, Ont.
COLE, GUERNEY H., Section Engineer, M. & P. Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
CURTIS, EDWARD C., Chief Engineer, Cia Cubana de Electricidad, Inc., Havana, Cuba.
DACE, FRED E., Head, Department of Electricity, Bradley Polytechnic Institute, Peoria, Ill.
DOERSCHUK, HERBERT M., Electrical Supt., Aluminum Co. of America, Niagara Falls, N. Y.
ENSTROM, AXEL F., Director, Royal Swedish Institute of Scientific Industrial Research, Stockholm, Sweden.
FINNEY, ALFRED C., Consulting Engineer (Switchboard Practice), General Electric Co., Schenectady, N. Y.
FOGLER, WILLIAM A., Laboratories Supt., Philadelphia Electric Co., Philadelphia, Pa.
GARDNER, STERLING M., President & Chief Engineer, Gardner Electric Mfg. Co., Emeryville, Calif.
GIBBS, JESSE B., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.

GLANCY, ROBERT C., Chief Engineer, Eastern Bell Telephone Co. of Pennsylvania, Philadelphia, Pa.
GRAY, FRED J., Transmission Engineer, Upstate Territory, New York Telephone Co., Albany, N. Y.
HALL, JACK H., Electrical Engineer, Ewa Plantation Co., Ewa, Oahu, T. H.
HALPERIN, HERMAN, Engineer, Commonwealth Edison Co., Chicago, Ill.
HENNINGSEN, EARLE S., Electrical Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.
HOLLAND, WAYMAN A., Electrical Engineer, Switchboard Dept., General Electrical Co., Schenectady, N. Y.
JOHNS, ALBERT N., Consulting Engineer, Los Angeles, Calif.
JOHNSON, CLARENCE N., General Engineer, Westinghouse Electric & Mfg. Co., Philadelphia, Pa.
KARKER, EARL C., Instructor in Electrical Engineering, Mechanics Institute, Rochester, N. Y.
KELMAN, J. N., President & Manager, Kelman Electric & Mfg. Co., Los Angeles, Calif.
KERR, HENRY H., Supt., Electric Operating Dept., Public Service Company of Colorado, Denver, Colo.
KIDDER, JAMES W., Supervising Engineer, New England Tel. & Tel. Co., Boston, Mass.
KORNER, A. J., Consulting Engineer, Stockholm, Sweden.
LUKE, GEORGE E., Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
LUTZ, ROBERT A., Electrical Engineer, Utilities Power & Light Corp., Chicago, Ill.
MARR, GEORGE M., Manager, Marine Sales, Charles Cory & Son, Inc., New York, N. Y.
MAYER, J. H., Equipment Engineer, Postal Telegraph Cable Co., New York, N. Y.
McCLAIN, JOHN R., Materials & Process Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
McDONALD, C. G. H., Acting Chief Electrical Engineer, Victorian Railways, Melbourne, Australia.
McFARLIN, JOHN R., Electrical Engineer, Electric Service Supplies Co., Philadelphia, Pa.
McNEELY, JOHN K., Research Professor of Electrical Engineering, Iowa State College, Ames, Iowa.
MILLER, GEORGE M., Supt. Electric Distribution & Construction, Louisville Gas & Electric Co., Louisville, Ky.
NIGH, EDSON R., Supt. Light & Power, Puget Sound Power & Light Co., Bremerton, Wash.
NORRIS, FERRIS W., Asst. Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.
PETERS, ALFRED S., Valuation Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.
PRAGST, ERNEST W., Electrical Engineer, General Electric Co., Schenectady, N. Y.
REYNOLDS, WILLIAM H., Foreman of Elec. Maintenance of Erie Works, General Electric Co., Erie, Pa.
RICE, CHESTER W., Research Engineer, General Electric Co., Schenectady, N. Y.
RIGGS, ALBERT C., Supt. Light & Power, Puget Sound Power & Light Co., Bellingham, Wash.
SEIBEL, CHARLES F., Jr., Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
SMITH, GLEN H., Engineer, Outside Construction, Department of Lighting, City of Seattle, Wash.
SMITH, J. BRODIE, Vice-President & General Manager, Manchester Traction, Light & Power Co., Manchester, N. H.
SNOW, WILBER C., Industrial Power Salesman, Lighting Department, City of Seattle, Wash.
SPRARAGEN, WILLIAM, Secretary, Division of Engineering and Industrial Research, National Research Council, New York, N. Y.
SWOBODA, ADOLPH R., Apparatus Development Engineer, Bell Telephone Laboratories, New York, N. Y.
TREAT, ROBERT, Section Head, Central Station Engg. Dept., General Electric Co., Schenectady, N. Y.
TRUMBULL, ARTHUR J., Assistant Engineer, Distribution Department, Brooklyn Edison Co., Inc., Brooklyn, N. Y.
WAITE, LESLIE O., Engineer, Stone & Webster, Inc., Boston, Mass.
WALLIS, CHARLES R., Sales Engineer, General Electric Co., Seattle, Wash.
WALTHER, JOHN T., Professor of Electrical Engineering, Municipal University of Akron, Akron, Ohio.
WARD, RALPH B., Chief, Electrical Bureau, Newark, N. J.
WATKINS, SAMUEL S., Electrical Engineer, Gibbs & Hill, New York, N. Y.
WIESEMAN, Special Designing Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.
WILSON, HARRY R., Central Station Engineering Dept., General Electric Co., Schenectady, N. Y.
WOOD, EDWIN D., Electrical Operating Engineer, Louisville Gas & Electric Co., Louisville, Ky.
WOODS, GEORGE M., General Engineering, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
WOODSON, J. C., Manager, Industrial Heating Engineering Dept., Westinghouse Electric & Manufacturing Co., Mansfield, Ohio.
YERXA, RUSSELL A., Electrical Supt., Dwight P. Robinson & Co., New York, N. Y.

OFFICERS OF A. I. E. E. 1926-1927

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Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janiero, Brazil, S. A.
Charles le Maistre, 28 Victoria St., London, S. W. 1, England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

A. I. E. E. COMMITTEES

The list of committees is omitted from this issue, as new appointments are being made for the administrative year beginning August 1. The new committees will be listed in the September issue.

A. I. E. E. REPRESENTATION

A complete list of A. I. E. E. representatives on various bodies will be published in the September issue.

LIST OF SECTIONS

Name	Chairman	Secretary
Akron	A. R. Holden	H. L. Steinbach, Electrical Engineering Dept., Goodyear Tire & Rubber Co., Akron, Ohio
Atlanta	W. E. Gathright	W. F. Oliver, Box 2211, Atlanta, Ga.
Baltimore	W.B. Kouwenhoven	R. T. Greer, Madison St. Building, Baltimore, Md.
Boston	J. W. Kidder	W. H. Colburn, 39 Boylston St., Boston, Mass.
Chicago	K. A. Auty	William Wurth, 1634 Peoples Gas Bldg., Michigan Ave. at Adams St., Chicago, Ill.
Cincinnati	W. P. Beattie	L. J. Gregory, Union Gas & Electric Co., Cincinnati, Ohio
Cleveland	H. L. Grant	W. E. McFarland, 720 Illuminating Bldg., Cleveland, Ohio
Columbus	R. J. B. Feather	W. T. Schumaker, 25½ North High St., Columbus, Ohio
Connecticut	A. E. Knowlton	R. G. Warner, Yale University, 10 Hillhouse Ave., New Haven, Conn.
Denver	W. H. Edmunds	R. B. Bonney, Telephone Bldg., P. O. Box 960, Denver, Colo.
Detroit-Ann Arbor	Harold Cole	F. H. Riddle, Champion Porcelain Co., Detroit, Mich.
Erie	F. A. Tennant	L. H. Curtis, General Electric Co., Erie, Pa.
Fort Wayne	D. W. Merchant	C. F. Beyer, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	H. M. Anthony	J. D. Bailey, 48 Monument Circle, Indianapolis, Ind.
Ithaca	R. F. Chamberlain	G. F. Bason, Electrical Engineering Dept., Cornell University, Ithaca, N. Y.
Kansas City	R. L. Baldwin	S. M. De Camp, 510 Dwight Bldg., Kansas City, Mo.
Lehigh Valley	W. E. Lloyd, Jr.	G. W. Brooks, Pennsylvania Power & Light Co., 8th & Hamilton Sts., Allentown, Pa.
Los Angeles	R. E. Cunningham	L. C. Williams, H. W. Hellman Bldg., Los Angeles, Calif.
Lynn	E. D. Dickinson	F. S. Jones, General Electric Co., Lynn, Mass.
Madison	E. J. Kallevang	H. J. Hunt, D. W. Mead & C. V. Seastone, State Journal Bldg., Madison, Wis.
Mexico	E. F. Lopez	H. Larralde, Isabel La Catolica, 33 Mexico, D. F., Mexico
Milwaukee	H.L.VanValkenberg	P. B. Harwood, Cutler Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	S. B. Hood	M. E. Todd, University of Minnesota, Minneapolis, Minn.
Nebraska	C. W. Minard	N. W. Kingsley, 1303 Telephone Bldg., Omaha, Nebr.
New York	E. B. Meyer	O. B. Blackwell, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
Niagara Frontier	H. B. Alverson	A. W. Underhill, Jr., 606 Lafayette Bldg., Buffalo, N. Y.
Oklahoma	E. R. Page	C. C. Stewart, Oklahoma Gas & Electric Co., Norman, Okla.
Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
Philadelphia	Nathan Shute	R. H. Silbert, 2301 Market St., Philadelphia, Pa.
Pittsburgh	W. C. Goodwin	D. M. Simons, Standard Underground Cable Co., Cor. 17th & Pike Sts., Pittsburgh, Pa.
Pittsfield	E. F. Gehrkens	C. H. Kline, General Electric Co., Pittsfield, Mass.
Portland, Ore.	J. C. Henkle	J. E. Yates, Gasco Bldg., Portland, Ore.
Providence	Edwin E. Nelson	F. W. Smith, Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
Rochester	Earl C. Karker	J. Rowley Clark, 25 Favor St., Rochester, N. Y.
St. Louis	W. H. Millan	L. N. Van Hook, 3869 Park Ave., St. Louis, Mo.
San Francisco	R. C. Powell	A. G. Jones, 807 Rialto Bldg., San Francisco, Calif.
Saskatchewan	S. R. Parker	W. P. Brattle, Dept of Telephones, Telephone Bldg., Regina, Sask.
Schenectady	R. E. Doherty	R. F. Franklin, Room 301, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	C. E. Mong	C. R. Wallis, 609 Colman Bldg., P. O. Box 1858, Seattle, Wash.
Sharon	H. L. Cole	L. E. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	Richard McKay	James B. Fisken, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	L. F. Curtis	J. Frank Murray, United Electric Light Co., 251 Wilbraham Ave., Springfield, Mass.
Syracuse	C. E. Dorr	F. E. Verdin, 615 City Bank Bldg., Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	M. B. Hastings	F. F. Ambuhl, Toronto Hydro-Electric System, 226 Yonge St., Toronto, Ontario
Urbana	J. T. Tykociner	L. B. Archer, 308 Electrical Engineering Lab., University of Illinois, Urbana, Ill.
Utah	John Salberg	D. L. Brundige, Utah Power & Light Co., Box 1790, Salt Lake City, Utah
Vancouver	R. L. Hall	C. W. Colvin, B. C. Electric Railway Co., 425 Carrall St., Vancouver, B. C.
Washington, D. C.	C. A. Robinson	D. S. Wegg, Elec. Equipment Div. Bureau of Foreign & Domestic Commerce, Washington, D. C.
Worcester	C. F. Hood	F. B. Crosby, Morgan Construction Co., 15 Belmont St., Worcester, Mass.

Total 51

LIST OF BRANCHES

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Alabama Polytechnic Institute, Auburn, Ala	J. D. Stewart	I. L. Knox	W. W. Hill
Alabama, University of, University, Ala	C.E. Rankin	Sewell St. John	
Arizona, University of, Tucson, Ariz	J. W. Cruse		Paul Cloke
Arkansas, University of, Fayetteville, Ark	Carroll Walsh	W. H. Mann	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	M. T. Goetz	C. W. Schramm	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	F. Wanpel	Joseph Heller	Robin Beach
Bucknell University, Lewisburg, Pa	A. Fogelsanger	J. D. Johnson	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	Thomas Gottier	Alan Capon	R. W. Sorensen
California, University of, Berkeley, Calif	C. F. Dalziel	R. S. Briggs	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	J. R. Power	R. O. Perrine	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. A. Baldwin	A. B. Anderson	H. B. Dates
Catholic University of America, Washington, D. C	B. J. Kroeger	J. E. O'Brien	T. J. MacKavanaugh
Cincinnati, University of, Cincinnati, O	F. Sanford	W. C. Osterbrock	W. C. Osterbrock
Clarkson College of Technology, Potsdam, N. Y	W. R. MacGregor	L. G. Carney	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	B. V. Martin	W. H. Sudlow	S. R. Rhodes
Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, Univerxity of, Boulder, Colo	A. D. Thomas	J. A. Setter	W. C. DuVall
Cooper Union, New York, N. Y	F. H. Miller	H. T. Wilhelm	Norman L. Towle
Denver, University of, Denver, Colo	Harold Henson	Allen Ohlson	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	H. D. Baker	R. S. Eininger, Jr.	E. O. Lange

LIST OF BRANCHES—*Continued*

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Florida, University of, Gainesville, Fla	O. B. Turbyfill	R. Theo. Lundy	J. M. Weil
Georgia School of Technology, Atlanta, Ga	W. M. McGraw	F. L. Kaestle	E. S. Hannaford
Idaho, University of, Moscow, Idaho	J. W. Gartin	S. Blore	J. H. Johnson
Iowa State College, Ames, Iowa	P. E. Benner	H. J. Biddulph	F. A. Fish
Iowa, University of, Iowa City, Iowa	L. Dimond	A. C. Boeke	A. H. Ford
Kansas State College, Manhattan, Kans	A. M. Young	John Yost	C. E. Reid
Kansas, University of, Lawrence, Kans	W. L. Immer	H. R. Hilkey	G. C. Shaad
Kentucky, University of, Lexington, Ky	J. A. Weingartner	C. E. Albert	
Lafayette College, Easton, Pa	A. H. Gabert	F. G. Keim	Morland King
Lehigh University, S. Bethlehem, Pa	F. G. Kear	J. H. Shuhart	J. L. Beaver
Lewis Institute, Chicago, Ill	O. D. Westerberg	R. G. Raymond	F. A. Rogers
Maine, University of, Orono, Me	S. B. Coleman	H. S. McPhee	W. E. Barrows, Jr.
Marquette University, Milwaukee, Wis	C. H. Legler	M. J. Smith	J. F. H. Douglas
Massachusetts Institute of Technology, Cambridge, Mass	Stuart John	H. W. Geyer	W. H. Timbie
Michigan State College, East Lansing	Mr. Way	Mr. Phelps	L. S. Foltz
Michigan, University of, Ann Arbor, Mich	M. H. Nelson	H. R. Stevenson	B. F. Bailey
Milwaukee, Engineering School of, Milwaukee, Wis	S. A. Moore	B. J. Chromy	B. A. Bovee
Minnesota, University of, Minneapolis, Minn	R. L. Christen	A. A. Lee	H. Kuhlmann
Missouri, University of, Columbia, Mo	M. P. Weinbach	L. Spraragen	M. P. Weinbach
Missouri School of Mines and Metallurgy, Rolla, Mo	W. J. Maulder	R. P. Baumgartner	I. H. Lovett
Montana State College, Bozeman, Mont	W. E. Pakala	J. A. Thaler	J. A. Thaler
Nebraska, University of, Lincoln, Neb	R. Worrest	C. J. Madsen	F. W. Norris
Nevada, University of, Reno, Nev	George Fairbrother	Cornelius Fort	S. G. Palmer
New York, College of the City of, New York, N. Y	Harold Wolf	I. Leipziger	Harry Baum
New York University, New York, N. Y	H. U. Hefty	Henry Och	J. Loring Arnold
North Carolina State College, Raleigh, N. C	F. P. Dickens	H. Baum	G. C. Cox
North Carolina, University of, Chapel Hill	H. L. Coe	C. M. Lear	P. H. Daggett
North Dakota, University of, University	V. L. Cox	O. B. Medalen	D. R. Jenkins
Northeastern University, Boston, Mass	W. P. Raffone	John L. Clark	W. L. Smith
Notre Dame, University of, Notre Dame, Ind	C. A. Rogge	J. T. Burton	J. A. Caparo
Ohio Northern University, Ada, Ohio	M. Heft	P. W. Wadsworth	J. W. Gray
Ohio State University, Columbus, O	Lee P. Doyle	J. S. Heddy	F. C. Caldwell
Ohio University, Athens, Ohio	N. R. Smith	J. E. Quick	A. A. Atkinson
Oklahoma A. & M. College, Stillwater, Okla	W. J. Beckett	Lee Rogers	Edwin Kurtz
Oklahoma, University of, Norman, Okla	G. B. Brady	J. C. Glaze	F. G. Tappan
Oregon Agricultural College, Corvallis, Ore	F. D. Crowther	E. F. Reddy	F. O. McMillan
Pennsylvania State College, State College, Pa	F. F. Wilkins	C. C. Huggler	L. A. Doggett
Pennsylvania, University of, Philadelphia	F. H. Riordan, Jr.	W. H. Hamilton	C. D. Fawcett
Pittsburgh, University of, Pittsburgh, Pa	S. A. Swetonic	L. M. Brush	H. E. Dyche
Purdue University, Lafayette, Ind	A. Howard	T. B. Holliday	A. N. Topping
Rensselaer Polytechnic Institute, Troy, N. Y	F. M. Sebast	K. C. Wilsey	F. M. Sebast
Rhode Island State College, Kingston, R. I	G. A. Eddy	C. Easterbrooks	Wm. Anderson
Rose Polytechnic Institute, Terre Haute, Ind	J. H. Utt	E. Letsinger	C. C. Knipmeyer
Rutgers University, New Brunswick, N. J	E. C. Siddons	W. H. Bohlke	F. F. Thompson
South Dakota State School of Mines, Rapid City, S. D	C. Allen	Harold Eade	J. O. Kammerman
South Dakota, University of, Vermillion, S. D	L. J. Stverak	R. T. Brackett	B. B. Brackett
Southern California, University of, Los Angeles, Calif	J. H. Shideler	E. E. Smith	C. E. Guse
Stanford University, Stanford University, Calif	A. V. Pering	J. G. Sharp	H. H. Henline
Stevens Institute of Technology, Hoboken, N. J	D. B. Wesstrom	Gene Witham	Frank C. Stockwell
Swarthmore College, Swarthmore, Pa	J. S. Donal, Jr.	R. W. Lafore	Lewis Fussell
Syracuse University, Syracuse, N. Y	K. N. Cook	R. H. Watkins	C. W. Henderson
Tennessee, University of, Knoxville, Tenn	F. N. Green	B. M. Gallaher	Charles A. Perkins
Texas A. & M. College, College Station, Texas	L. H. Cardwell	C. A. Altenbern	F. C. Bolton
Texas, University of, Austin, Tex	F. W. Langner	H. W. Zuch	J. A. Correll
Utah, University of, Salt Lake City, Utah	F. C. Bates	C. E. Hoffman	J. F. Merrill
Virginia Military Institute, Lexington, Va	R. P. Williamson	M. L. Waring	S. W. Anderson
Virginia Polytechnic Institute, Blacksburg, Va	M. R. Staley	R. M. Hutcheson	Claudius Lee
Virginia, University of, University, Va	R. C. Small	G. L. Lefevre	W. S. Rodman
Washington, State College of, Pullman, Wash	S. H. White	H. R. Meahl	H. V. Carpenter
Washington University, St. Louis, Mo	E. B. Kempster, Jr.	George Simpson	H. G. Hake
Washington, University of, Seattle, Wash	C. M. Murray, Jr.	Roy H. Crosby	George S. Smith
Washington and Lee University, Lexington, Va	D. S. McCorkle	C. M. Wood	R. W. Dickey
West Virginia University, Morgantown, W. Va	R. W. Beardslee	W. F. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis	Benj. Teare	N. B. Thayer	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyo	John Hicks	J. O. Yates	G. H. Sechrist
Yale University, New Haven, Conn	S. A. Tucker	G. C. Bailey	Charles F. Scott
Total 87			

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Control Apparatus.—Booklet, 36 pp., entitled "Industry's Electrical Progress." Describes numerous applications of C-H equipment for electrical control. The Cutler-Hammer Manufacturing Co., Milwaukee, Wis.

Motors.—Bulletin 106, 4 pp. Describes direct and alternating-current crane and hoist motors. Bulletin 102, 4 pp., describes direct-current motors ¼ to 150 h. p. Northwestern Manufacturing Company, Milwaukee, Wis.

Marine-Electric Oil Engines.—Booklet, 24 pp. entitled "Marine Oil Engines for Direct and Electric Drive." Attractively illustrated with typical installations. Ingersoll-Rand Company, 11 Broadway, New York.

Molybdenum Steel in Ball Bearings.—Booklet, 8 pp. entitled "Mo-lyb-den-um Means More-Life-in-'em" describes the development and use of molybdenum steel for bearing purposes. Standard Steel & Bearings, Inc., Plainville, Conn.

Relays.—Bulletin 550, 8 pp. Describes Roller-Smith new type SR line of relays. These supersede the old Imperial type of relays and have many marked advantages over the old type. The scales are longer, the accuracy is much greater and the torque has been increased several times. The new 7½ inch round pattern style of case matches type SA and type SD lines of indicating instruments. The Roller-Smith Company, 12 Park Place, New York.

Copperweld Wire.—Bulletin E. D. 502, 6 pp. The economic reasons justifying the use of copperweld guy, messenger and span wire are set forth by both text and tables in this publication. The claim is made that copperweld wire effects a saving of 90% over the final cost of materials that rust and have to be replaced. Included in the bulletin are sketches showing guying and messenger cable construction in standard use. Copperweld Stee Company, Rankin, Pa.

NOTES OF THE INDUSTRY

Large Orders to Westinghouse.—The Westinghouse Electric & Manufacturing Company has received an order for the largest horizontal waterwheel generators ever built, consisting of two 45,000 kv-a. units. These will form the No. 1 and No. 2 units of the Southern California Edison Company's Big Creek 2-A station. The generators will be totally enclosed, and complete with suitable direct connected exciters and usual accessories. Their total weight will be about 600,000 lbs. each, the overall width and height being approximately 25 feet and 23 feet respectively. The length of the generator itself will be about 14 feet.

Three of the main generators for the Conowingo development now being undertaken by the Philadelphia Electric Company will be furnished by the Westinghouse Company. They are of the vertical type, rated at 40,000 kv-a. each. In addition, the Westinghouse Company was awarded two 1600 kv-a. vertical water wheel generators and exciters, the total contract amounting to considerably above $1,000,000.

Among other orders recently received is one from the Union Electric Light and Power Company, McClellan & Junkersfeld, Inc., engineers, for the third section of the Cahokia plant. This order amounts to approximately $200,000 and calls for twenty-two, segregated phase, type 0-33, oil circuit breakers and three single pole grounding breakers, with associated control equipment, consisting of control desk, and relay and instrument boards. Eleven of these breakers will be of the type 0-33, 3000 ampere, three-pole, and eleven of the 600 ampere, three-pole, type 0-33. The remaining three will consist of type 0-33 neutral, 1200 ampere, single pole breakers.

New York Office for Cook Porcelain Insulator Corporation.—The Cook Porcelain Insulator Corporation, Cambridge, Ohio, manufacturers of high-tension insulators, announces the establishment of a New York office located at 161 Grand Street. Mr. J. H. Parker, formerly associated with the General Porcelain Company, has been appointed eastern sales representative, with headquarters in New York.

First Half of 1926 Brings Increased Business to G-E.—Orders received by the General Electric Company for the first six months of 1926 totaled $165,405,720, representing an increase of 10 per cent over the $150,315,228 booked in the corresponding six months of 1925, President Gerard Swope has announced. For the three months ending June 30 this year, orders totaled $78,972,062, compared with $66,468,992 for the second quarter of 1925, an increase of 19 per cent. In the first six months of this year there were 152 working days, including Saturdays, showing General Electric orders received thus far this year have been at a rate of better than $1,000,000 per day.

The company will hereafter report its earnings quarterly to the stockholders. The dividend date has been changed from the 15th to about the 25th of the month, and the next quarterly dividend will be payable on or about October 25, 1926, and will be accompanied by a statement of orders received and earnings for the first nine months of this year.

New Factory for Absolute Contactor Company. The Absolute Contactor Company has let the contract for the construction of its new factory building at Elkhart, Ind. Greatly increased plant facilities will enable the company to take care of its rapidly expanding business. The factory at Beloit, Wis., will continue in production pending the completion of the new plant.

H. D. Randall Now Sales Manager of G-E Gear Section.—H. D. Randall has been made sales manager of the gear section of the industrial department of the General Electric Company. He will have his headquarters at the River Works, West Lynn, Mass. The non-metallic gear business has developed rapidly during the last few years and it is expected that under Mr. Randall's direction it will continue to expand.

Kuhlman Electric Company, Bay City, Mich., manufacturers of power, distribution and street lighting transformers, announces the establishment of a factory office at 3-260 General Motors Building, Detroit. Richard P. Johnson will have charge of this office.

It is also announced that the Continental Sales & Engineering Company, 839 Oliver Bldg., Pittsburgh, Pa., have been appointed Kuhlman district representatives. Henry M. Hughes is manager of the company.

Largest Synchronous Condensers to be Built.—Synchronous condensers of far greater capacity than any ever previously built are being constructed by the General Electric Company for the Southern California Edison Company, for regulating the voltage along the transmission lines which carry power from remote hydroelectric developments into Los Angeles. Each of the three condensers is rated at 50,000 kv-a., 13,200 volts, 50 cycles, 600 revolutions per minute. Two are to be installed in the new Lighthipe substation and the other in the Eagle Rock substation. The largest synchronous condensers previously constructed by the General Electric Company have a capacity of 30,000 kilowatts each; condensers of this size are now being used in the Laguna Bell and Eagle Rock substations of the company. With the condenser the G-E Company is also supplying the necessary transformers. These nine units, three for each condenser, are of 16,700 kv-a. capacity each, and have forced coil air pressure cooling. They have 73,000-volt primary and 13,000-volt secondary windings.

JOURNAL OF THE A·I·E·E·

SEPTEMBER 1926

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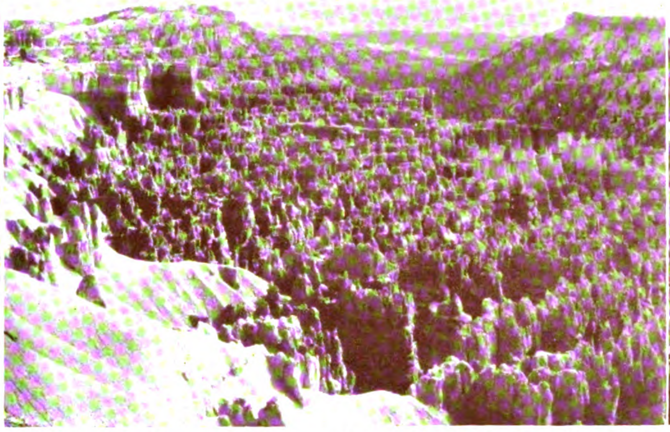
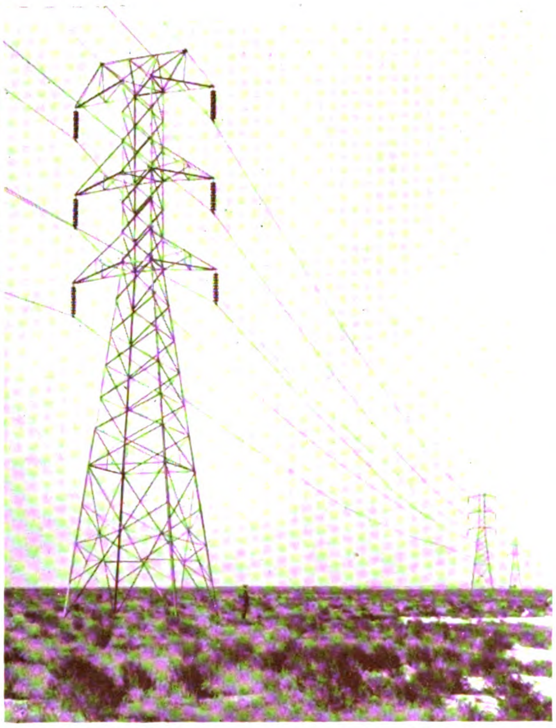
PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

PACIFIC COAST CONVENTION NUMBER

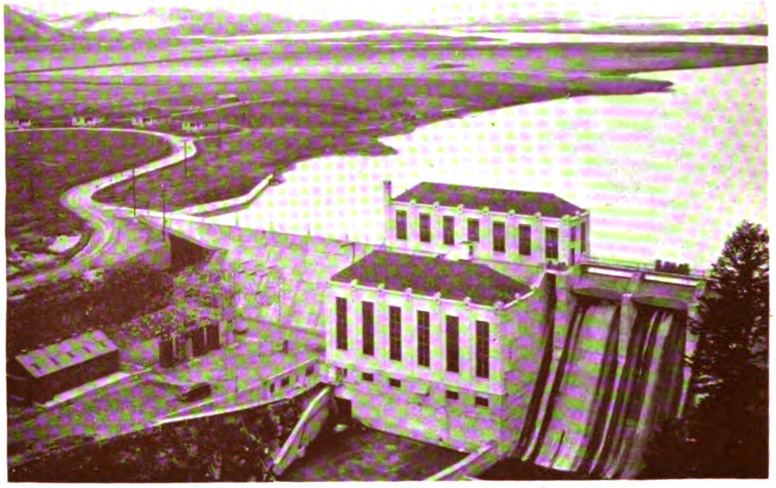


Bryce's Canyon, Southern Utah

Surface Mine-Utah Copper Co., Bingham Canyon, Utah



130,000-Volt Transmission Line, Utah Light & Power Co.



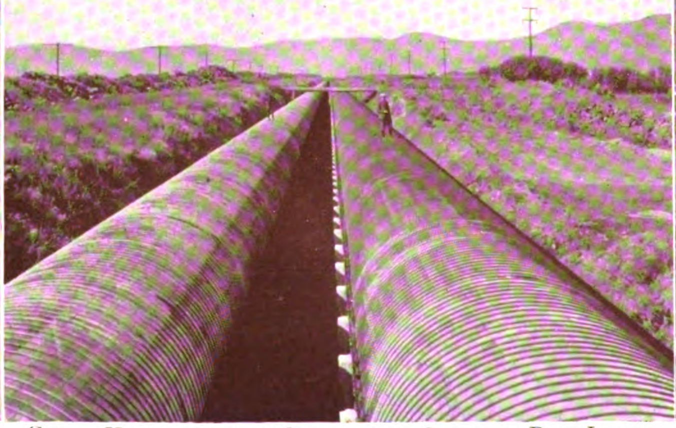
Soda Hydroelectric Generating Station

The A. I. E. E.

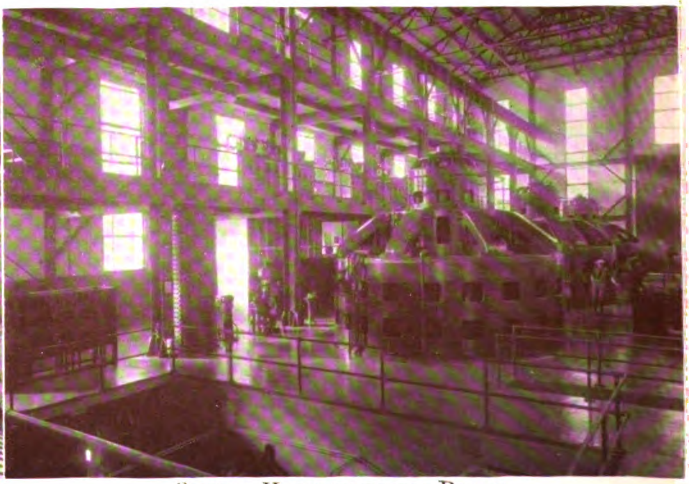
PACIFIC COAST CONVENTION

Salt Lake City, Utah

A few of the attractions offered by its location



Grace Hydroelectric Generating Station, Pipe Line 11 Ft. in Diameter 23,000 Ft. Long



Oneida Hydroelectric Plant, Three 10,000-Kw. Units

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

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Vol. XLV SEPTEMBER, 1926 Number 9

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Papers, Discussions, Reports, Etc.

Institute and Related Activities

A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any change in business connections.

Current Electrical Articles Published by Other Societies

Iron & Steel Engineer, July 1926

Guarding against the Invisible Hazards of Electrical Installations, by W. Greenwood

Electrification and Simplification—Their Effect upon the Foundry's Future, by L. W. Egan

Proc. Enginrs. Soc. of West. Pennsylvania, May 1926

Safety and Construction Standards for Transmission Lines, by J. S. Martin

Steam Railway Electrification, by W. B. Spellmire

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV | September, 1926 | Number 9

Work of the A. I. E. E. Sections Committee

The Institute was founded in 1884. By 1900 it had attained a membership of 1142. In 1902-3, under the administration of President C. F. Scott, the establishment of Sections and Branches was approved and encouraged. Five years later, in 1907, there were 19 Sections and 17 Branches, with a total membership in the Institute of 4861. Together with the rapidly developing profession of electrical engineering and the impetus given by the activities of the Institute and its Sections and Branches, there has come the remarkable growth of the Institute during the last twenty years. This is indicated by the following tabulation:

Year	National Membership	No. of Sections	No. of Sections Meetings	Total Attendance at Sections Meetings	Amount of Sections Budget
1909	6,400	24	169	16,427	3,389.51
1913	7,654	29	244	22,825	12,645.18*
1917	8,710	32	265	31,299	10,596.96
1921	13,215	42	303	37,823	20,563.89
1924	15,438	47	381	58,945	25,219.31
1925	17,319	49	386	49,029	27,309.52
1926	18,158	51	405	58,959	30,060.76

The accelerated activities of the Sections and the Sections Committee were probably first clearly evident in connection with the work of the Sections Delegates Conference of 1921, conducted at Salt Lake City by the Sections Committee. Here it was evident that the Sections Delegates Conference was becoming an effective and important agency in the shaping of Institute policy through its recommendations to the Board of Directors. This is a natural result of the normal operation of such a body as defined by the Constitution and By-Laws and made up, as it is, of representatives from all the Sections distributed throughout the country.

That this is the case and the importance of the work done is shown by the following statement of some of the present policies now actively in force but which may be traced to initial action and recommendation of the Sections Committees and the Sections Delegates Conferences of the past few years.†

*Including an item of $4,345.29 for special and unusual expenditure.

†See printed report of Sections Delegates Conference, White Sulphur Springs, June 21, 1926.

1. *Delegates' Conferences*

1916 Program Committee to formulate program for annual conference and mail it to the Delegates in advance.

1922 Meetings to be held annually on the day before the Summer Convention proper begins.

2. *Local Affiliations*

1916 Subcommittee to report.

1918 Committee reported.

1919 Request for further study, resulting in the appointment of a special committee by the national societies.

1924 Statement of policy prepared and approved by the governing bodies of all four Founder Societies.

1925 Subject given further study and previous statement of policy approved.

1926 Recommendation to the Board of Directors for appointment of a special committee on contacts with the public for further study and report. Committee appointed.

3. *Geographical Districts*

1919 Division of the country into ten Districts and election of a Vice-President from each District.

1923 Traveling expenses to be authorized for the members of the Executive Committee of each District to one meeting each year.

4. *Vice-Presidents*

1923 Increase terms of Vice-Presidents from one to two years and provide that no Director shall hold office for more than six consecutive years.

1924 Traveling expenses authorized for one visit each year of each Vice-President to all Sections in his District.

5. *Publications*

1919 to 1923 Recommendations made which have resulted in the present well-defined policy regarding the Institute publications.

6. *Transfers*

1923 Plan recommended whereby desirable candidates for transfer to higher grades may be recommended to the Board of Examiners by other members.

7. *Prizes*

1923 First Paper and Best Paper Prizes for each District recommended. Now available.

1925 Recommended that a committee be appointed to prepare a statement of policy and procedure in connection with all national and regional prizes. Appointed and reported. 34 annual prizes now available.

8. *Finances*

1922 Recommended that the basis of financial support for Sections be changed from $100.00 flat plus $1.25 per member, to $175 flat per Section plus $1.00 per member. Now in force.

1922 Recommended that Sections be left free to expend their appropriations as they deemed best, but to send a report of expenditures to headquarters for the Finance Committee. Now in force.

9. *Branches and Counselors*

1925 Recommendation that a counselor be appointed for each Student Branch, these counselors in all cases to be members of the Institute and of the faculty in the institution in which their Branch is located.

1926 Recommended payment of travel expenses of counselors and Branch chairmen to Regional conventions and of District

Branch representatives to Sections Delegates Conferences. Approved by Directors. Referred to Finance Committee.

10. Speakers' Bureau

1922 Action taken to establish a speakers' bureau in limited form.

1926 Recommendation for appointment of a special committee to study question of public relations and development of more effective plan of speakers' bureau. Committee appointed.

11. Regional Meetings

1923 to 1926 Present policy of holding meetings under the auspices of the Geographical District officers developed. Regional meetings have been held as follows:

No. of Meeting	District	Location	Dates	Technical Papers	Attendance
1	No. 1	Worcester, Mass.	June 5, 6, 1924	9	275
2	No. 2	Washington, D. C.	Jan. 23, 24, 1925	6	212
3	No. 1	Swampscott, Mass.	May 7, 8, 1925	21	370
4	No. 2	Cleveland, Ohio	March 18, 19, 1926	3	430
5	No. 5	Madison, Wis.	May 6, 7, 1926	9	180
6	No. 1	Niagara Falls, N.Y.	May 26, 27, 28, 1926	23	330

Plans are already under way for similar regional meetings of Section and Branch membership for the coming Institute year for Districts No. 1, 2, 3; 5, 8, 9, and it is expected that this list may be extended in the course of the year.

The accomplishments of recent years point the way to further advisable activites for the Institute membership in its effective Section and committee work for the future. The relations of the Section membership to neighboring membership of other technical and professional societies, to the Institute Student Branch membership, to its District and National Membership, to the general public and to itself are interesting and profitable fields for study. It is hoped that tangible and important results will come in the near future from the study in committees now being given to these relationships.

HAROLD B. SMITH,
Chairman, Sections Committee.

Some Leaders of the A. I. E. E.

Comfort A. Adams, the 31st president of the Institute, 1918-1919, was born in Cleveland, Ohio, Nov. 1, 1868. His early education in the public schools of Cleveland was followed by four years at Case School of Applied Science from which he received the degree of B. S. in Electrical and Mechanical Engineering in 1890, the degree of E. E. in 1905 and in 1925 the honorary degree of Doctor of Engineering. During three years of his undergraduate period, Mr. Adams was assistant to Dr. A. A. Michelson in the Physical Laboratory.

After spending the summer of 1890 on a scientific expedition of explorations and surveys of the Muir Glacier district, Alaska, he served four months as engineer for the Brown Hoisting and Conveying Machine Co. of Cleveland and then joined the Engineering Staff of the Brush Electric Co. of Cleveland where under Sidney Short he took part in the design of the first geerless railway motor.

In September 1891, he accepted an appointment as Instructor in Electrical Engineering at Harvard University, was made Assistant Professor in 1895 and Professor of Electrical Engineering in 1905. Since 1914, he has been Lawrence Professor of Engineering.

When the Harvard Engineering School reorganized after the war, Prof. Adams was appointed Dean, but resigned shortly thereafter to accept the chairmanship of the Div. of Engineering National Research Council.

He has served in the capacity of consulting engineer for a large number of clients including Stone & Webster; American Tool and Machine Co.; The Okonite Co.; Edison Illuminating Company of Boston; Public Service Electric Company of N. J.; American Sugar Refining Co.; Warner Sugar Refining Co.; National Cable & Conduit Co., etc.

He has served the Institute as manager, vice-president and president; also as chairman of the Standards Committee; chairman of the Edison Medal Committee; chairman of the Committee on Code of Professional Conduct; and as member of several other committees, including the U. S. Committee of the International Electrotechnical Commission.

He has been very active also in the cooperation movement of the Engineering Societies, having organized the American Engineering Standards Comm. and being its first chairman. He reorganized the Engineering Division of the National Research Council after the war, serving as its chairman for two years. He was a member of the first American Engineering Council, took part in the organization of the Federated Am. Engineering Societies, has since continued on its Council and on the present Am. Engineering Council. He also served as member and president of the John Fritz Medal Board of Award.

He is author of several important papers in the general field of the theory and design of electrical machinery presented before the Institute during the past 20 years. His contributions to induction motor design were particularly significant.

During the world war he served as chairman of the General Engineering Committee of the Edison Commission of the Council of National Defense; chairman of the Welding Committee of the Emergency Fleet Corporation and chairman of the Electrical Engineering Section of the National Research Council.

Prof. Adams is a member of the A. S. C. E., A. S. M. E., S. A. E., A. S. T. M., N. E. L. A. and of the British Inst. of Elec. Engrs.; a fellow of the Am. Academy of Arts & Sciences, Am. Assoc. for the Advancement of Science and of the American Physical Society. He organized and was first president of the Am. Welding Society of which he is now an honorary member. He is also Director of the Am. Bureau of Welding.

Electrical Practise in the Lead-Silver Mines of Utah

BY LEONARD WILSON[1]

Non-member

Synopsis.—*Special features of industry react on selection of equipment. Speed of conducting operations directly affects value of property; the mining personnel has a somewhat unique psychology; the cost of providing space underground is enormous. Certain requirements result and equipment must be selected accordingly.*

Compressed air has been the only power medium and still reigns supreme for rock drills. Electric power has captured the field for large, underground pumps, hoists, and fans, but not for miscellaneous service. Mines have, and always will have, a complete distributing system for compressed air. In the future, they will also have distribution system for electric power.

Results of practical experience are outlined. Power cables should be of small capacity and all of the same size. Three separate types of protection should be used for overloads, short circuits, and grounds, respectively. Distribution is generally at 2300 volts but might, with advantage, be at 4000 volts, grounded neutral. Magnet switches have solved the problem of starting and controlling motors. Reduced voltage starting is undesirable. Sealed type bearings eliminate much bearing trouble. A new type of large hoist occupying the minimum of space is now being installed at the Park-Utah. The field of mechanical haulage is undeveloped, but conditions to be met are formulated. Mechanical loaders are beginning to receive serious attention.

* * * * *

THE lead-silver mining of Utah is a very important contributor of wealth to the State and presents several interesting and unique features as an industry using electric power, particularly in view of the fact that the use of power to replace manual labor and animal haulage is becoming of great importance in the reduction of cost of mining and the intensifying of production.

Any analytical study of present practise and the future trend of electrification must be based on a knowledge of the outstanding features of the industry, and in using the term *industry*, it is to be noted that this paper deals only with the operations of the large, established mining corporations.

The industry is essentially a combination of the processes of prospecting for new ore, extracting it, and marketing it. This calls for great skill in financing and in the broader functions of general management. The cost of borrowing money is high, the burden of taxation is beyond belief to those not acquainted with the facts, and the basic costs of labor and railroad rates are far above the average for other industries. These present handicaps may be viewed with optimism in the sense that there is great probability of their being decreased in the future, but they have a distinct bearing on the fundamentals of the mechanical operation of the properties.

Perhaps the most important result of these conditions is the necessity for speeding up the operations. The old idea that ore in the ground is the same as money in the bank no longer applies. The present value of a given probable tonnage is more than doubled if the rate of production is doubled. The human element—the psychology of the miners, bosses, and managers—also has a marked effect on the development of new mechanical methods.

Underground, conditions are fraught with physical hardship and danger hazards and the successful miners are of the hardy, adventurous, independent type, willing to go the limit and therefore rightly demand that all mechanical equipment shall endure the same hardships and hazards. There is also a feeling which may best be described as intense loyalty to all established and well-proved equipment, and this feeling of necessity carries with it an equally intense distrust of anything new.

One other feature of mining is of importance, and that is the enormous cost of providing space underground for the equipment and the much higher unit cost for larger excavations than for smaller ones. To meet the conditions above outlined, the electrical and mechanical equipment must be selected to comply with the following requirements:

1. Each and every part must be of sturdiest and most enduring design.

2. Maintenance and attention required must be reduced to a minimum.

3. The equipment must be compact and the dimensions of individual units must be suited to the sizes of shafts and tunnels through which they have to be transported.

4. Cost of installation must be minimized.

5. Equipment units must be standardized so that they may be moved from place to place and used under as wide a range of conditions as is practicable.

In the history of mining in this State, it is only a short time ago that all power used underground was transmitted by the mediums of compressed air or steam. Even at this time, there is no prospect of electric power supplanting compressed air for the operation of rock drills, and therefore there will always be a complete distributing system of compressed air available for the operation of small hoists, pumps, fans, conveyers, scrapers and loaders. For these items, the superiority of electric power is gradually proving itself and in due course of time, all the mines will have a complete distribution system of electric power.

For the larger underground power-using units, (pumps, hoists, and fans), electric power is a necessity. In the immediate future, there is going to be a rapid

1. Consulting Engineer, Salt Lake City, Utah.

To be presented at the Pacific Coast Convention of the A. I. E. E., at Salt Lake City, Utah, Sept. 6-9, 1926.

increase in the use of mechanical methods for underground handling of ore and waste. First, the equipment will be developed to use compressed air, but later on, it will be replaced by suitably designed electrical units.

The following is a review of present practise in the selection and use of electrical equipment for this industry.

Power is purchased at high voltage and transformed down to 2400 volts at outdoor substations of conventional design, with more liberal margins, however, on capacity and insulation. Such substations require no attendance during regular normal operation. The transmission of power from the 2400-volt bus bar to the points of use is by means of a number of small capacity cables, each feeding out through an oil circuit breaker with suitable time-limit overload protection. This development in the use of small capacity cables has in practise shown many advantages. In the earlier electrifications, cables as large as 250,000 cir. mils were used, but more recently, for the same amount of power, use has been made of three separate three-conductor cables of No. 4, B & S size. This particular size of conductor is well adapted as a standard for underground use, as its capacity is sufficient for the largest sized motor (300-h. p.) that is practicable underground, and its cost, installed, is less per unit of capacity than smaller or larger cables. With this subdivision of cables, it is permissible to use high grade rubber insulation without a lead sheath, but, of course, with a light metallic sheath for protective purposes. Such a cable has a low installation cost and a high salvage value.

The standardization of cable to a single size and type for all purposes is of great advantage to each individual mining property, in that it leads to great simplification in the protection of the cable system, and reduces the cost of the original installation and future changes and extensions. The effective space required for cables is less, in general, for a number of small cables than for one large cable.

With regard to protection of the cable system, separate methods are used for protection against overloads, short circuits and grounds. For overloads, the protective device is an oil circuit breaker with thermal type relays having thermal characteristics suited to the standard cable and therefore capable of carrying a very high overload current for a few seconds. For short-circuit protection, use is made of group circuit breakers with relays set for high current and short time interval. The grouping of the cables at a centralized underground switch is made to suit the particular conditions of the underground motor installations. For ground protection, a single ground-detector relay for each 2300-volt system operates an alarm, and the location of the defective insulation is determined by switching the various circuits. In a well installed system, such grounds are of rare occurrence, and if attended to at once, lead to no trouble whatever.

The voltage of motors is, in general, 2200 volts for 50-h. p. and larger sizes. It was the tendency in the past to shun such a high voltage—particularly for hoist motors—but now, with improvement in design of motors and the perfection of the magnet switch, the use of 2200-volt motors is preferable; in fact, if the manufacturing companies had not abandoned the old 4000-volt, grounded-neutral standard equipment at about the time that the mines were being electrified there would be many more mines in this district now using that voltage.

The selection of starting equipment is a matter of importance. Reduced-voltage starters are, in themselves, a source of trouble underground, and full-voltage starting is adopted wherever practicable. In all cases the starting should be by push button (unless it is automatic) in order to insure the switch being properly closed. For frequent operation, the hoist-type air-break contactor has proved superior to all others.

With regard to specific applications of motors for the surface plants, as well as underground, a few points are of interest.

For compressor drives, direct-connected, synchronous motors are standard practise and it is preferable to use automatic full-voltage starters with automatic air valves so that only one operation is necessary to put the compressor unit on the line. For surface hoists, the general practise is to use induction motors with full magnetic control. Ward Leonard control has many advantages, particularly in the matter of rapid and safe manipulation, but the additional cost is not always warranted. For underground hoists of large capacity, the limiting factor is cost of excavation for the hoisting equipment, head sheaves, and ropeways. An interesting solution of this problem has been worked out at the Park-Utah mine by the adoption of the Nordberg-Bollen design, in which a single head sheave functions as a hoist. In this installation, Ward Leonard control is used and the hoist, together with all the electrical equipment, is located in a rock chamber cut out above the top of the shaft. Complete remote control is used, with the operator on the level of the skip pocket.

For small and medium sized motors, the standard induction motor is about perfect if the bearings are properly maintained. The older designs of ring oiling bearings were not satisfactory, as they required too much attention and were liable to be robbed of oil for cleaning purposes. The newer types of sealed bearings and ball bearings are satisfactory.

The problem of underground haulage is far from a standardized solution. At present, the tendency is to use hand tramming or mule haulage whenever it is physically possible to handle the tonnage by those means. Practically no storage-battery locomotives are used, and trolley locomotives are used only when the weight of ore per train can be made as high as 30 tons. The standard gage is 18 in. and the standard

mine car, loaded, weighs about 3000 lb. A man can just tram a single car. A mule can pull seven or eight cars on the somewhat uneven grades of the smaller drifts. A four-ton trolley locomotive on the main transportation tunnels can handle about 30 cars. For complete electrification of the haulage, it is desirable to have two classes of locomotives, each operating, if so desired, as tandem units. The small size of 1½ tons would handle seven cars single, or 14 double, in the smaller drifts; and the four-ton size would handle 30 cars single, or, in a tandem unit, could handle 30 tunnel cars of about 2½ times the tonnage. It is to be noted that the cost of track facilities for handling trains is one of the big factors in the problem. It appears from some recent results that a double-trolley system is superior to storage batteries, and can be used where a single trolley is unsafe. It is important to note that with 1½-ton locomotives, it is not practicable to use the rail as a return for low-voltage operation because the surface cannot be kept clean enough.

In conclusion, it is to be observed that the methods in use are, of necessity, crude, but that the increasing use of electric power is having a very desired effect in demonstrating the advantage of more efficient operation and will lead to more complete electrification of all operations except rock drilling.

Iron and Steel Production

Annual Report of Committee on Applications to Iron and Steel Production*

F. B. CROSBY, Chairman

To the Board of Directors:

To anyone who has followed closely from its insignificant status at the beginning, on through the first and into the second quarter of this 20th century, the application of electricity in the iron and steel industry, the steady growth to its present gigantic proportions has always seemed inevitable, though none the less amazing.

In some respects, the year 1925-26 has seen all previous records broken in the rate of electrification. The applications of electric power have become so diversified that it renders entirely out of the question more than the briefest outline of outstanding features in the developments of the past year.

I. Generation of Power

The steam turbine continues to prove the most reliable of prime movers in the steel plant power station. With the increased economies in boiler room practise, with blast furnace gas as fuel, and the further use on the mills of cooling water from the condensers, the production cost per kw-hr. from the turbine driven generator, closely approaches that of the gas engine. Coal or oil can be used as auxiliary fuel supplementing the supply of blast furnace gas and thus avoiding delays which may arise due to shortage of gas during periods of castings or furnace repairs.

The thermal efficiency of the gas engine is very attractive and where an ample supply of blast furnace gas is available this prime mover finds warm support. Five new installations of gas-engine-driven blowers, and one gas-engine-driven generator are reported for the current year.

The ideal arrangement appears to be a combination of steam turbines, gas engines and purchased power, with dependence upon the gas engine and central station for the base load while the turbines float on the line carrying the peaks. Under these conditions a large block of power can be purchased at favorable rates owing to the comparatively low maximum demand charge, especially if hydropower happens to be available.

One steel company which is putting through a complete electrification program of old and new mills is building a modern power plant with two 12,500-kv-a., 6600-volt, 60-cycle, turbo generators to supply power for the plant. Steam will be obtained from blast furnace gas and powdered-coal-fired boilers designed for 300-lb. pressure at 180 deg. superheat.

There is no question but that blast furnace gas should be used as efficiently as possible and wherever possible, before any other fuel is considered. Considerable economies can yet be made in the use of gas for heating blast furnace stoves. This will leave more gas available for the generation of power, either through gas engines or boilers and turbines, for the production of steam for plant uses, or when mixed with coke-oven gas, for use in heating furnaces throughout the plant.

Coke-oven gas finds a ready application in practically every heating, reheating and annealing furnace operation in the plant, but where a large city offers a ready market, it is often necessary to restrict its use in the steel plant to effect an economic balance between city and plant consumption.

The steel industry is still looking to the central sta-

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tions for an answer to the question of pulverized versus solid coal. In this field the opinion is prevalent that powdered fuel research and application are in the incubation stage and that developments in the near future may revolutionize present standards of boiler practise.

II. Distribution

Many steel plants have reached and passed the economic limit of 2200 volts for distribution. The large powers often required result in prohibitive current values at this voltage. This is reflected in excessive costs of protective oil switches and line losses even in the relatively short transmission distance from the load center to the numerous mill motors.

A distribution voltage of 6600 has become quite usual, so that only in the smaller plants, and in some cases where power is purchased, is 2200 volts standard. The increasing loads in the larger plants are taxing even the 6600-volt systems, but, so far, only one plant is reported as having main roll motors fed directly from a 13,200-volt system.

III. Main Roll Drive

Many of the mills laid out previous to the advent of the steel mill motor, now, each year, are reaching a point where, because of competition with recent equipment, it is necessary to throw them out or re-build them so far as possible along modern lines. The first consideration is usually the replacement of the original engine by a suitable motor and control.

One electrical manufacturer reports the sale of an aggregate of 33,270 h. p. of motors replacing engine drives during the past year. During this period the company has installed and placed in operation 31,000 h. p. (continuous rating) of reversing-mill motors and has taken orders for six additional reversing equipments aggregating 24,600 h. p. Three of these six units are replacing engine drives of existing mills, while two are for new mills which are to replace engine driven mills.

Notable among the reversing equipments installed during the year are two 7000-h.p. motors, the largest single armature machines thus far built for this service. An 8000-h. p. unit of slower speed but nearly 50 per cent larger in physical dimensions is, however, nearing completion in the factory.

Developments in the frequency converter type of alternating-current, adjustable speed drives provide for operation at constant torque above and below synchronism. This method of speed adjustment requires only two rotating machines,—the main motor and the frequency converter,—both on the same shaft. The slip energy of the induction motor is changed to line frequency in the frequency converter and returned to the line through speed adjusting transformers. Three units of this type, one of 770 h. p. and two of 1600 h. p. each, are now being built.

A 5000-h. p., 99-rev. per min., 60-cycle, induction motor built for a continuous billet mill drive is of interest particularly in that it is designed for 13,200-volt operation. Heretofore, except in one instance (see Report for 1925) main-roll motors have not been built for voltages above 6600 as it was thought that insulation troubles on higher potentials would be aggravated by the dirty atmosphere and conducting dust usually found in steel plants.

The necessity of maintaining constant speed relation between the several drives of modern tandem mills has brought about the development of a new method of control for compound wound, adjustable speed, direct current motors. This involves a series exciter and a variable potential field rheostat mechanically connected to the main shunt field rheostat, with resistance so proportioned that the series excitation is of the correct value to give very nearly zero speed regulation at any speed setting. This method of control is being applied to a 10-in., semi-continuous, merchant mill in three sections which are driven by 1000-, 1200- and 2000-h. p., d-c. motors respectively.

Another electrical manufacturer reports unprecedented activity in its steel mill business for the past year with an aggregate h. p. rating of mill motors sold from 1st June, 1925 to 1st May, 1926, of 102,910 h.p. This company also reports placing in operation a 4000-h. p. reversing drive in which the single motor is supplied from a fly-wheel motor generator consisting of two 750-volt generators permanently paralleled, a scheme first suggested by them in 1922 and now generally adopted.

This same electrical manufacturer also reports a new tonnage record for electrically-driven blooming mills made by a 40-in. mill, driven by one of its reverse equipments; namely 90,175 tons of ingots rolled in one month. A repeat order duplicating the electrical equipment was obtained for a 46-in. mill, using a motor rated 7000 h. p., 50 to 100 rev. per min.

Another of its installations of especial interest is a 9000-h. p. unity power factor, 107-rev. per min., 6600-volt, 25-cycle synchronous motor which, from the standpoint of continuous h. p. capacity, is the largest motor of any type used for industrial purposes in the United States or, so far as can be learned, in any other country. It is also notable in that it is the first really large synchronous motor to be used for driving a rolling mill. The motor may be started, stopped, or reversed from a master switch exactly the same as any other type of rolling mill motor. The Korndorfer system of control is used and the complete operation of starting on the low voltage tap of the auto-transformer, switching to a higher tap, applying field at the correct time, and throwing on the line, is taken care of automatically. In the design of the motor, particular attention has been given to obtaining very good starting torque characteristics. The excitation for the motor field is derived from a separate motor-driven exciter.

One of the best examples of motor drive for so-called tandem mills was put in operation about the first of the year. Practically every stand is driven by an individual direct-current motor, furnished with power from several synchronous motor-generator sets; a wide range of speeds is obtained by a combination of generator voltage and motor field control.

The aggregate capacity of the several motors driving this mill amounts to 15,850 h. p. (40 deg. cent.) The electrical apparatus is located in the best possible surroundings, emphasizing the growing importance which the mill operators are assigning to the electrical part of their equipment.

While the cost of such an elaborate drive is relatively high, the equipment is, on the whole, very economical; the flexibility and the wide speed range permits of rolling on this mill a great variety of products which would otherwise require at least two separate mills of a less flexible type.

The following tabulation includes only main mill motors on a continuous rated basis, in units above 300 h. p. as reported by the three principal electrical manufacturers in this country, up to 1st May, 1926.

	1923	1924	1925	1926
60-cycle	452840	478390	543440	586440
25-cycle	475825	490225	538450	582430
Direct-Current	299670	324860	430610	530060
	1228335	1293475	1512500	1698930

IV. Automatic Control

The year 1925 showed great activity in the application of automatic control to cranes and auxiliary mill machinery. Its dual functions of *control* and *protection* are now universally accepted so that there is now little opposition to its general use. Although there were no new developments of remarkable importance a most interesting feature was the rapidly increasing use of the inductive time element control system.

This system of control was commercially introduced in 1924 by one manufacturer and shortly afterwards a similar system was brought out by another. The essential features of these systems of control are: (1) -the short circuiting of accelerating resistance within a definite time, regardless of the load, and (2) the securing of a time interval purely by electro magnetic means. In the first system, the time interval is secured by making use of the transient voltage induced in a transformer or "inductor" due to changes in the motor current. In the second system, use is made of the slowly decreasing magnetism of shunt-wound relays when their coils are short circuited. Both systems fill a long felt need. Theoretically, current-limiting control provides a valuable protection to the motor. Practically, the protection actually afforded in many instances is almost nil since the current-limiting relays must be adjusted to start the motor under the heaviest load which may be encountered. With current-limiting control, therefore, the motor starts slowly under heavy load and quickly under light load, in either case subjecting the motor to excessive current. On the other hand, time-element control imposes excessive current on the motor only when the motor has an excessive load to accelerate and thus gives the motor much better average protection.

Although the larger portion of these installations has been for the control of mill tables and other auxiliary drives, a very considerable number has been installed for the control of open-hearth charging machines, soaking-pit cranes and standard cranes, particularly for the bridge motions. Installations of particular interest include a dynamic lowering controller for a bucket hoist and an ore-bridge trolley controller. Recent installations placed in control rooms entirely separated from the mill proper with control panels mounted in continuous switchboards, resistors mounted overhead in tiers on structural supports, with foot walks between, and with ample provision for ventilation, mark the growing appreciation of the fact that proper and substantial installation contributes probably as much as first class equipment to continuity and economy of operation.

A very interesting development of the past year which will surely have an important effect on crane control is the increasing use of roller bearings. One large installation has been made of cranes equipped throughout with roller bearings even including the sheave bearings in the hook block. An obvious effect of these anti-friction bearings is to increase the free running speed of bridges and trolleys and the light hook hoisting speeds. This imposes a greater responsibility than ever before on the control equipment to protect the motors and gearing in plugging and emphasizes the necessity for reliable brakes and limit switches for the hoists. Brakes on the trolley motors, hitherto rather unusual, would appear to be necessary on a trolley equipped with roller bearings. In some cases the hoist control will need to provide some means of limiting the light hook hoisting speed.

Automatic control of the electro-pneumatic type is being applied to the control of two 275-h. p., compound-wound motors in parallel for the drive of a large bloom shear. The cycle for this machine requires a complete operation in about six seconds and the pneumatically operated contactors of the large capacities involved are much faster and more positive in action than magnetic contactors of similar capacity. The electro-pneumatic contactors are assembled in steel frame work, and make a more conpact and rugged controller than the usual contactors mounted on slate or other insulating panels.

V. Automatic Sub-Stations

The use of automatically controlled sub-stations in steel plants has increased very greatly since the first installation in 1924. An installation recently put into

operation provides for the automatic control of two 1500-kw. synchronous motor generator sets and of twelve 4000-ampere, d-c. feeders. This automatic equipment is in a substation with several large reversing mill drives with an attendant always present, but it was felt that the more reliable operation was of sufficient value to warrant the installation of automatic equipment just the same. Several other installations are being made for the automatic control of motor generator sets and a-c. and d-c. feeders.

VI. Yard Electrification

The Diesel electric locomotive of which special mention was made in this report last year has grown rapidly in favor as experience has demonstrated its possibilities. Larger sizes up to 60 tons or more are now available and with their proved economy and reliability appear to have successfully solved the dangerous problems of third rail or overhead trolley in the steel plant.

VII. Illumination of Yards and Buildings

This past year has seen a marked impetus in the increasing recognition of the value of good lighting in mill buildings and yard. More attention has been given to the specific requirements of different kinds of mills and to the different operations within a given mill.

The kw-hrs. required for lighting range from 10 to 15 per cent of the total power load and is an appreciable item in the total cost. More efficient lighting units have been developed of larger wattage yielding more light per unit current consumption and, incidentally, requiring less time for cleaning.

VIII. Electric Heating

The use of electricity for heating is increasing rapidly in a great variety of applications. One instance of especial interest is the heating of ingot hot tops.

Early in 1925 an equipment was installed for heating the tops for ingots,—primarily of monel metal and nickel. Before using this equipment, 3800 lb. of metal was poured to obtain a 3000-lb. ingot, the waste averaging 20 per cent to 30 per cent. Now 3250 lb. of metal is poured and 85 per cent of the ingots are used with very little cropping while a large percentage of the remaining 15 per cent is worked into commercial products.

The electrical equipment consists of one 1800-kv-a., three-phase transformer designed to supply power to the ingot heating equipment and also to serve as a spare for a six-ton arc melting furnace. Other equipment consists of one 10-per cent, three-phase, air core reactor for use in the 2200-volt circuit, instrument and control panel; also six automatic, single-phase, electrode regulating equipments for controlling the input to the arcs used to heat the top of the ingot.

IX. Electric Furnace

Last December, several units of the first commercial installation of Northrup induction furnaces operating at 480 cycles were put in operation. This particular installation was made for melting nickel silver and similar alloys, but these equipments have many possibilities in the heating and melting of ferrous metals and alloys, several applications being under consideration at present.

The initial installation consists of two motor-generator sets, each delivering 600-kw., single-phase, 1875 volts, 480 cycles, to six Northrup high-frequency furnaces, each generator being driven by a 3-phase, 60-cycle, 2300-volt synchronous motor, with direct connected exciter. To compensate for the low power factor and obtain best circuit conditions, a bank of capacitors is included with each furnace.

Last fall, the equipment for the first three-voltage-control arc melting furnaces was sold. These equipments are used with six-ton, three-electrode furnaces, one originally installed with a 1200-kv-a. bank of transformers and the two others with a 1500-kv-a. bank of transformers.

Each new equipment consists of a 2550-kv-a. bank of transformers which will deliver full output at 165, 156 or 147 volts and a lower capacity at 138, 120, 95, 85, 80 or 70 volts. Air core reactors of 25 per cent capacity for connection in the 11,500-volt circuit, together with suitable switching equipment, were also included.

The melter has a choice of several voltages to start the heating, probably using 2550 kv-a. at 165 or 156 volts, 2400 kv-a. at 138 for the intermediate voltage and a still lower kv-a. at the refining voltage,—probably 85 or 90 volts, depending upon the furnace equipments.

Marked economies are effected in furnace operation, especially from the standpoint of the life of the side walls and roof, together with possible reduction in electrode consumption.

In conclusion, I wish to give full credit to the members of this committee for their effort as individuals in gathering the data which forms this report.

MESSAGES FOR MISSOURI

A short-wave set, operating on four to eight meters, is aboard. It is to be used to send out messages that can be picked up by amateurs in case of necessity at great distances. Some operator in Missouri or deep in the interior of Europe may hear this set during the Fonck flight and relay the message by wire to his government if the call is an S. O. S.

Both these sets are operated on storage batteries that are charged by two tiny generators. Each generator is driven by a fan with four-inch blades extending out into the "air slip" or stream of air that passes the plane during flight.—*Elec. Rev.*, July 25.

Engineering Education—Its History and Prospects

BY HENRY H. HENLINE*

Associate, A. I. E. E.

Synopsis.—*A brief history of the development of engineering education in the United States and a consideration of the usual type of curriculum in particular branches of engineering are followed by reasons for the development of a new type of curriculum and a discussion of its principal characteristics.*

The recently adopted curriculum leading to the degree of Bachelor of Arts in Engineering at Stanford University is given in detail. The ideals discussed in the paper are emphasized by a few selected quotations from statements of leading executives and teachers.

IN order to gain a true perspective of the subject of engineering education, one must consider its early history in the United States. The first American colonies were forced by Parliament to limit their production to agriculture and raw materials, and when they made the non-importation agreement in 1774, there appeared an urgent need for skilled workers in all mechanic arts. This situation was relieved by the formation of societies which exerted all possible effort to encourage the useful arts and by prizes offered "for the best achievement in every essential line of industry." After the war, similar activities were made necessary by the fact that England attempted to stop the development of industries by underselling methods.

During the years immediately following the war, many engineering developments were made, notably:

1787 —First flour mill machinery.
1790 —First textile mill driven by water power
1793 —Invention of the cotton gin
1801 —First high-pressure steam engine
1801 —High-capacity double steam pump
1807 —First steamboat
1786-93—Several canals begun

The war of 1812 again made it necessary that American industries manufacture all necessities, and this, together with the fact that much of the soil was becoming exhausted, produced a very urgent demand for scientific information which would lead to greater production in both agriculture and manufacturing.

As a result of this demand, the Rensselaer Polytechnic Institute was established at Troy, New York, in 1824. The curriculum, which was one year in length, contained a great variety of subjects. During the last nine weeks of the year, a study was made of the practical applications of the sciences previously studied. In 1835, instruction in civil engineering was added and students who completed the new curriculum were awarded the degree of Civil Engineer. Following a thorough study of instruction in French technical schools, the Rensselaer curriculum was lengthened in 1849, to three years. The first half of the curriculum was planned so as to lay a general foundation for all engineering, and the last half contained courses designed to allow for specialization in some particular branch.

In much of the early demand for such schools, the need for training as an aid to industrial production was very strongly emphasized, but there was also a rather insistent demand for instruction in science as part of a liberal education.

The Lawrence Scientific School at Harvard and the Sheffield Scientific School at Yale were established in 1847. At the same time, the University of Michigan decided to give a course in civil engineering. No other engineering schools were established before the Civil War[1].

One of the most significant steps ever taken in providing for higher education was the passage by Congress of the Morrill Act in 1862. By this Act, the National Government presented to each State in the Union 30,000 acres of public land for each senator and representative in Congress. The purposes as stated in the Act were, " . . . the endowment, support, and maintenance of at least one college, whose leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanical arts, . . . in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life."[2]

The results of this Act were extremely gratifying to those who had been appealing for more technical schools. In 1870 there were seventeen such schools as compared with the four established before 1862. The number continued to increase very rapidly, and there were forty-one in 1871, seventy in 1872, and eighty-five in 1880[1]. At the present time there are approximately 130 engineering schools of college grade in the United States.

A number of these early schools were called industrial universities because the greatest demands for them had been based on industrial needs. The idea that manual labor occupied an important place in their training soon became so widespread that many objections to

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1. For references see end of paper.

such names arose, and changes were made. For instance, the Illinois Industrial University became the University of Illinois in 1885.[3]

Although the first schools offered civil engineering only, the curricula were soon extended to include several branches of science and engineering. The Massachusetts Institute of Technology, which was established in 1865, offered six four-year curricula as follows:

Civil Engineering
Mechanical Engineering
Mining Engineering
Practical Chemistry
Architecture
General Science

The first curricula of the Illinois Industrial University, established in 1867, were:[4]

Agriculture
Polytechnic—including
  Mechanical Science and Art
  Civil Engineering
  Mining and Metallurgy
  Architecture and Fine Arts
Military
Chemistry
Natural Science

Four years were required for the completion of each. The above examples are fairly representative of curricula offered by all of the early technical schools. The general plan in all cases was to provide training in mathematics, drawing, physics, chemistry, etc., in the earlier parts of the curricula, and to have the work in applied science follow such training according to the plan used in French schools. English and foreign languages were usually included in the curricula.

The number of curricula in engineering increased very rapidly with the extensive development which occurred in the applications of engineering knowledge of all kinds. There are now available curricula in about forty branches of engineering, including aeronautical, agricultural, architectural, automotive, ceramic, chemical, civil, electrical, marine, mechanical, metallurgical, mining, sanitary, etc.

The great increase in the number of curricula offered has been accompanied by numerous changes in their content. The chief tendency has been to include more technical subjects to keep pace with the phenomenal expansion of engineering activities. This expansion itself has made even more necessary than before a very thorough education in the fundamental subjects. Hence, serious overcrowding has resulted.

This has been relieved to some extent in many schools by the growth, from each curriculum in a particular branch of engineering, of several curricula covering the various sub-specialties. This process is only a partial remedy, however, because some of the sub-specialties have grown into branches of great magnitude, and the growth has by no means ended.

The type of curriculum now in most general use is one leading to a Bachelor's Degree in a particular branch of engineering (any one of approximately forty) at the end of four years. Such a curriculum contains a common core of subjects required of all engineering students, and consisting of the following groups of subjects:[5]

Science: Mathematics, chemistry, physics, mechanics
Mechanics Arts: Drawing and shop work
Humanities: English, foreign language, economics, etc.

These foundation courses are followed by the various engineering subjects considered essential in the specialized curricula. As a general average, the student's time during the four years is distributed about as follows[6]:

Languages and humanities........... 19 per cent
Mathematics and sciences............ 29 per cent
Engineering subjects................. 52 per cent

Since the languages and humanities group receives only 20 per cent of the time, and English and foreign languages are usually strongly emphasized, little or no time is spent on certain very important subjects such as biology, economics, geology, history, political science, psychology, business law, etc.

The group of subjects including mathematics and the sciences, principally chemistry and physics, receives strong emphasis in nearly all curricula because these subjects really constitute the foundation of all engineering. These, together with the group mentioned above, are usually given in the first two years.

Drawing and shop work are usually considered very essential subjects, and receive their proper proportion of time. The value of shop work, however, has been seriously questioned during the past few years. Many experiments in the handling of such courses have been tried. In a few schools, the university shops have been operated on a production basis in order that students might have experience as production managers, foremen, machine operators, etc., and thus receive a training designed to enable them to understand shop operations of all kinds. Others have developed cooperative courses with neighboring industries so that shop training as well as many other kinds of training can be obtained under practical industrial conditions. Throughout the period covered by these experiments there has been a considerable strength of opinion that shop work is being allowed to take time which should be allotted to other subjects, and the reasons why all engineering students should develop facility in handling tools have not been clearly shown.

Following these two years of preparation, the latter half of the curriculum is usually nearly filled with engineering subjects. This makes it necessary that each student decide early in his university career which one of the many branches of engineering he is most interested in and best fitted for. The time at which such a decision must be made if he is to graduate with his class depends upon the school chosen. In

some it is as early as the beginning of the first year. A large number require this decision at the beginning of the second year, and about one-fourth permit it to be made as late as the beginning of the third year. Very few schools permit greater delay[7].

During the work of the last two years, there is usually a considerable number of courses dealing with the various phases of the specialty chosen. There are also courses in related branches of engineering. Thus a student in civil engineering is usually required to take a course or two in electrical and mechanical engineering, and a student in electrical or mechanical engineering usually takes surveying in the civil engineering department. However, the major portion of the time is spent on the subjects closely related to that chosen for specialization.

In connection with the very thorough investigation of engineering education now being conducted by the Society for the Promotion of Engineering Education, many questionnaires have been used to secure information on all phases of education and related matters. One such questionnaire now being circulated gives ten divisions of electrical engineering, and asks which ones are considered so important that special curricula in them should be offered.

A serious result of the tendency to keep adding technical courses to curricula which are already completely filled is found in many schools in which the requirements for graduation in engineering include a considerable number of units more than required for graduation in other curricula. It is quite common to find this situation made more serious by the fact that there are few if any courses in subjects which prepare men for dealing with people, namely, citizenship, economics, political science, etc., or subjects which provide any cultural value. Many such curricula are extremely rigid, and allow almost no choice of subjects. Therefore, students are expected to follow a certain list of courses with very little thought as to their own interests.

The established order of subjects in most curricula, *i. e.*, languages, chemistry, physics, mathematics, mechanics, drawing, and shop work in the first two years, and engineering subjects in the last two, is often severely criticized because practical applications always follow theoretical principles. Another result of this order of subjects is that the students have very little contact with engineering or engineering faculty members during the first two years. Several institutions have tried the experiment of giving engineering problems throughout the first year. The success has apparently been great, as such work stimulates the students' interest and assists in making the final decision as to the special branch of engineering in which they wish to specialize. However, it seems to be impossible to coordinate theory and practise in a curriculum in such a manner as to meet all objections. Certain fundamental subjects must precede the more advanced subjects, and no Utopian scheme which includes all subjects mixed in proper proportions and arranged in ideal order has been proposed. It seems that the students of a worth while type should be able to maintain their interest through two years of work in fundamental subjects. It is a serious question whether one who cannot do so does not more properly belong in a trade school than in a university.

The investigation now being conducted has shown that about 62 per cent of the students admitted to engineering curricula fail to graduate, and the elimination occurs largely in the first two years[8]. This fact is causing a serious consideration of the factors involved with the hope that the mortality can be reduced. It has been suggested that the adoption of two-year curricula leading to a certificate or diploma, and preparing students definitely for certain kinds of technical employment, might be a satisfactory solution. There are a number of very serious objections to this procedure. Such a two-year curriculum would not provide the most suitable first two years' training for those who wish to complete a four-year curriculum, and it would be difficult or impossible for most institutions to provide facilities and personnel to handle both classes of students. The most serious objection, however, is the fact that this would definitely lead many able men into mediocre technical positions where their future progress would be slow. The failure of a student in mathematics or some of the other subjects placed early in the engineering curricula does perhaps indicate that he cannot be successful in the higher types of technical work, but it by no means indicates that he cannot become a successful man in the business or management side of engineering.

It seems obvious that the greatest need is for some means of determining what each student is best fitted for and the type of intellectual effort in which he is most interested. If each could receive expert assistance in the determination of his strongest natural aptitudes, the number of such eliminations would be greatly reduced. Many men now turned out as failures in the engineering curricula would be highly successful in some field of human endeavor, and this would be a far more satisfactory outcome than would be obtained by guiding all such men into mediocre technical positions.

To sum up the characteristics of most of the curricula now in effect: They are too rigid in that little allowance is made for the interests or initiative of the students when a decision has been made to specialize in a particular branch. This decision must, in most cases, be made before students are mature enough or have had sufficient experience to decide wisely. They devote too small an amount of time to broad education and too much to narrow specialized training.

A number of universities have developed five- or six-year curricula in order that more general subjects might be included without omitting the engineering courses which are considered necessary. In several

cases no degree is received until the completion of the entire five- or six-year period.

The cooperative type of education has some well recognized advantages in schools of all grades. The Massachusetts Institute of Technology and the University of Cincinnati are the two outstanding examples in the engineering field. At the former, the cooperative curriculum is five years in length. The first two years are the same as the usual electrical engineering curriculum, but during the last three years, alternate terms, including summer terms, are spent in the industries. The fifth year is devoted to graduate work and research in both the Institute and the companies. Each man has a choice of manufacturing and utility companies, but works in the same company during the three years. His compensation averages about $1500 for this period.[9]

The ideas expressed below, regarding some of the ideals of engineering education, are not those of any one man alone, but represent the aggregate opinion of the author and others. An earnest effort has been made to include the best thought on the subject.

The requirements of engineering education could be determined more definitely if there were a generally accepted definition of engineering. The following definition was given in his president's address in 1908, by Past-President Stott:

> "Engineering—The art of organizing and directing men, and of controlling the forces and materials of nature for the benefit of the human race."[10]

The first part of this definition shows that an important part of education consists of subjects which will enable those men who will become executives to develop more rapidly.

Probably a large majority of undergraduates in engineering schools believe they will be engaged for many years in work primarily technical. The results of the S. P. E. E. investigation show that of the three most recent classes 71 per cent are in work primarily technical, while more than 70 per cent of those in classes out fifteen years or more are in work primarily administrative.[8] Such records certainly indicate clearly that a broad education is more important than training in technical subjects. In 1916 a circular letter was sent to thirty thousand members of the four large engineering societies requesting them to number six groups of qualities headed Character, Judgment, Efficiency, Understanding of Men, Knowledge, and Technique, in the order of importance given them in accounting for engineering success and in considering young men for employment. Of the seven thousand replies received, 94.5 per cent placed the Character group at the top of the list, and about the same number placed Technique at the bottom[11]. Success in engineering obviously depends upon many factors besides technical knowledge and skill. The really successful engineer must be able to coordinate theory, practise, and economics, and to handle men. As shown above, most of the engineering curricula now in effect were planned in the earlier years of engineering education, and the changes made since have consisted principally in the addition of more technical courses. Most of the curricula furnish excellent preparation for certain types of work into which some of the graduates enter. On account of the extremely rapid progress that has been made in many branches of engineering during the past few years, the applications of engineering knowledge are now so many and so diversified in character that any curriculum designed to meet directly certain needs in industry may indeed prepare men in a most excellent manner for those needs, but fail utterly to prepare them for a great range of engineering problems, both executive and technical, which all graduates will be called upon to solve.

The very strong and growing tendency to choose executives from men with engineering training is a force which must be reckoned with. Problems which executives meet are becoming so complex and so closely associated with fundamentals of engineering that some technical knowledge is essential. No one believes the schools can train executives, as ability in this direction depends primarily upon inherent characteristics. However, if engineering graduates are to receive their fair share of such positions, they must be given the broad, general foundation which is absolutely essential.

During the past few years many high executives in some of our largest industries have advocated a broad type of training for engineers. In employing recent graduates, they prefer to obtain men who have had a thorough training in fundamentals and who have not specialized in some small branch of one of the principal types of engineering.

What, then, are the principal characteristics of a satisfactory engineering curriculum? The answer to this question depends upon the types of activity for which the schools attempt to prepare men. In the present stage of development, it seems necessary to recognize the needs of two general groups of students, *viz.*, those who expect to spend their lives in highly technical design or research, and those who will be engaged in commercial, industrial, or administrative phases of engineering. Both groups need a broad foundation consisting of such subjects as English, economics, biology, geology, history, business law, political science, etc., and thorough training in chemistry, physics, mathematics, mechanics, and other subjects which make up the heart of engineering. Such training should be mixed with and followed by courses giving the fundamentals of all of the principal branches of engineering, and there should be a reasonable amount of time available for elective subjects. Thus far there is no serious difference between the wishes of executives in industry and teachers of engineering. It therefore seems that the chief cause of argument is the relatively small group of men who will engage in research and other highly technical phases of engineering. This group must have better oppor-

tunities for the development of research ability and for specialized study than can be provided in any four-year curriculum which contains sufficient training in fundamentals. It seems clear that the usual type of four-year curriculum fails to meet the needs of all except those who wish to remain in the specialized divisions of engineering which do not require either a very broad training or an advanced technical education.

Many professional engineers believe a university curriculum should provide broad and thorough training in the fundamentals of engineering, and that considerable emphasis should be placed upon humanistic subjects such as English, economics, sociology, history, etc., not merely on account of their usefulness to the engineer, but also on account of their broadening influence[12]. Another phase of the investigation of engineering education now being conducted has developed the strength of this demand. The opinions of 1931 graduates of the classes of 1919, 1914, 1909, 1904, 1899, 1894, 1889, and 1884 on the principal objectives of engineering education are as follows[13]:

	No.	Per cent
To train broadly for the general needs of the industry	398	20.6
To train for specific needs of specialized divisions of engineering practise	229	11.9
To provide the former type of training for the majority, but provide the latter type for those who desire to spend the additional time required	1304	67.5

The enormous physical plant which has been built up during the last few decades has produced problems never thought of in the early engineering curricula. The country-wide net-words of railroad, telephone, power, and radio systems have brought with them a host of problems in all branches of engineering, ranging by degrees from management, with all of its extremely complicated personnel and technical questions, on the one side to the most advanced scientific research, with its exacting demands in mathematics and the sciences, on the other. The size of the field in which a young engineer finds himself shows clearly the futility of any four-year curriculum of a specialized nature. The only adequate preparedness for such a field is a broad education in the humanities, fundamental sciences, and engineering fundamentals.

The results of the investigation indicate that the most serious criticism of engineering education arises from the lack of training in business and economics[14]. The fact that success depends largely upon a good understanding of those subjects seems to be very generally recognized.

It has been said that engineering graduates of the past have risen to high executive positions and that this indicates that no great changes in curricula are necessary. Many of the questionnaires covering various phases of the investigation contain replies which show that in general engineering alumni think the curricula were not seriously deficient in any important respects except in the lack of business and economics. It must be remembered, however, that the questionnaires were planned to bring out the facts regarding existing curricula, and those who answered them were given no real opportunity to express their opinions of the recent movement toward more liberal engineering curricula.

In 1920 Stanford University put into effect the Lower Division plan which replaces the major department system during the first two years. The principal object is to require more training in fundamental subjects. During this period, the students are registered under the supervision of the Lower Division Committee which is appointed by the President. Each is required to take certain subjects and to choose other subjects from specified groups. Some of the requirements can be met by certain high school subjects. The requirements do not completely fill the first two years, and the remainder of the time can be devoted to electives. The following is a brief summary of the requirements[15]:

Group Requirements

I	Languages and literature and formative art	18 units
II	Natural sciences and mathematics	18 "
III	Social sciences	18 "

Subject Requirements

English composition	6 "
Foreign language	22 units in one, or 15 units in each of two foreign languages
May be anticipated in high school in whole or in part.	
Biological science	9 units
Physics or chemistry	9 "
One of the sciences may be anticipated in the high school.	
American history	9 units
General history	9 "
One of the history requirements may be anticipated in the high school.	
Citizenship	12 units

At the beginning of any quarter, a Lower Division student may designate the department in which he expects to register during the last two years. Those who thus make a tentative choice of major subject are then advised to consult the department regarding the most suitable courses to take as electives during the first two years.

In the autumn of 1924, the President appointed a special committee made up of representatives of all of the engineering departments, and requested that the various phases of work in engineering be considered and recommendations be made to him. That committee presented its report in March 1925. In this it recommended that a School of Engineering be organized, that a more general type of engineering curriculum leading to the degree of A. B. in Engineering be adopted, that the department curricula, with certain modifications, be retained at the option of the departments, and that two-year graduate curricula leading to the degree of Engineer be adopted by those departments

which had been requiring only one year. The recommendations were adopted by the University, and Professor Theodore J. Hoover, Executive Head of the Department of Mining and Metallurgy, was appointed Dean. Committees were appointed last October, and the registration of students in the tentative form of general engineering curriculum was begun in January 1926.

A revised form of curriculum has recently been adopted by the Faculty of the School of Engineering, and a copy of it is given below.

FOUR-YEAR CURRICULUM LEADING TO THE DEGREE OF BACHELOR OF ARTS IN ENGINEERING**

FIRST YEAR, TOTAL UNITS, 44

Subject	Course No.	Autumn	Winter	Spring
Foreign Language		3	3	3
Linear Drawing and Lettering	C. E. 1, 2	..	1	1
Chemistry		4	4	4
Co-ordinate Geometry	Math. 10, 11	3	3	..
Calculus	Math. 21	..	..	3
Citizenship	Citizenship 1-3	4	4	4
Total		14	15	15

SECOND YEAR, TOTAL UNITS, 46

Subject	Course No.	Autumn	Winter	Spring
English Composition	Engl. 2a, 2b	3	..	3
Freehand Drawing	M. E. 11	3	..	..
Calculus	Math. 22, 23	3	3	..
Heat and Electricity	Physics 13, 14	..	4	4
Mechanic Arts	M. E. 1, 2 or 3	*..	2	2
Descriptive Geometry	M. E. 10	..	4	..
History		3	3	3
Extemporaneous Speaking	Engl. 7	3	..	..
Elementary Machine Drawing	M. E. 12	..	..	3
Total		15	16	15

THIRD YEAR, TOTAL UNITS, 45

Subject	Course No.	Autumn	Winter	Spring
Theoretical Mechanics	C. E. 30, 31	5	5	..
Hydraulics	C. E. 106	..	..	5
Surveying	C. E. 20	5	..	..
Engineering Geology	Geol. 1a	5	..	..
Electricity in Engineering	E. E. 102, 103	..	3	3
Elementary Accounting	Econ. 3	..	5	..
Principles of Mining	M. & M. 101	..	..	5
Electives		..	2	2
Total		15	15	15

FOURTH YEAR, TOTAL UNITS, 45

Subject	Course No.	Autumn	Winter	Spring
Mechanics of Materials	C. E. 110	5	..	..
Pyrometallurgy of Iron and Steel	M. & M. 105	..	3	..
Exposition	Engl. 131	4	..	..
Business Law	Law 100	4	..	..
{ Prime Movers	M. E. 123		5 or	.. }
or Elementary Machine Design	M. E. 113	..	4	.. }
Engineering Economics	C. E. 130	..	..	3
Human Relations in Business		..	3	3
Electives		2	4 or 5	9
Total		15	15	15

*All these Mechanic Arts Courses are given in the Autumn, Winter, and Spring Quarters. Any two courses may be chosen by the student, limited only by the capacity of the laboratories. Although scheduled for the Winter and Spring Quarters, sufficient registration is desired for the Autumn Quarter to make operation of all three laboratories possible.

**Since the presentation of this paper before the San Francisco Section, minor corrections have been made in this schedule to place it in complete accord with the curriculum appearing in the Stanford University Announcement of Courses for 1926-27.

This curriculum is founded on the belief of many that any considerable amount of specialization in engineering subjects during a four-year course is undesirable. All students should have a good foundation in general or cultural subjects. In addition to this, engineering students must have rather extensive training in chemistry, physics, and mathematics. There is a number of subjects such as mechanics, hydraulics, surveying, geology, business law, etc., which all engineering students should take. Finally, a young man who hopes to become a broad minded and well balanced engineer must have some knowledge of the contents of all of the principal branches of engineering, first, in order that he may be able to choose more intelligently the branch he wishes to follow as a specialty, and, second, in order that he may be able to consider all problems in their proper relation to the whole field of engineering. It is desirable also that such a curriculum allow a reasonable amount of time for elective subjects.

The above curriculum is not considered final. It is hoped that improvements can often be made in it. However, we believe it does follow closely the ideals expressed above.

The decision has recently been reached that the A. B. degree will not be awarded in the separate branches of engineering at Stanford after 1929.

The graduate study in each department is to continue over a two-year period leading to the degree of Engineer in the various branches. It is firmly believed that students who complete the six years will be very much better prepared for their life work than are those who take a more specialized course for four years and then one year of graduate work.

The question will often arise as to whether students who complete the four-year curriculum only will be prepared to begin work in certain engineering organizations. It is true that they will not be as well prepared in a certain few special phases of engineering as would the graduates of a more specialized curriculum. However, they will have a much wider range of choice, and need not feel limited to only a few specialties. If they devote their electives to carefully chosen courses, there need be no feeling that they are not prepared to become immediately useful. Future progress should be materially faster due to the broad foundation.

A few quotations from statements of leading executives and engineers will emphasize some of the statements made above.

SECRETARY OF COMMERCE HERBERT C. HOOVER[16]

"There is somewhere to be found a plan of individualism and associational activities that will preserve the initiative, the inventiveness, the individual, the character of man and yet will enable us to socially and economically synchronize this gigantic machine that we have built out of applied sciences. Now, there is no one who could make a better contribution to this than the engineer, but to make that contribution our engineers in the future have got to have a broader and stronger place in our world affairs than they have today. We cannot be turning men out of our universities as we are in many cases today purely mechan-

ical machines devoted to some theory built on applied sciences. If the engineer is going to take his part in this community, is going to give expression to those things that he can express best, he must start with a sense of his public obligations as well as his professional knowledge."

* * * * * * *

* * * "but we had better reduce the volume of science and applied science we are pouring into our young men in order to make room for some stimulation of their public relationships, some realization of their public obligations."

F. C. Pratt, Vice-Pres., General Electric Co.[17]

"Voicing my own opinion on this subject, we are not looking to the colleges and technical schools to turn out finished engineers, but we do look to them for a steadily increasing supply of young men who have been thoroughly trained in the fundamental theories of the mathematical and physical sciences, and to the fullest practicable extent in economics and in what are commonly called cultural studies. We believe that, with this ground-work thoroughly prepared, the large industries are in a particularly favorable position to offer exceptional opportunities to young men for gaining practical knowledge and experience along special lines.

"In this connection, I wish to make it quite clear that in the foregoing remarks I am not including those exceptional students who by natural qualifications and inclinations are prepared to pursue post graduate studies in theoretical work in any branch of science or engineering which contributes to the industry."

F. C. Pratt[18]

"My observations also leads me to the conclusion that the percentage of those who fail to attain a reasonable degree of success is greater in the group of men of mediocre ability but narrowly specialized education than in almost any other group coming within my knowledge."

Professor Edward Bennett, University of Wisconsin[19]

"One of the most gratifying developments of recent years has been the recognition on the part of the engineering industries that they do not wish to have the engineering colleges train men for immediate service in their specific fields."

Dean F. L. Bishop, University of Pittsburgh[20]

"There are two factors which enter fundamentally into the life of an engineering student. One is education, the other is training. In the very early days of the engineering school, education was the controlling idea; later, training or specialization became the controlling factor. In other words, we shaped our courses, modified our curriculum, and selected our teachers with the sole purpose of graduating professionally trained engineers.

"The reaction soon became evident. The cry went up that the engineer, although thoroughly trained, was narrowly educated. He lacked the proper perspective of life. He was unable to grasp the economic principles underlying great problems. He was too intent upon design and the solution of specific problems.

* * * * * * *

"We must look forward to the time when engineering schools will consider themselves as educating a large body of men who will become effective managers of the industries and who will exert, through their education and training, an important influence on the political and social side of the community.

"If our engineering schools will look upon the education and the training of this large mass of men as their primary object, and delay the specialization and technical training to additional years in the schools or industries, our instruction will be changed to meet this demand so that the emphasis will be placed more on education and less on specilization. Our teachers will not be such highly specialized technical experts but that they will be broadminded educators. The public will show an increasing confidence in our graduates because they will be educated as well as trained."

Dr. F. B. Jewett, Vice-Pres., American Telephone and Telegraph Company[21]

"Consequently I am interested in having those young men who come to us and who are going to be the leaders of our business of the future well grounded in the sciences. First, because we need them in the technical side of our business, and second, because I believe we are going to need them in a larger measure as the recruiting source for the executive directors of our business in years to come."

John Mills, Director of Publication, Bell Telephone Laboratories, Inc.[22]

"After we have answered these intermediate questions, we shall probably agree that we turn to the colleges in the hope of obtaining men of good mental ability and personality, who have acquired habits of thought and study which will enable them to see broadly the business and technical problems of the future, to analyze the factors involved, to arrive objectively and without prejudice at solutions, and, through personality and executive ability give to those solutions weight and effectiveness. We look, I believe, for trained brains in vigorous bodies with pleasant but dynamic personalities; men who may make creative contributions to our respective businesses or arts and, in a sufficient number of cases, develop as capable executives."

Dr. M. I. Pupin, President, A. I. E. E.[23]

"Nothing resists a change so obstinately as the mental attitude of man. The history of science from Archimedes to Newton offers many illustrations of this well-known fact. The change in the mental attitude of our age is one of the greatest achievements of our intellectual renaissance. Less than two generations ago, educational training was expected by many to operate like a penny-in-the-slot machine; that is, learn your lesson and convert your learning into cash without much delay. The so-called practical man who managed our American industries was at that time an ardent advocate of this utilitarian theory. He worshipped the art of making a living. Franklin and Lincoln, my patron saints, had no sympathy with this theory. The art of making a living was not the determining factor in their schooling, but the art of making life worth living was everything to them. They would find no fault with the American college because its diploma does not testify that college graduates are loaded with a knowledge of the art of making a living, provided, however, that they carry with them some definite ideas about the art of making life worth living, not only their own individual life, but also the life of our nation. The expansion of these ideas is the gospel of the American university."

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Instruments and Measurements

Report of Committee on Instruments and Measurements*

A. E. KNOWLTON, Chairman

To the Board of Directors:

The Committee on Instruments and Measurements undertook to continue this year two of the studies begun in 1924 and to start a third major study.

POWER AND ENERGY MEASUREMENT

One of the first two was that of the measurement of energy and power under the following conditions:

1. A study of methods of measurement of variable power, with particular regard to cases of commercial importance, such as efficiency tests on large machines.
2. A study of methods of measurement of energy in large blocks where the high value of the product makes every practicable improvement of the method desirable.

The subcommittee originally consisted of H. B. Brooks, Chairman, F. V. Magalhaes, and J. R. Craighead; because of weight of other business, Mr. Brooks resigned as chairman and Mr. Craighead was appointed chairman, and G. A. Sawin added to the committee. It was decided that, in both problems, great advantage could be secured by improvement in watthour meters and the subcommittee took the first steps toward accumulating data on the present performance of watthour meters as a basis upon which to proceed. The presentation in February, 1925, of the paper by Messrs. Kinnard and Faus on *Temperature Errors in Induction Watthour Meters* indicated such an advance in the field of watthour meters that it was considered unnecessary to accumulate the data referred to above; this branch of the work was dropped, therefore, because that and other work now in progress makes it seem probable that meters of substantially improved accuracy, particularly with regard to errors with varying temperature, would be available.

In connection with the further study of the first problem, the paper by Mr. E. S. Lee, presented in May 1925, entitled *Measurement of Electrical Output of Large A-C. Generators*, covered to a satisfactory degree the necessary details of application of indicating instruments to the testing of variable power.

In the measurement of energy in large blocks, present commercial methods require the use of instrument transformers and watthour meters. Therefore, the subcommittee has prepared the following short discussion of methods and devices in use:

This discussion refers to the measurement of energy on three-phase circuits at large supply or interchange points, where the value of the energy is large enough to justify any reasonable complication or expense to improve the accuracy and certainty of measurement.

When power is measured in large blocks, the current and voltage are practically always of such values as to require instrument transformers, both for convenience in application to meters and instruments and for protection of operators. The systems are usually three-phase. Grounding conditions of the systems vary, but for metering purposes may be classified in three groups:

1. Ungrounded.
2. Having one or more grounds on only one side of the metering point.
3. Having grounds on both sides of the metering point or a fourth wire so that there is the possibility of currents passing the metering point outside the three-line conductors.

*Committee on Instruments and Measurements:

A. E. Knowlton, Chairman
F. V. Magalhaes, Vice-Chairman
H. B. Brooks, Secretary

O. J. Bliss,	W. M. Goodwin, Jr.,	H. A. Perkins,
Perry A. Borden,	C. M. Jansky, Jr.,	L. T. Robinson,
W. M. Bradshaw,	W. B. Kouwenhoven,	Bryon W. St. Clair,
J. R. Craighead,	P. M. Lincoln,	G. A. Sawin,
W. A. Del Mar,	W. M. McConahey,	I. B. Smith,
E. D. Doyle,	W. J. Mowbray,	Roy Wilkins.

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, June 21-25, 1926.

1. Ungrounded Systems. The usual form of metering is by the use of two potential and two current transformers with a polyphase meter shown in Fig. 1. The advantages lie in the fact that there are only four transformers and one meter to care for, and that the meter will rotate forward under all conditions where the energy flow is in a given direction. The disadvantages lie in the necessity of having elements with closely similar characteristics and with negligible interference, and in the fact that the power factor under which the elements actually operate differs from the line power factor due to the use of voltages which in a balanced circuit are dephased 30 deg., one in the lagging and one in the leading direction from the position representing the true power factor of the three-phase circuit. For this use, therefore, the meter selected should have:

a. Close balance of elements and negligible interference between elements.

b. Excellent power-factor characteristics.

The substitution of two single-phase meters for the polyphase meter is sometimes advocated. This does not change the situation in regard to power factor, but substitutes the adjustment of the two meters for the balance of elements. Where the effect of low power factor or of unbalance of load at somewhat higher power factors causes one meter to run backward, the system will be in error due to the light load adjustment on the reversed meter, which will produce torque in the wrong direction. This may be met by the use of separate meters to record the backward reading, with a ratchet arrangement which allows each meter to record energy delivered in one direction only, as has been done in cases where the direction of the total flow of energy is expected to reverse at intervals. The polyphase meter is usually considered preferable.

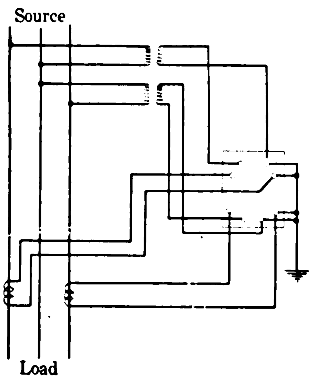

Fig. 1—Connection for Metering on Three-Wire, Three-Phase System with not more than One Point Grounded.

2. Systems having grounds on one side of the metering point. These may be treated as ungrounded systems, using the methods described above, or the system shown in Fig. 2 may be used. Here three potential transformers are connected with primaries in *Y*, the common point grounded, and three current transformers are used with a three-element, polyphase meter, or with three single-phase meters. The three-element, polyphase meter has the advantage of simplicity as compared with the three single-phase meters, but it should be assured that interference between elements is negligible and that a satisfactory balance between elements is assured; once obtained, the balance among elements is quite permanent, while the balance among the three single-phase meters is subject to the usual small variations requiring occasional adjustment.

This method has the advantage of having the power factor of each element of the three-phase meter, or of each single-phase meter, the same as the line power factor on a balanced circuit, approaching the line power factor under unbalanced conditions more closely than the methods previously described.

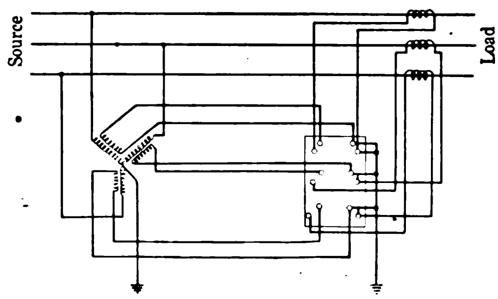

Fig. 2—Connections For Metering on Four-Wire, Three-Phase System or Three-Wire, Three-Phase System with Ground on Both Sides of the Metering Point

To secure good results, it is necessary that the grounding of the primary circuit be sufficient to maintain the neutral at a satisfactory balance at all times among the three phases. If this is not accomplished, the voltages on the individual potential transformers vary with circuit conditions and with the characteristics of the potential transformers themselves, involving certain errors in the potential transformer ratio and phase angle and in the meters.

In some cases this method has been proposed for application to ungrounded circuits, but the uncertainty of the position of the neutral renders it unsatisfactory for the best accuracy. For other reasons it is undesirable also to ground the neutral of the primaries of the potential transformers when the circuit is not otherwise grounded. It is possible to omit the ground on the potential transformer primary and obtain an artificial neutral by balancing the secondary burdens of the potential transformers, but the method requires care in adjustment and therefore, is not to be recommended.

3. Systems having grounds on both sides of the metering point, or a fourth wire. These systems should be treated as four-wire, three-phase systems, using the method shown in Fig. 2. In the unlikely case of an ungrounded, four-wire, three-phase system, the common point of the potential transformer primaries should be connected to the fourth wire.

In some cases, switching operations under different

conditions of load and supply cause important variations in the ground connections. Here the following two fundamental principles govern the method selected:

a. The minimum number of current transformers and corresponding meter elements must be such that under any condition, where a correct record is desired, no more than one possible path for return current past the metering point shall be without a transformer and meter element; in other words, in the circuit of n wires or paths, the minimum number of current transformers and corresponding meter elements required is $(n-1)$.

b. The connection of potential transformers must be such that the unbalance of voltages on their primaries is not in excess of the unbalance of the delta voltages on the primary lines.

In illustration of the first principle, consider a three-phase, three-wire circuit, having a permanent neutral ground on one side of the metering point and an occasional neutral ground on the other; the connection of Fig. 1 cannot be properly used because of possible ground current past the metering point during the presence of the second ground but the connection of Fig. 2 is correct.

An illustration of the second principle: Suppose that, at times, the entire circuit is ungrounded; if the connection of Fig. 2 is used, the voltages on the potential transformers will be subject to unbalance because the relation of the various lines to ground is no longer definitely controlled. Assuming the practise once used in emergency of disconnecting the system ground to continue operation when one line is grounded be followed, two transformers will receive delta voltage and the third transformer no voltage. In this case, the ground must be removed from the potential transformer primary neutral and a voltage balance be obtained by adjusting secondary burdens. These latter practises have been recognized as harmful for other reasons as well, and they are practically obsolete for the type of circuits under consideration. They are mentioned as an illustration of an extreme case only.

Selection of Instrument Transformers

The errors of an instrument transformer appear as an error of ratio and as a phase angle by which the secondary voltage or current departs from its theoretically correct phase for metering. Since the rate of the watt-hour meter and its lag are both adjustable, it is possible to offset known errors, to some extent, by special adjustment of the watthour meter. Since, however, the ratio and phase angle of ordinary instrument transformers vary appreciably with voltage, current, burden, etc., any adjustment of the watthour meter to meet these errors is based upon an estimated average condition and therefore cannot be very accurate. It is, therefore, desirable to select transformers and adjust conditions to give the best possible accuracy without corrective adjustment of the watthour meter. This applies particularly to phase-angle errors of which the variation with power factor makes satisfactory correction impracticable.

Potential Transformers

Standard commercial potential transformers are designed to cover a range of burdens. In the higher voltage sizes, used on most circuits of large power, the accuracy is usually somewhat better than on low-potential transformers. The no-load phase angle is ordinarily negative (secondary voltage reversed leading primary voltage), and several types of transformers are available where this does not exceed 8 minutes at 60 cycles. Non-inductive current drawn from the secondary windings tends to change this angle in the positive direction and lagging current in the negative direction. In the best transformers, it is possible, by increasing the non-inductive current, to reduce the phase angle practically to zero by proper adjustment of

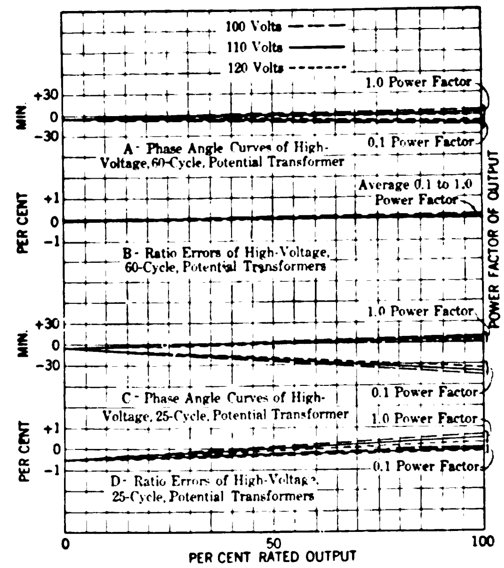

Plate 1—Ratio Error and Phase-Angle Curves of High-Voltage 25- and 60-Cycle Potential

the secondary burden. Even without this adjustment the phase angle with two watthour meters and necessary leads as sole burden may generally be kept within 10 to 12 minutes at 60 cycles.

The no-load ratio is usually low, but this error in many high-voltage transformers is not more than 0.2 per cent at 60 cycles. Either non-inductive or lagging current drawn from the secondary tends to increase ratio, so that frequently the reduction of phase angle by burden adjustment referred to above is accompanied by an increase in accuracy of ratio. The variation in errors of a potential transformer for changes of voltage within the limits caused by ordinary regulation is very small. Whatever ratio error remains may, therefore, be fairly considered a constant error subject to correction by compensation in the watthour meter or by the application of a correction to the final result.

Plate 1, a and b, show average ratio errors and phase

angles of a number of transformers from 22,000 to 66,000 volts at 60 cycles, and c and d show test results on a single 33,000-volt transformer at 25 cycles.

Current Transformers

Standard current transformers are designed to cover a range of burdens. The ratio errors and the phase angle between primary and (reversed) secondary currents vary appreciably with current, secondary burden and large changes of frequency. The phase angles are usually positive, and are increased by increase in non-inductive burden. It is desirable, therefore, to keep both burden and its power factor as low as possible. This means low resistance leads and only the necessary one or two watthour-meters for the best results. The variation of ratio and phase angle with current must also be considered. It is desirable to obtain transformers having as little variation of these errors with current as possible.

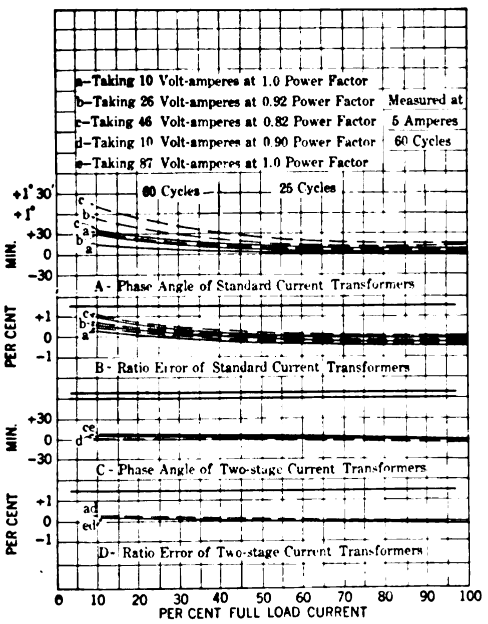

Plate 2—Ratio Error and Phase-Angle Curves of Standard and Two-Stage Current Transformers at 35 and 60 Cycles, with Stated Burdens

On account of the range for which the transformer is designed, the ratio is usually low at low burdens to prevent it from being too high for reasonable accuracy at high burdens. The amount by which the ratio is low on the lowest practicable burdens varies with the practise of the various manufacturers, but does not usually exceed 0.8 per cent maximum. No attempt should be made to bring a low ratio up by additional burdens, as it requires very careful adjustment of the amount and power factor of the burden to produce satisfactory results on ratio and phase angle at a single value of current, while the resulting phase angle (and sometimes ratio) at other values of current becomes rapidly worse. This difference between treatment of potential and current transformers should be noted as resulting from the fact that the potential transformer must be accurate at a roughly constant voltage and current, while the current transformer must be accurate at widely varying currents and voltages. The same results may be obtained by adjustment of the watthour-meter as by a change in the ratio of the current transformer.

Improvement of current-transformer accuracy by special means has been proposed in several forms. A method recently brought out, for which apparatus is beginning to be available, is the two-stage transformer with special watthour-meter. ("The Two-stage Current Transformer," Brooks and Holtz, A. I. E. E. Journal, June 1922.) The two-stage transformer is, in principle, a combination of two transformers in one, in which the second transformer corrects the errors of the first by the use of a simple corrective winding in the watthour-meter. By this arrangement the errors of ratio and phase angle due to the current transformer are greatly decreased as compared with standard current transformers. Typical curves show ratio error held within 0.2 per cent and phase angle within about 6 minutes for a test from 10 per cent to 100 per cent current at 60 cycles with a burden of two watthour-meters in the corrected circuit.

In Plate 2, A and B show average ratio errors and phase angle at 25 and 60 cycles of standard current transformers, and C and D show test results on a two-stage transformer designed for a working pressure of 32,000 volts.

Secondary Connections of Instrument Transformers

To assure the best results, it is preferable that separate leads be used for all secondary circuits, and that the length of leads be kept as short as possible. All secondary circuits of current and potential transformers should be connected to a common ground.

Watthour Meter

The watthours per disk revolution of a watthour-meter will depart somewhat from the nominal value for load current values other than those for which it has been adjusted. On this variation are superposed whatever errors result from changes of temperature, power factor, frequency, voltage and wave form. Certain work now in progress (such as that of Kinnard and Faus, already cited) makes it seem probable that meters of substantially improved accuracy, particularly with regard to errors with varying temperature, are to be available. Temperature compensation is more readily obtained for meter elements operating at unity power factor; inasmuch as one of the two elements of the ordinary polyphase meter usually operates at low power factor, it is greatly to be desired that such studies be prosecuted with a view to obtaining temperature compensation for all conditions of phase departure within the meter elements.

The power-factor error is partly compensated by lag adjustment. The frequency and voltage errors are negligible for the variations occurring in the usual circuits under operating conditions. If special wave-form conditions, serious enough to cause error, exist, the greater part of the error may be eliminated by calibrating the watthour-meter in place by the use of indicating instruments the wave-form error of which is negligible.

The watthour-meter in general service is one of the most reliable devices in measurement work. In view, however, of the large value of the energy measured at the points here under consideration there are cases where it may be advantageous to use two watthour-meters similarly connected to assure a proper record in case of the accidental failure of one meter. In such cases it is proper to designate one meter as the regular standard, and to substitute the reading of the second meter only when reasonable proof of the failure of the first meter to record correctly has been obtained.

Owing to the recent rapid improvement in the watt-hour-meter, detailed data on performance is omitted.

High Frequency Measurements

The second of the studies undertaken in 1924 was in the field of measurement of high-frequency quantities; progress is being made in this investigation but the subcommittee (C. M. Jansky, Chairman, E. D. Doyle, B. W. St. Clair) makes no report at this time.

Dielectric Losses and Power Factor

The matter of measurements in connection with dielectrics, especially solid dielectrics, was surveyed by the committee and a subcommittee appointed as follows: W. A. Del Mar, Chairman, O. J. Bliss, and W. N. Goodwin, Jr. This committee arranged a symposium of papers presented at the First District Regional Convention at Niagara Falls May 26, 27, 28, 1926. The papers submitted are as follows:

The Power Factor of Dielectrics and Insulation, by J. B. Whitehead, Johns Hopkins University

The Mechanism of Breakdown of Dielectrics, by P. L. Hoover, Harvard University

Standards for Measuring Power Factor of Dielectrics, by H. L. Curtis, Electrical Testing Laboratories

The Significance of Errors in Dielectric-Loss Measurements, by C. F. Hanson, Habirshaw Electric Cable Co.

Use of Dynamometer Wattmeter for Measuring Dielectric Power Loss, by E. S. Lee, General Electric Co.

Commercial Dielectric-Loss Measurements, by R. E. Marbury, Westinghouse Elec. & Mfg. Co.

Three Methods of Measuring Dielectric Power Loss and Power Factor, by E. D. Doyle and E. H. Salter, Electrical Testing Laboratories

Compensation for Errors of the Quadrant Electrometer, by D. M. Simons, Standard Underground Cable Co.

The Dielectric-Loss-Measurement Problem, by B. W. St. Clair, General Electric Co.

Zero Method of Measuring Power with a Quadrant Electrometer, by W. B. Kouwenhoven and P. L. Betz, Johns Hopkins University

It is believed that these papers in the total give a reliable index of the present state of the art of measurements involving the higher voltages and small phase angles.

TIDE-POWER DREAMS ARE COMING TRUE

The flow of tides may yet generate a large amount of electric power. This type of project, for years held to be fanciful, is about to get a real start on the international boundary between Maine and New Brunswick. The Federal Power Commission recently granted Dexter P. Cooper a preliminary permit covering a proposed huge development of tidal power in Passamaquoddy and Cobscook Bays, Washington County, Maine. The next step is to secure the same sort of permit from the Canadian government.

On May 27 the private bills committee of the Canadian House of Commons approved the bill to permit Mr. Cooper's plan to be carried out, but added a number of amendments as the bill went to the House for action. One of these provides the Dominion authorities must be satisfied with the allocation of power as between the United States and Canada before the project begins to operate. Other amendments require that a majority of the directors be British subjects and that not more than ten million dollars of bonds be issued.

Mr. Cooper purposes to build a series of dams between various islands and the Canadian and American mainlands so as to trap vast volumes of water in two great pools at a coastal point where the ebb and flow of the Atlantic Ocean tides are strong. Water is to be admitted through 43 gates during the hours that the tide is rising and to be discharged steadily through one or more great electrical generating stations.

The calculations are to obtain a mean operating head of 13 ft. between the two pools created by natural barriers and the dams. A flow of 300,000 second-feet will be counted upon to develop two and a half million kilowatt-hours of electric energy annually through the operation of generators of 600,000 horsepower capacity. There are few electric generating stations in the world with so large a capacity for producing current for electric light and power. The principal market for this power will be down the Maine and Massachusetts coasts to Boston.

Stability Characteristics of Alternators

BY O. E. SHIRLEY[1]

Associate, A. I. E. E.

Synopsis.—*During the past few years, stability characteristics of systems using long lines have been discussed at considerable length, but not so much attention has been given to the characteristics of the load. This paper shows that power limits may be reached with very short lines and certain classes of load.*

The characteristics of several classes of load, such as motors of various kinds with constant shaft output, variable impedance loads (synchronous converters for railways), constant impedance, and miscellaneous combinations, are discussed as they affect the stability of the generator. The criterions for the stability of an alternator as developed by this paper are "short-circuit ratio," saturation, power factor of the load, and character of the load.

A series of curves and a formula for the minimum allowable value of short-circuit ratio as a function of saturation and power factor are proposed for general purpose alternators which may be called upon to deliver power to any of the various classes of load. These curves are derived from characteristic curves of typical machines.

It is not intended that these curves shall be used for generators which supply power over long transmission lines, as the characteristics of these lines may require considerably higher values of short-circuit ratio, and the generator must be specially designed to meet the individual requirements.

* * * * *

For the past few years, the problem of power limits and stability of alternators has been given considerable attention especially from the standpoint of transmission over lines of lengths approaching the maximum economical distances. The effect of exciter stability, the possibilities of automatic voltage regulators, and compensation for armature reaction by compounding through rectifiers have all been quite fully presented. That there are practical limits for stability in operation for certain classes of load, even with short lines, has been suggested in some papers and discussions, but usually as incidental only to the presentation of other features which were covered much more completely.

The purpose of this paper is to discuss the characteristics of the various classes of load, and to propose a set of curves based on the inherent characteristics of a-c. generators to secure a practical degree of stability with the kinds of load for which this factor must be considered, to secure successful operation. These curves are intended for machines operating under ordinary conditions with comparatively low line drop, and will not be applicable for those operating with very long, high-voltage transmission lines.

In recent years the tendency in the design of alternators has been to decrease the short-circuit ratio, that is, the ratio of field current for normal voltage on open circuit to the field current for rated stator current on short circuit. In many cases this short-circuit ratio may go to extremely low values without serious consequences, aside from poor regulation, but with some kinds of load, an alternator with a short circuit ratio very much below unity may not carry swings appreciably above full load and the voltage will "fade" so that part of the load will be dropped. Such a disturbance may be very puzzling to the operator, as the generator will dip in voltage, dropping a considerable part of the load which caused the instability (due to operation of low-voltage relays), and the voltage will then recover to approximately normal. The machine may then operate as though nothing had happened, unless the maximum load for stability is again exceeded. The fading of voltage, or instability, results from a combination of characteristics of machine, line and load. The principal factors determining stability of the alternator are degree of saturation, power factor of load, and short-circuit ratio. For any particular class and power factor of load, and for alternators with the same degree of saturation, there will be a minimum value of short-circuit ratio which is the lower limit for design of these machines if they are to carry full load with the necessary margin in stability. This margin in stability is necessary to enable the machines to carry the ordinary swings in load successfully.

The degree of saturation in the alternator may be represented by the "saturation factor" as defined in the A. I. E. E. Standards.

Curves showing the proposed minimum values of short-circuit ratio for various lagging power factors and saturation factors are derived in this paper by combining load and generator characteristics.

Load Characteristics

1. *Constant Power Output.*

a. Induction motors with practically constant shaft output, such as those driving fans, pumps, compressors, direct-current generators, etc.

b. Synchronous motors for same classes of service as "a."

2. *Variable Impedance.*

a. Synchronous converters supplying power to series motors for railway service.

3. *Constant Impedance.*

a. Light and heating.

b. Electric furnaces, welders, etc.

c. Synchronous converters for lighting load.

4. *Miscellaneous.*

Combination of constant power, variable impedance, and constant impedance loads.

1. Designing Engineer, General Electric Co., Schenectady, N. Y.

To be presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

Constant Power Output. Figs. 1A and 1B represent diagrammatically alternators furnishing power to a synchronous motor load and an induction motor load, respectively.

The curves in Fig. 2 show the variation in power factor with voltage for synchronous and induction motors having constant shaft output. The synchronous motor curves are based on adjusting the motor field currents for rated power factors at normal voltage and holding these motor field currents constant for other voltages. The induction motor curve is based on operation at 90 per cent power factor at normal voltage and load. Curves showing variation of current with voltage corresponding to these power factor curves are given in Fig. 3.

The alternator characteristics are represented by the

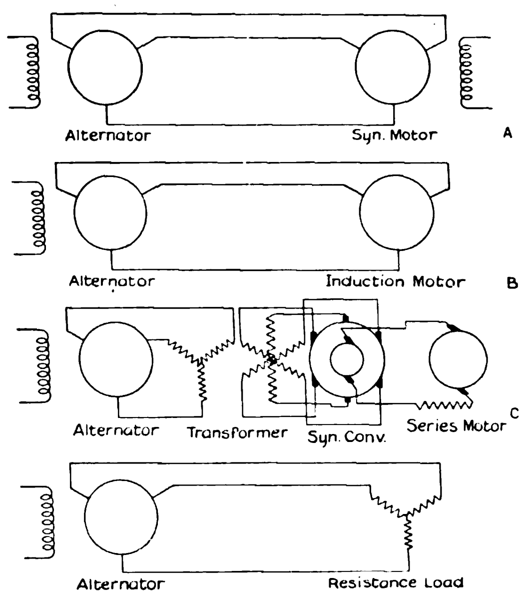

Fig. 1—Diagrams for Various Classes of Load

usual open circuit saturation and synchronous impedance curves. It is possible to design machines with a very wide range of characteristics, but, for the purpose of illustrating the combination of machine and load characteristics, curves for a general purpose alternator with fairly high saturation have been selected.

The values of alternator excitation required with constant power output for a number of voltages, above and below normal, were calculated for the different classes of motors represented in Fig. 2, for the stator currents Fig. 3.[2] Refer to Fig. 5 for these curves. They show that excitation decreases slowly with the voltage to a minimum point and then increases again. The minimum excitation and the corresponding voltage determine the limit of steady-state, stable operation. Refer to Fig. 5, Curve *B*. If the generator excitation corresponds to 92 per cent voltage, and the voltage starts to decrease, due to addition of a very small increment of load, the excitation required at a slightly lower voltage will be less than that actually on the machine, and the voltage therefore will be stable. However, if the excitation is decreased to that required for 88

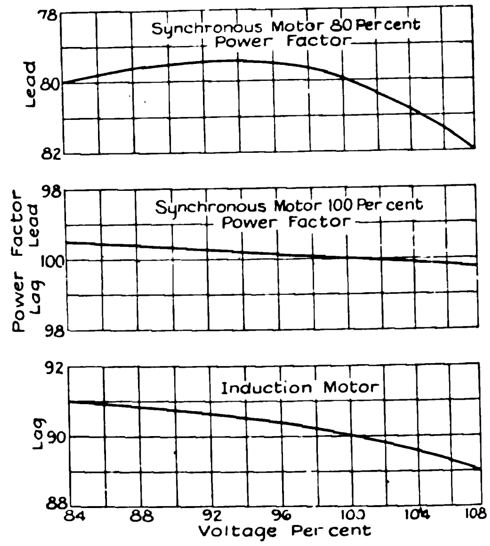

Fig. 2—Variation of Power Factor with Voltage. Constant Power Output

per cent voltage, and the small increment of load is added, the voltage will start to decrease and it will then pass through no value for which the excitation is

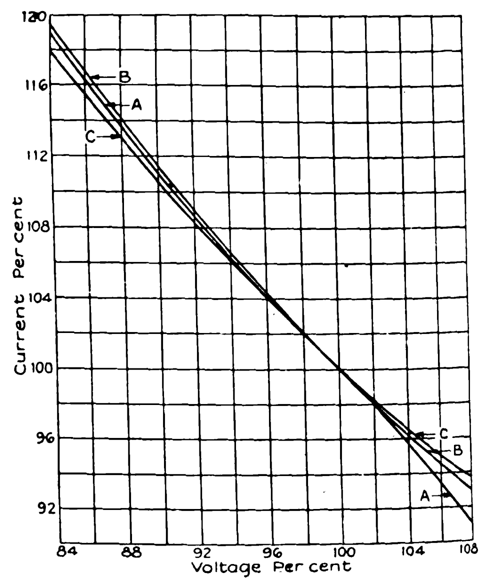

Fig. 3—Variation of Alternator Current with Stator Voltage. Constant Power Output

A. Synchronous motor—80 per cent. power-factor lead at normal voltage
B. Synchronous motor—100 per cent. power factor at normal voltage
C. Induction motor—90 per cent. power-factor lag at normal voltage

sufficient. The voltage will continue to drop until the generator and motors pull out of step.

The curves in Fig. 5 show quite clearly the behavior of an alternator with motor load having constant shaft output, but the maximum power output of the generator

2. *Reactance*, Appendix C., Doherty and Shirley, A. I. E. E. Transactions, Vol. 37, Part 2, p. 1293.

may be determined more simply by a method which has been used in various forms for several years.[3]

The curve between current and voltage at a given power factor and for a constant excitation current is obtained by calculation or test. These curves, calculated for normal load excitation and at the power factor

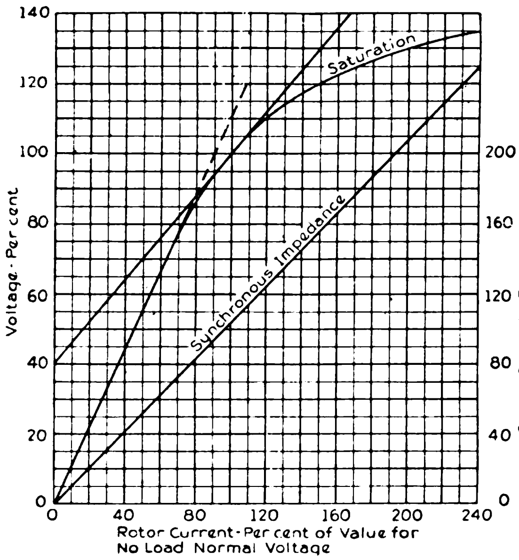

FIG. 4—CHARACTERISTIC CURVES OF ALTERNATOR

Saturation factor—1.65 at normal voltage
Short-circuit ratio—1.04
Stator reactance—18 per cent

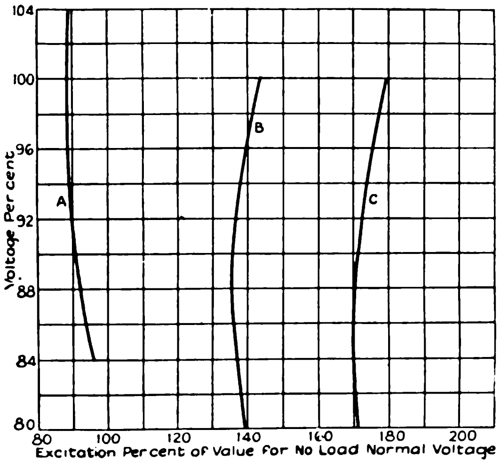

FIG. 5—ALTERNATOR EXCITATION—VOLTAGE CURVES CONSTANT POWER OUTPUT

A. Synchronous motor—80 per cent, power-factor lead at normal voltage
B. Synchronous motor—100 per cent, power factor at normal voltage
C. Induction motor—90 per cent, power-factor lag at normal voltage

for normal voltage of each of the classes of motor load in Fig. 3, are shown in Fig. 6. The kv-a. output curves, derived from these curves, are also given in Fig. 6. The voltages for the maximum kv-a. points in Fig. 6 correspond very closely to the voltages for the minimum excitation points in Fig. 5. The curves do not check exactly, because in Fig. 5 the effect of varying power factor is taken into account, and in Fig. 6, constant power factor is assumed. The difference between the two methods is very small, as will be explained later in connection with Fig. 9.

The behavior of an alternator with increasing load at constant power factor is represented by current-voltage and kv-a-voltage curves at excitations corresponding to 80-, 100-, 120-, and 140-per cent load at normal voltage (See Fig. 7). The kw. load, expressed as a per cent of the kv-a. rating, is also given by the dotted curves for comparison. These curves show that the maximum kv-a. points occur at voltages increasing up to a certain value and then decreas-

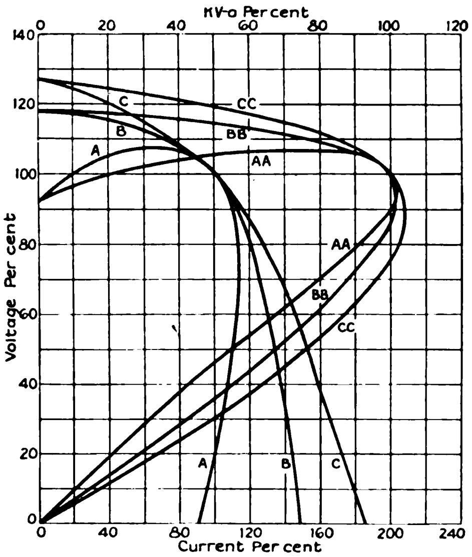

FIG. 6—ALTERNATOR CHARACTERISTICS—CONSTANT EXCITATION

Saturation factor—1.65
Stator reactance—18 per cent
Short-circuit ratio—1.04
Current-voltage curves $A—B—C$
Kv-a.-voltage curves $A\ A—B\ B—C\ C$

$A—A\ A$ 80 per cent power-factor lead
$B\ BB$ 100 per cent power factor
$C—C\ C$ 90 per cent power-factor lad

ing, so that the load will not be reached under practical operating conditions where the machine will be unstable at normal voltage. The curves also indicate that alternators with high saturation would operate at very high loads without becoming unstable, but practical experience has shown that it is necessary to maintain a considerable margin in voltage above the minimum point, and in kv-a. below the maximum point.

In Fig. 9, curves *A* and *A A* are calculated for normal load excitation at 90 per cent power-factor lag; curves *B* and *B B*, for 91 per cent power factor; and curves *C* and *C C*, for 89 per cent power factor. The dotted curves, *D* and *D D*, take into account the variation of power factor with voltage for the induction motor represented in Fig. 2. These curves show that the maximum kv-a. for operation at variable power factor,

3. *Elements of Alternating Currents*, Franklin and Williamson, The MacMillan Company, 1901, p. 124.

"Alternating Current Generators," W. J. Foster, *General Electric Review*, June 1923, Vol. 26, p. 365.

A. I. E. E. Discussion, C. A. Nickle, TRANSACTIONS A. I. E. E., Vol. 43, p. 89.

such as that with induction-motor load, is very closely approximated by the curve of kv-a. for normal power factor.

The curves in Fig. 7 show clearly the importance of keeping up the excitation so as to maintain normal voltage with this class of load. This result may be secured with hand regulation by operating with excitation corresponding to normal load and voltage, which will give a voltage above normal when the load is lower than the machine rating. A regulator is very effective in maintaining stability up to the steady state maximum capacity of the alternator at normal voltage, but if the load exceeds this maximum value, the use of any of the

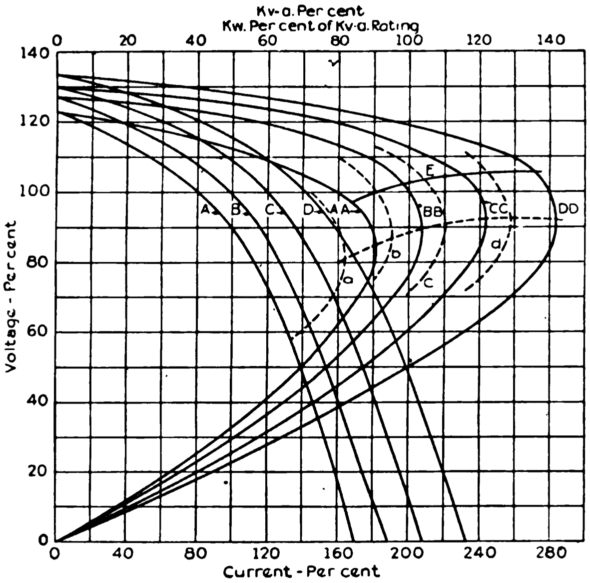

FIG. 7—ALTERNATOR CHARACTERISTICS—CONSTANT EXCITATION

Saturation factor—1.65; A—A A—a 80 per cent kv-a. at normal voltage
Stator reactance 18 per cent; B—B B—b normal kv-a. at normal voltage
Short-circuit ratio 1.04; C—C C—c 120 per cent kv-a. at normal voltage
Power factor—90 per cent lag; D—D D—d 140 per cent kv-a. at normal voltage

E. Kv-a.-voltage curve for 15 per cent margin in voltage above maximum kv-a. points
Current-voltage curves A, B, C, D
Kv-a.-voltage curves A A—B B—C C—D D
Kw.-voltage curves a, b, c, d

present standard regulators will not maintain stability. If, however, the load conditions are such that the maximum load is exceeded only slightly, stable operation may be obtained by regulating for a voltage a little over normal, provided the machine will not be injured by the higher voltage operation.

The maximum kv-a. values given by the excitation curves do not include any allowance for the effect of the lines and the connecting apparatus, or swings in load, and practical operation will require a margin in the maximum capacity of the alternator to take care of these factors. The required margin is a point that must be determined largely from operating experience.

The more important characteristics of the alternator which affect stability are saturation, relation of no-load field strength to armature reaction, and power factor.

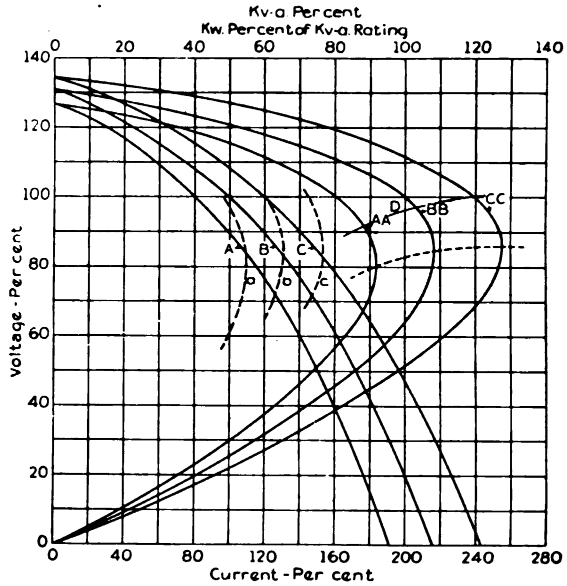

FIG. 8—ALTERNATOR CHARACTERISTICS—CONSTANT EXCITATION

Saturation factor—1.65; A—A A—a, 80 per cent kv-a. at normal voltage
Stator reactance 18 per cent; B—B B—b, normal kv-a. at normal voltage
Short-circuit ratio 1.04; C—C C—c, 120 per cent kv-a. at normal voltage
Power factor—60 per cent lag

D. Kv-a.-voltage curve for 15 per cent margin in voltage above maximum kv-a. points
A, B, C current-voltage curves
A A—B B—C C kv-a.-voltage curves
a, b, c kw.-voltage curves

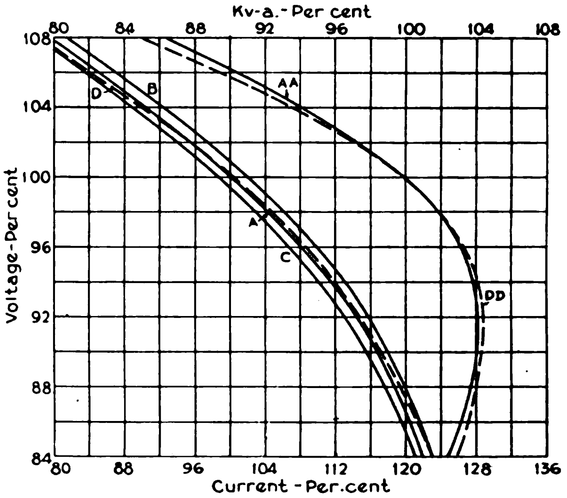

FIG. 9—ALTERNATOR CHARACTERISTICS—CONSTANT EXCITATION. EXCITATION HELD AT VALUE FOR NORMAL KV-A. AT RATED VOLTAGE AND 90 PER CENT POWER FACTOR

Saturation factor 1.65; A—A A 90 per cent power factor
Stator reactance 18 per cent; B 91 per cent power factor
Short-circuit ratio 1.04; C 89 per cent power factor

D—D D power factor varying between 89 per cent at 108 per cent voltage and 91 per cent at 84 per cent voltage
A—B—C—C current-voltage curves
A A—D D kv-a.-voltage curves

It is proposed that the saturation factor, as defined by the A. I. E. E. Standards and the short-circuit ratio,

be used as the criterion of stability for an alternator at any given power factor. The relation of these two factors for obtaining a consistent margin in stability for synchronous-motor or induction-motor load at different power factors is worked out in a later section of this paper.

The problem of stability with long high-voltage lines

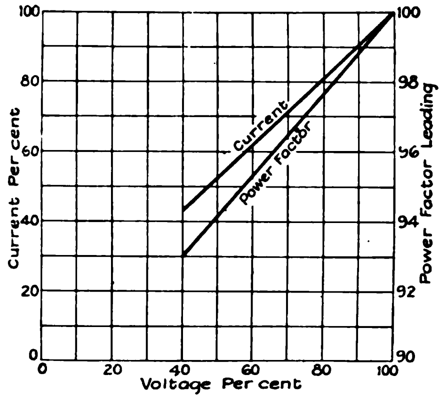

FIG. 10—SYNCHRONOUS CONVERTER CHARACTERISTICS SERIES MOTOR LOAD

D-c. current assumed to vary directly with d-c. voltage.
Curves showing variation of current and power factor on high-voltage side of transformer with voltage on high-voltage side of transformer

and power transmission approaching the maximum line capacity requires a very large increase in stability of the generators and receiving apparatus. A considerable number of papers dealing with this subject have

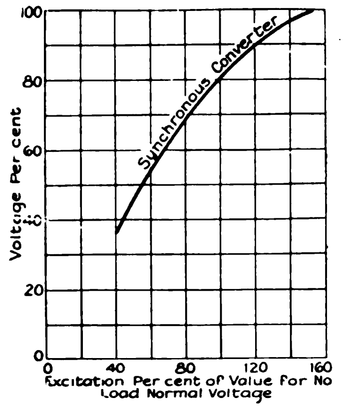

FIG. 11—ALTERNATOR EXCITATION—VOLTAGE CURVES
Synchronous converter with characteristics on Fig. 9

been presented to the Institute, and no attempt is made in this paper to cover this problem.

Variable Impedance Load. A synchronous converter furnishing power to series railway motors is an example of a load with quite different characteristics from the one just discussed. For simplicity in working out the curves, the current on the d-c. side of the converter is assumed to vary directly with the voltage. The power factor on the high-voltage side of the transformer will remain quite close to unity due to the converter being self-excited. The current and power-factor curves are drawn as straight lines, and will approximate the actual conditions quite closely. Fig. 10 shows the assumed curves and Fig. 11 is the corresponding excitation-voltage curve. It will be noted that the excitation continues to decrease with the voltage, instead of having a minimum point as with induction or synchronous motor load.

The stability of the alternator is not a practical factor in a design for this class of load. It is therefore possible to use a machine with a short-circuit ratio of unity to carry very high short-time overloads (one to five minutes) on synchronous converters without trouble from instability, provided the alternator field is increased with load by automatic regulation.

The characteristics of a converter with lighting load are very similar to those just given, and the point of instability is not within the operating range of voltage, but very far below normal. It is possible, by hand or automatic regulation, to maintain normal voltage for

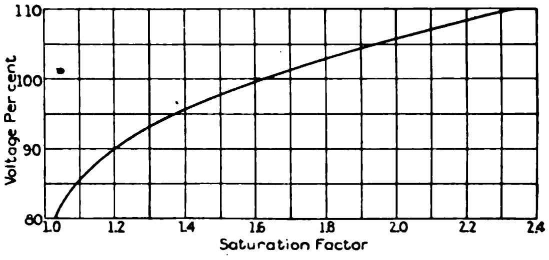

FIG. 12—ALTERNATOR CHARACTERISTICS
Variation of saturation factor with voltage—saturation curve from Fig. 4

any excitation within the heating limits of the rotor winding, and to carry any ordinary swings of load.

Constant Impedance Load. The current in this case will vary directly with the voltage throughout the entire range of load, and the excitation-voltage curve will be almost identical in shape with Fig. 11. With this class of load, the alternator will operate stably at any point on the kv-a-voltage curve, and the load limit will again be determined by the heating characteristics of the machine.

Alternator Characteristics for the Usual Commercial Load. The usual commercial load is a combination of the various classes just discussed and the selection of the generator with the proper characteristics is largely a matter of judgment. The calculation of excitation voltage curves similar to Fig. 5, for various values of load of the same characteristics as the given load, will show whether conditions of instability will be approached sufficiently to be a factor in the design of the generating equipment.

The kv-a-voltage curves, Fig. 7, indicate the maximum capacity for load which is practically all Class 1, but if there is a considerable percentage from Classes 2 and 3, the alternator may operate successfully at voltages below the maximum kv-a. point.

This may be illustrated by an example: Assume operation at 90-per cent voltage, Fig. 7. The maximum kv-a. capacity with Class 1 load under this condition is 104-per cent kv-a. as indicated by the maximum point of curve, *BB*, but, with other classes of load, it would be possible to operate at any point on any of the curves. Combinations of all of these different classes of load will give load characteristics, so that stable operation may be obtained somewhat below the maximum kv-a. point on the kv-a. curves. Just how far below the maximum point stable operation can be secured depends upon the percentages of the different kinds of load.

Derivation of Curves for Short-Circuit Ratio

The saturation factors for several values of voltage, below and above normal, for the saturation curve in Fig. 4 are plotted as a function of voltage in Fig. 12. The kv-a. values for an operating margin of 15 per cent in voltage, as determined by Figs. 7 and 8, are also shown as a function of voltage in Fig. 13.

The short-circuit ratios for various machine ratings corresponding to the kv-a., and voltage values for 90-per cent power factor from Fig. 13, Curve *A*, are derived as shown in Table I, which also includes the saturation factors for corresponding voltages taken from Fig. 12. Similar data were calculated also for the 60-per cent power factor, Curve *B* in Fig. 13. In Fig. 14, Curves *A* and *B* represent, graphically, the relations of short-circuit ratio and "saturation factor" as determined by these calculations.

TABLE I
CALCULATIONS FOR 90-PER CENT POWER FACTOR

Volts per cent	Kv-a. per cent	Current per cent	Open circuit field current per cent from Fig. 4	Short-circuit field current per cent from Fig. 4	Short-circuit ratio	Sat. factor
100	90	90	100	87	1.15	1.65
103	101	98	105	94	1.12	1.84
105	112	107	109	103	1.06	1.94
106	125	118	110	114	1.03	2.04

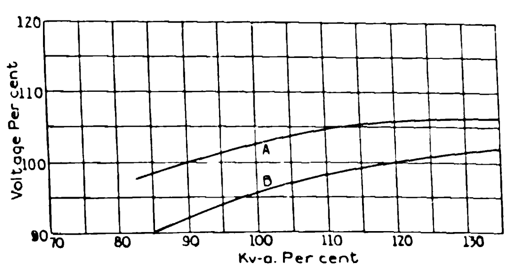

FIG. 13—ALTERNATOR CHARACTERISTICS

Kv-a-voltage curves for 15-per cent margin in voltage—From Figs. 7 and 8

A 90-per cent power-factor lag
B 60-per cent power-factor lag

The determination by trial of a simple formula to approximate these curves in the working range with reasonable accuracy, resulted in the following equation:

$$\text{Minimum } S\,C\,R = 1.4\sqrt{\frac{\text{Power factor}}{100\,F}}$$

Where minimum $S\,C\,R$ = minimum value of short-circuit ratio for rating to give a safe margin in stability for operation at normal rating and F = saturation factor as defined by the A. I. E. E. Standards 7-59: "The saturation factor of a machine is the ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the no-load excitation required at rated speed and voltage."

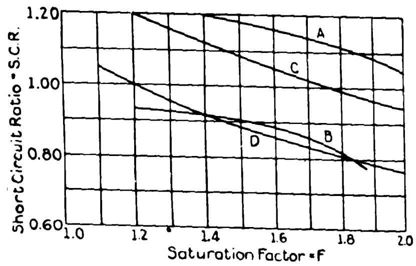

FIG. 14—CURVES FOR RELATION OF SHORT-CIRCUIT RATIO AND SATURATION FACTOR

From Figs. 12 and 13—(See Table I)
A 90-per cent power-factor lag
B 60-per cent power-factor lag

From formula $S\,C\,R = 1.4\sqrt{\frac{\text{Power factor}}{100\,F}}$

C 90-per cent power-factor lag
D 60-per cent power-factor lag

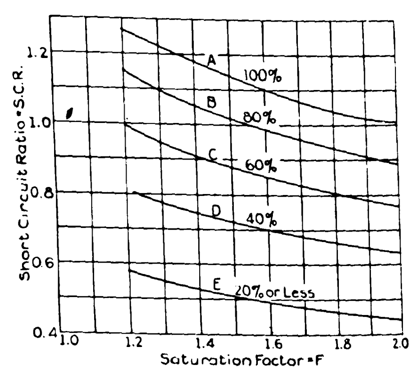

FIG. 15—PROPOSED CURVES FOR MINIMUM VALUE OF SHORT-CIRCUIT RATIO OF ALTERNATORS

A 100 per cent power-factor lag
B 80 per cent power-factor lag
C 60 per cent power-factor lag
D 40 per cent power-factor lag
E 20 per cent power-factor lag

From formula $S\,C\,R = 1.4\sqrt{\frac{\text{Power factor}}{100\,F}}$

The maximum allowable rating for any particular machine is determined by this minimum value of short-circuit ratio.

In Fig. 14, Curves *C* and *D* are derived from tish proposed equation, and a comparison with Curves *A* and *B* shows that for all practical purposes the equation will give the proper values of short-circuit ratio in the usual range of values of saturation factor.

Fig. 15 derived from the equation, covers the entire range of lagging power factors and the usual range of saturation factors. The equation will give results approaching zero as the power factor approaches zero, but since this is obviously impractical, the same values are proposed for power factors of 20 per cent or less. The curve covers lagging power factors only and no attempt is made to work out similar curves for leading power factor, since machines of this class are special and will come within the scope of the design of machines for very long transmission lines.

It will be noted that Fig. 15 gives the proposed minimum value of short-circuit ratio, and it is obvious that any machine with a higher short-circuit ratio will be satisfactory from the standpoint of stability.

Conclusions

Stability of operation of alternator depends on the characteristics of the load as well as on those of the alternator and line.

The minimum allowable value of short-circuit ratio for successful operation is determined by the character of the load, the saturation factor of the alternator, and the power factor. This assumes that the line drop is small enough to be covered by the proposed margin, which will usually be the case with general purpose machines.

When the character of the load is such that the current decreases with voltage, the stability characteristics will not be the determining factor in the selection of the proper value of short-circuit ratio.

The stability characteristics of an alternator for general service, when the load is predominantly motors with practically constant shaft output and line drop is not a serious factor, will be satisfactory with automatic regulation if the short-circuit ratio is not less than that given by Fig. 15.

When the load consists of a few comparatively large motors with swinging load, the proposed curves will give successful operation if the short-circuit ratio at a rating corresponding to the maximum load does not exceed the values indicated by the curves and automatic regulation is used.

Machines designed in accordance with these curves will operate successfully with hand regulation if the increments of load, due to adding more motors, are small enough to prevent excessive drop of voltage before the field rheostats can be adjusted to compensate for the added load.

The proposed values of short-circuit ratio are not applicable to generators for use with very long transmission lines, and the design of these machines is a special problem beyond the field of this paper.

Acknowledgments

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"ELECTRIC LIGHT BED" CURE

Proceeding upon the theory that the dry heat of the sun ever since the creation has been nature's best curative agent and that the light and heat from ordinary electric lamps is the nearest artificial approach to it, Dr. Milton Fairchild of Chevy Chase, just outside of Washington, D. C., has built a long box in which are seven or eight house lamps. It is suspended over his bed by sash cord and window weights and can be drawn down over him leaving only his head protruding after he has turned in for the night. By a rheostat he can adjust the lamps to produce just the right degree of heat. He says it is a great success and that anybody can make one. Already 30 doctors of the Washington district agree with him.

ELECTRIC SHOVEL DIGS BACK TO DEVONIAN AGE

For generations fossil hunting has been a back-breaking process of laboriously picking and shoveling remains of prehistoric fauna out of rock and clay 'way out in a sun-baked desert. Today a huge electric shovel excavated fossilized fishes which lived in the Devonian period. It is doing this in a suburban region that some day will be overgrown by Cleveland and will be rendered forbidden ground for the excavations of paleontologists. The shovel is digging up geologic information by the ton, its electric power having removed all back-break from the process.

Vibration Recorder

For Electrically Measuring and Recording Small Mechanical Movements

BY A. V. MERSHON*

Associate, A. I. E. E.

General Description

THE vibration recorder was first designed to measure vibrations of rotating turbine wheels and the whipping of rotating shafts. The development of this instrument was necessary because ordinary hand micrometers or indicating devices could not be applied to the moving parts due to their inaccessible location.

Most of the parts in a steam turbine are made of iron or steel; therefore, the fundamental thought was to make use of magnetic flux changes to detect these vibrations. A bridge circuit was constructed having a test coil and a transformer coil as one arm, and a dummy coil and a duplicate transformer coil as the other arm. The dummy coil has an iron core with an adjustable air-gap, and the test coil has an iron core the air-gap of which varies with the vibration or motion to be recorded. Any unbalance of the magnetomotive forces produced by the currents in the two transformer windings gives a flux, which produces a voltage on a third winding connected directly to an oscillograph vibrator. An alternating current of approximately 500 cycles is used to excite this circuit.

The voltage of the internal or test coil is balanced against the external or dummy coil to obtain the greatest sensitivity. For convenience in balancing the voltages of these two coils a transformer was constructed with two windings so arranged that the currents in the two windings oppose one another. A third winding was constructed on this transformer to pick up any differences in the voltages of these two coils. The current of the third transformer winding is calibrated to measure the vibrations, in thousandths of an inch, that take place in front of the core of the test coil.

Fig. 1 shows a graphic representation of the currents in the differential three-winding transformer. When the circuit is balanced the primary currents I_2 and I_3 are equal and 180 electrical degrees out of phase. This produces zero flux in the transformer core. If the air-gap in front of one of the coils is changed, it will unbalance the circuits: I_2 will differ from I_3 as shown in the figure and a flux will be set up in the differential transformer core. The flux in the differential transformer core will generate a voltage in the secondary winding No. 1 of the differential transformer, and produce current I_1 in the oscillograph vibrator circuit. The unbalanced currents may not be exactly 180 electrical degrees out of phase with one another, as shown in the figure, as most of the unbalanced condition is due to the change in the inductive reactance of the circuit. This phase variation does not cause errors, as the same variation occurs during calibration.

In each branch of the vibration-recorder circuit there is a variable inductor, a three-dial resistor with steps of 0.1, 1.0 and 10.0 ohms respectively, a coil and a winding of a transformer, all connected in series. The two branches of the electric micrometer circuit are exact duplicates. The connections are shown in the wiring diagram, Fig. 2. Resistances R_1 and R_2 and inductances L_1 and L_2 are secondary parts of the circuit. Their function is to keep the resistance components and the inductive components of the two arms of the electric micrometer exactly equal so that the currents in each half of the circuit will have the same magnitude and the same phase displacement from the impressed e. m. f.

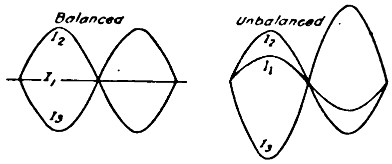

Fig. 1—Graphic Representation of the 500-Cycle Currents in the Differential Three Winding Transformer

Applications. Vibrations as small as five or ten thousandths of an inch have been measured on the periphery of a turbine wheel rotating at 1800 rev. per min. in a steel casing. This was done with the coils exposed to the steam heat and the moisture of the turbine. The whipping of rotating shafts has also been measured. The two above applications were made with an open type coil holder (without a magnetic diaphragm.) Transient oil pressure due to an explosion produced by opening a high-voltage switch in a sealed vessel have been measured with a magnetic diaphragm type of coil holder.

Investigations of the mechanical motions in various kinds of apparatus require changes in the size of the coils and the design of the coil holders. In the majority of investigations coils one inch in diameter by three-quarters of an inch deep have been found satisfactory. The number of turns required varies widely from 500 to 1500. An iron core one-half of an inch in diameter is generally used. The two coil holders in all cases should be built exactly alike so that the dummy coil and the test

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Complete copies containing Bibliography here omitted are available upon application.

coil will have the same magnetic characteristics and the same eddy-current. This will give a rough balance when the air-gaps of the two coils are the same.

A magnetic diaphragm is required in front of the test coil and dummy coil when transient pressures of gases or liquids are being investigated. The diaphragm must be suitably built as a part of the coil holder. In a case where a direct mechanical vibration is produced in a piece of apparatus the coil does not require a diaphragm in front of it. The front of the coil

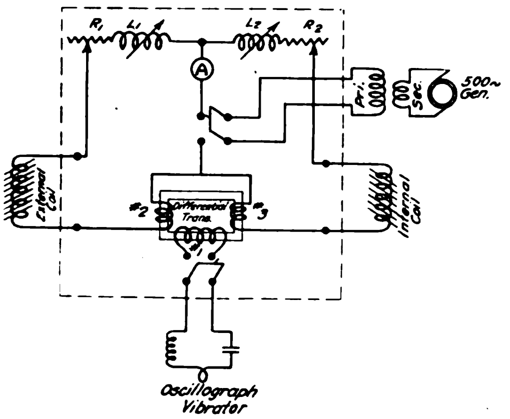

FIG. 2—CONNECTION DIAGRAM FOR THE VIBRATION RECORDER

is placed directly opposite a magnetic piece of material which may or may not be a part of the apparatus being tested. The coil is placed so that there is an air-gap between it and the piece of magnetic material in front of it. Any changes in distance between the magnetic material and the coil can be measured by the change in strength of the magnetic field at various air-gaps.

Sensitivity. Changes in the air gap between the core and the magnetic material of one-thousandth of an inch will produce a deflection on the oscillograph vibrator of from two to five millimeters. The amplitude of the vibration of the apparatus under test is magnified on the oscillograph vibrator 150 times. This magnification ratio is shown in Table I which gives the calibration of the vibration recorder. A magnification of 106 is obtained for small variations in the air-gap, but for larger variations, the magnification is 201.

Accuracy. The vibration recorder will measure accurately any small mechanical movements transient in nature, produced in a piece of apparatus. If this movement is 0.005 in. or greater, an accuracy of five per cent can be obtained.

INSTRUMENT DESCRIPTION AND CONNECTIONS TO AUXILIARY APPARATUS

Fig. 3 shows the vibration recorder as it is developed in instrument form. The two halves of the instrument are practically identical. It is approximately 25 in. long, 18 in. wide and 8 in. high. The ammeter shown in the middle is a standard G. E. type P3. The vibration recorder itself is portable although the oscillograph equipment including the 500-cycle generator is usually not constructed with this point in view.

A one-kw., 500-cycle, 110-volt generator is connected externally through a transformer to the upper left hand terminals marked "500-cycle generator." The oscillograph vibrator circuit is also connected externally to the upper right hand terminals marked "Oscillograph Vibrator." In series with the vibrator in this circuit is an inductance coil and a condenser which is set in dull resonance for 500 cycles. Tuning the oscillograph vibrator circuit accomplishes two results; it reduces the impedance to approximately four ohms effective resistance and likewise keeps down all the harmonics in the 500-cycle wave.

Before the oscillograph vibrator circuit is tuned it is very difficult to produce a balanced condition on account of the harmonics interfering. When it is tuned the harmonics disappear and the circuit can easily be balanced so that the zero line on the oscillograph including all the residual deflection is not more than two millimeters wide. The circuit is balanced roughly by setting the air-gap of the external coil approximately the same as that of the internal coil. A fine balance is obtained by moving the dial resistors and the dial inductors until a satisfactory balance is obtained as indicated on the oscillograph vibrator.

CALIBRATION

The internal or test coil is used to obtain a voltage variation due to the vibration to be measured. The external coil is a dummy coil and its function in the circuit is to furnish a voltage to balance the voltage of the internal coil. The voltage of the external coil is of

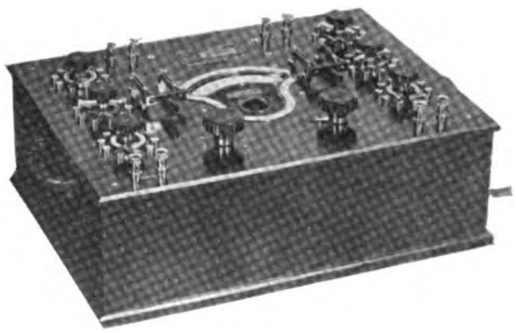

FIG. 3—THE VIBRATION RECORDER
Used to measure transient pressures and mechanical vibrations

a specified value assumed as a zero from which to measure the amplitude of vibration.

When a calibration is started the air-gap in front of the external coil must be set approximately the same as that of the internal coil. The air-gap of the external coil is very seldom changed during the test after the balance is once obtained. The apparatus under test furnishes the internal coil with a varying air-gap corresponding to the vibration that we wish to measure. The variations in the air-gap will be recorded by de-

flections shown on the ground glass of the oscillograph, as illustrated on the calibration curves shown in Figs. 4 and 5. Curves were taken by varying the air-gap of the internal coil while holding constant that of the external coil.

Fig. 4 shows calibration curves for the internal coil for four air-gap settings of the external coil. The air-gap settings should be chosen to correspond with the nature of the test. In order to obtain calibration curve marked "50 mils" the external coil was kept at this

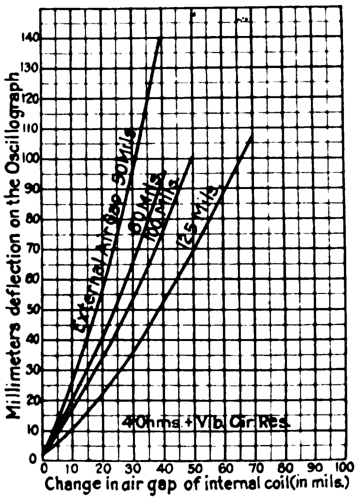

FIG. 4—CALIBRATION CURVES FOR THE VIBRATION-RECORDER CIRCUIT

Showing the effects of various air-gaps between the test coil and the piece of apparatus being investigated

constant air-gap and the air-gap of the internal coil was changed. Readings were taken on the oscillograph of the width in millimeters of the bright band produced by the 500-cycle wave and measurements were taken with a suitable thickness gage, in thousandths of an inch, of the corresponding air-gap in front of the internal coil. In adjusting this air-gap either the internal coil or the piece of apparatus under test may be moved.

The sensitivity of the instrument is best, for changes of five or ten-thousandths of an inch, when the width of the bright band during calibration at the smaller lengths of air-gap of the internal coil is greater than the width of the scale of the oscillograph. The total width that can be measured on the ground glass with the zero in the center of the oscillograph scale is approximately 100 mm. For deflections greater than 100 mm., the oscillograph zero is transferred to one side of the scale and the measurement is made from zero to the maximum deflection. In this case the value obtained by measurement is doubled in order to put the results on the same basis as the smaller deflections obtained with the zero in the center of the scale. The upper points of the curves and the tabulations are made on the basis of the full (or "double") deflection.

Fig. 5 shows the deflection obtained on the oscillograph vibrator using different resistances in series with

TABLE I

Calibration of Vibration Recorder for .050 in.
(This data is not plotted on a curve)

Mils or thousandths of an inch external coil	Mils or thousandths of an inch internal coil	Millimeters deflection on the oscillograph ground glass or film	Magnification ratio
0.050 in.	0.050 in.	2. mm.	....
0.050 in.	0.040 in.	29. mm.	106.
0.050 in.	0.030 in.	61. mm.	126.
0.050 in.	0.020 in.	102. mm.	161.
0.050 in.	0.010 in.	149. mm.	185.
0.050 in.	0.000 in.	200. mm.	201.

the vibrator. These curves are shown to bring out the importance of reducing the impedance of the oscillograph vibrator circuit to a minimum by the use of the 500-cycle dull resonant vibrator circuit.

The curve marked "Decreasing Air-gap 4 ohms," was taken by setting the air-gap of both coils at 100-thousandths of an inch and decreasing the air-gap of the internal coil by successive steps. From the increasing curve and the decreasing curve it can be seen that the circuit is unbalanced when the air-gap is changed either way from 100-thousandths of an inch.

Stability of the Circuit

The stability of the electric micrometer is good because the calibration is not affected by slight voltage and frequency fluctuations of the 500-cycle generator. Changes in frequency of $\pm$ 50 cycles will affect the

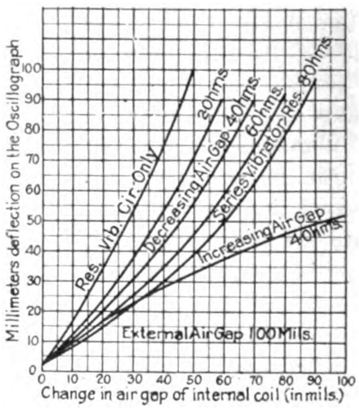

FIG. 5—CALIBRATION CURVES FOR THE VIBRATOR-RECORDER CIRCUIT

Showing the effects of changing the resistance in the oscillograph vibrator circuit

calibration as the iron losses change and the oscillograph vibrator circuit will not be in resonance.

The stability of the circuit is not disturbed seriously due to the internal coil heating up more than the external coil as this uneven heating can be compensated for by changing R_1 and R_2 at any time during the test. Adding 20 ohms to R_1 and 20 ohms to R_2 will not change the original calibration. The best results are obtained if the electric micrometer circuit and the oscillograph galvanometer field are allowed to heat up about one-half of an hour before using.

Tests Results Shown on Oscillograms

Fig. 6 shows a decaying mechanical oscillation of 36 cycles per second which was taken for illustrative purposes only. This oscillation was produced by a vibrating reed clamped to an iron support. Position marked *A* shows the reed pulled over and held 0.044 in. from rest towards the internal or test coil. The reed was first set at 0.125 in. in its rest position. The calibration curve for this film is shown on Fig. 4. Position *B* shows the first cycle after the reed was released and allowed to swing free. The first swing did not return entirely to its original position of 0.044 in. and it, therefore, returned to a position of 0.039 in. representing a total swing of 0.078 in. Position *E* likewise represents a mechanical deflection of 0.036 in. one-half amplitude of the reed. Position *F* represents 0.023 in. one-half amplitude and it is the 12th swing of the reed towards the internal coil which occurred approximately one-third of a second after the reed was released.

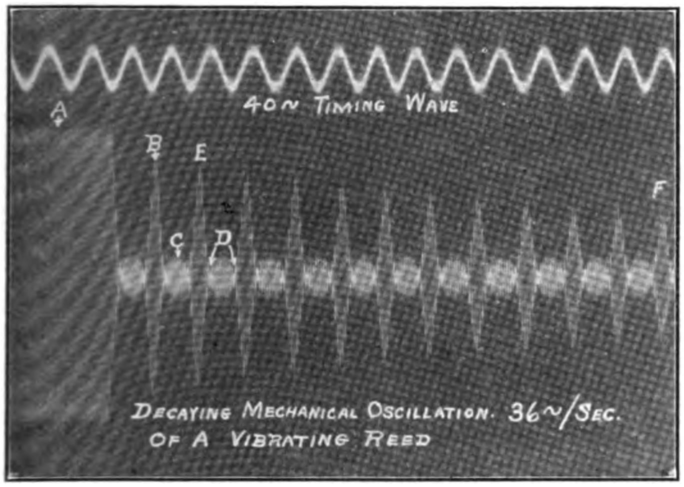

Fig. 6—Oscillogram Showing a Simple Mechanical Oscillation Produced by a Vibrating Reed

Position *B* represents the reed at its nearest position to the internal coil after release and position *C* represents the reed at its greatest distance away from the internal coil in the cycle of which *B* is the beginning. Position *D* represents the reed passing through its rest position or the balanced positions for the electric micrometer circuit. Any simple natural vibrating mass passes through its rest position twice in making a complete cycle.

Fig. 7 is a record of a vibration of an eight-foot diameter turbine wheel rotating 1280 rev. per min. and vibrating 0.024 in. in six segments or nodes around the periphery. The internal or test coil was held in a bracket fastened to a stiff wheel which rotated at the same speed and on the same shaft as the wheel under test. (See Fig. 8) The stiff wheel ran rigidly at all speeds for which wheels are ordinarily tested and had known vibration characteristics at speeds much higher than that of the wheel being tested. Positions marked with an arrow show every revolution of the wheel. In one revolution there are six different positions shown. These correspond to segments between the six nodes or rest positions of the vibrating wheel. Positions 1, 3, and 5 represent negative segments, or wheel displacements from rest, away from the internal coil. Positions 2, 4 and 6 represent positive segments, or vibration from rest, towards the internal coil.

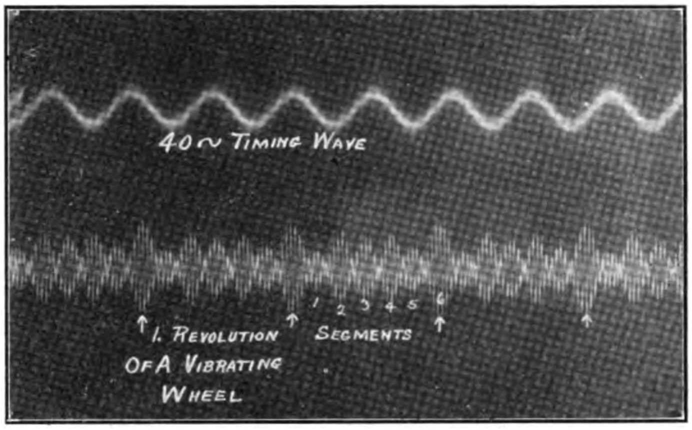

Fig. 7—A Record of a Vibration of an 8-Ft. Diameter Turbine Wheel

Rotating 1280 rev. per min. and vibrating 0.024 in. in six segments around the periphery

The deflections under the arrows are larger than the other five intermediate deflections: The reason for this is that the turbine wheel received a slight end thrust or quiver every revolution. This is likewise shown in producing a smaller deflection next to the largest deflection. This quiver in the wheel for every revolution represents approximately two-thousandths of an inch variation. These total deflections are actual measurements of mechanical movements of 0.012 in.

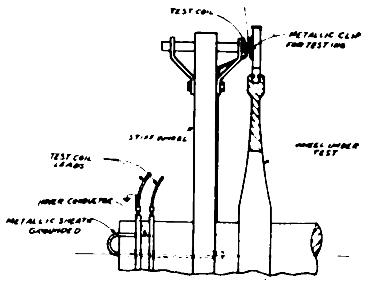

Fig. 8—Arrangement of Test Coil and Holder for Vibration Measurements on a Turbine Wheel

or one-half the total amplitude of the vibration of the wheel. The total amplitude of the vibration of the wheel is 0.024 in. The reason this deflection, shown on the oscillogram Fig. 7, represents one-half the total amplitude of the vibration is that the calibration was taken while the wheel was moved from rest towards the coil. Deflections away from rest do not require a calibration. The mechanical deflections of the wheel on both sides of the rest position are the same.

Abridgment of

The Mechanism of Breakdown of Dielectrics

BY P. L. HOOVER[1]

Associate, A. I. E. E.

Synopsis.—*In attempting to analyze various experimental data that have been obtained in researches on dielectric phenomena in high-voltage cable insulation and other dielectrics, the various existing theories of dielectric behavior have seemed inadequate. A critical study has therefore been made of these theories in an attempt to obtain a working hypothesis that more nearly meets the stringent requirements of experimental facts.*

The logarithmic formula is shown to give erroneous results if applied to high-voltage cables when they are operating under high stress. The gradient in a cable must be calculated from the volt-ampere characteristic of the dielectric when stresses above the elastic limit are used. For stresses below the elastic limit it makes no difference which method is used, but at high stresses an entirely different gradient distribution is obtained when calculated from the volt-ampere characteristic.

Likewise, when an insulation is operated above the elastic limit the stress ceases to be a critical factor, but the strain is of utmost importance. In comparing cables that are operating under high voltages, therefore, the strain at the core should be considered rather than the stress at the core. Stress is given by the voltage gradient and strain by the polarization or the current density in the dielectric.

Since there is always a conduction current flowing, there must be mobile or free ions present. It is assumed that these free ions or electrons come from the molecules of the dielectric and that the number that are present depends on a condition of equilibrium existing between the molecules and the free ions. There exists then a state of kinetic equilibrium between the molecules and the free or mobile ions. Any change in external or internal conditions will disturb the equilibrium and thus change the electrical behavior of the dielectric. Thermal effects and corona effects are accounted for on this basis.

Breakdown occurs when the equilibrium conditions are so disturbed that the insulation as a whole becomes unstable, electrically. High stress or strain and high temperature affect the conditions of equilibrium decidedly.

Corona in gases, oils, and solids consists of minute disruptive discharges that are initiated by rapid changes in equilibrium conditions when the dielectric is overstressed. In solids, however, where the ion mobility is very low and the ion friction high, there will not in general be a corona effect observed because there can be no rapid readjustment of equilibrium conditions. If the insulation is not homogeneous, or if it is composite, there will likely be internal discharges, a corona effect, when the weaker dielectric is overstressed. Moreover, since the molecules of a solid can not readjust themselves quickly to the new conditions of equilibrium imposed by a high voltage suddenly applied, there will be high local stresses and strains set up which may result in mechanical deterioration of the dielectric, that is, chipping or cracking of the dielectric.

Breakdown, therefore, will take place when the insulation is rendered unstable by disturbing the equilibrium conditions, regardless of whether it is due to mechanical strains, electrical strains, or to thermal effects. The tri-fold nature of the phenomenon must be considered in the complete analysis of the problem.

Introduction

The mechanism of breakdown of dielectrics is of the highest importance and yet at the present time it is very little understood. It is the purpose of this paper to discuss and to extend some of the theories of breakdown which have been presented heretofore.

The mechanism of breakdown of single-conductor cables has a particular interest, since the geometry is comparatively simple and it is possible to overstress parts of the insulation without complete rupture taking place. That is, if the gradient is calculated by means of the well-known logarithmic formula for a cable with a ratio of outer to inner radius greater than the Naperian base e and for a voltage near the breakdown value, it is found that the inner layers of insulation are operating at gradients considerably higher than any that the insulation would stand if it were made up in flat sheets. This same effect is brought about whenever a dielectric is in a non-uniform field, although, in general, it is not possible to derive a simple mathematical formula for the gradient distribution of a complex field.

There is, however, considerable justification for skepticism regarding the possibility of overstressed insulation, that is, regarding the validity of the logarithmic formula when used for calculating gradients when the insulation is stressed beyond the elastic limit. In using the logarithmic formula for calculating gradients, it is tacitly assumed that the dielectric has the same electrical constants at and beyond breakdown that it has at low gradients. Reasoning by analogy from other physical phenomena, we should not expect this to be the case; in fact, we would expect new laws to enter as soon as the elastic limit of the material is exceeded. For example, Hooke's law is used in determining the stress distribution in beams and supports of all kinds as long as the elastic limit is not exceeded but beyond the elastic limit Hooke's law does not hold and cannot be used.

Historical Review

To account for these phenomena of overstressed insulation, various theories have been proposed, such as the maximum stress theory, the average stress theory, Fernie's[2] minimum stress theory, Russell's[3] theory, and Osborne's[4] theory. These theories, and in partic-

1. Research Fellow, The Harvard Engineering School.

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2. F. Fernie, Insulating Materials, *Beama*, 1920, p. 244.

3. A. Russell, *Dielectric Strength of Insulating Materials and the Gradient of Cables*, Journal of A. I. E. E., Vol. 40, p. 6, 1907.

4. H. S. Osborne, *Potential Stresses in Dielectrics*, Journal of the A. I. E. E., Vol. 29, p. 1553, 1910.

ular the minimum stress theory, have been discussed at length by Simons[5] and will not be considered in detail in this paper.

Differing substantially from these theories just mentioned is the pyroelectric or thermal theory of breakdown as developed by Wagner[6] and by Hayden and Steinmetz.[7]

The pyroelectric theory assumes that solid insulators have volt-ampere characteristics similar to those shown in Fig. 1, and that this type of characteristic is due solely to the high negative temperature coefficient of resistance of the material.

The question arises, however, as to whether or not this type of volt-ampere characteristic is entirely the result of a high negative temperature coefficient of resistance. Might it not be due, at least in part, to change in resistivity with current density due to some molecular phenomenon? In any case, breakdown will occur when $d E / d I = 0$, for at this point the current will increase to the short-circuit value of the supply.

Günther-Schulze[8] has made a study of the phenomena of dielectric breakdown and states that different definitions of dielectric strength may be given according to the way in which the problem is approached. To quote from his paper:

"Accordingly, the dielectric strength is the lowest potential gradient at which the current through the dielectric is replaced by an independent discharge which is self-increasing. (a spark)." (*Translated*) This gives what Günther-Schulze calls the dielectric impact strength (Stossfestigkeit).

As a second point of view, he gives the following: "These considerations result in the following definition of the dielectric strength: the dielectric strength of a dielectric is the lowest potential gradient at which the bonds between the charges in a dielectric are severed so that a discharge passes through the dielectric." (*Translated*) This he calls the dielectric tensile strength (Reissfestigkeit).

Günther-Schulze then considers various data and concludes or assumes that breakdown in liquids is really a gas discharge in disguise. He states:

"Thus, if an increasing field is applied to the liquid dielectric, the velocity of the ions in the field will increase. But this again means an increased ion friction and an increased heating of those parts of the dielectric that surround the path of the ion. If the increasing field is continued, the heating finally becomes so great that the ions leave an extremely minute, sub-microscopic vapor track in the dielectric. If an ion comes into this vapor track, it is capable of producing new ions through collision, thus initiating the spark discharge, provided the potential drop along the path of the ion is sufficiently high." (*Translated*)

For solid dielectrics he states that the phenomena are somewhat similar. The extremely high ionic friction causes heating effects that result eventually in breakdown. It is, then, the dielectric impact strength that determines the stability of the insulation, the dielectric tensile strength playing a relatively insignificant part in breakdown phenomena.

Thus, dielectric breakdown, according to Günther-Schulze, is a pyroelectric effect. The concept of dielectric impact strength, as he describes it, is only a physical picture, in terms of ions and atoms, of the pyroelectric theory of breakdown.

The concept of dielectric tensile strength, however, should not be thrown aside so hastily. A further consideration of essentially this same idea, but modified considerably and from a different point of view, leads to some very interesting conclusions and results.

Theoretical Considerations

As was first pointed out by Maxwell, the total current in a dielectric consists of the polarization current and the conduction current, the two currents being super-imposed. Is it not possible that there is some relation between them since they are contemporaneous phenomena?

At low gradients there is always a current flowing and this current is due to moving ions or electrons. There is also a certain polarization of the dielectric. At higher gradients the polarization increases and so does the conduction current. That is, the number of mobile charges increases with the degree of polarization of the dielectric. This suggests that the mobile ions must come from the molecules of the dielectric. If this is the case, there must exist a state of equilibrium, a kinetic equilibrium, between the mobile or free ions and the molecules of the dielectric. Increasing voltage gradient would increase the polarization and establish new conditions of equilibrium, the tendency being to increase the number of free ions and thus increase the conductivity of the dielectric. Ultimately a gradient will be reached where the number of ions required to establish the equilibrium will be so great that the molecular bonds will be destroyed and dynamic rupture of the insulation will take place.

The idea of assuming molecular dissociation at comparatively low-voltage gradients may seem rather bold at first sight, but a little thought will show that it does not demand any radical departure from the already well established theories of molecular behavior. In the first place, with liquids, and especially with solids, the inter-molecular fields are quite as important as the intra-molecular fields. The great tensile strength

5. D. M. Simons, *On the Minimum Stress Theory of Cable Breakdowns*, Journal of the A. I. E. E., Vol. 41, p. 557, 1922.

6. K. W. Wagner, *The Physical Nature of the Electrical Breakdown of Solid Dielectrics*, Journal of the A. I. E. E., Vol. 41, p. 288, 1922.

7. J. L. R. Hayden and C. P. Steinmetz, Insulation Failure—A Pyroelectric Effect, *Electrical World*, October 1922, p. 865.

8. A. Günther-Schulze, The Dielectric Strength of Liquids and Solids, *Jahrbuch der Radioaktivität und Elektronik*, *1922*, Vol. 19, p. 92.

of solids can only be explained on the basis of strong inter-molecular fields. Any change in the molecular structure of a solid produces corresponding changes in all of its physical properties due to the changes in the inter-molecular fields. Consequently it must be assumed that, in solids at least, the electrons in the atom are influenced not only by their own nuclei but also by the fields of the neighboring atoms or molecules. Under such conditions it is probable that the atoms can be ionized; that is, an electron can be removed with much weaker external fields than would be necessary if the atom were isolated in space.

Furthermore, molecular theory demands that the molecules be in motion except at absolute zero, so that any theory dealing with molecular behavior must necessarily be a kinetic theory. With these ideas in mind, it is easy to picture an electron in a dielectric moving about with its nucleus, but also under the influence of the strong inter-molecular fields.

For low gradients, the number of ions drifting, that is the magnitude of the conduction current, will be proportional to the gradient. At higher gradients, as the polarization of the molecules increases, the molecular bonds will become weaker and weaker and the number of electrons which are drifting will increase more rapidly than the gradient increases, and there will be an increase in the conductivity of the dielectric. At some critical gradient the molecular bonds will be entirely broken and dynamic rupture will take place. The phenomenon throughout is essentially that of a kinetic equilibrium between the free or drifting electrons and ions and the polarized molecules of the dielectric.

On the basis of these ideas, the volt-ampere characteristic would have the form of the curves of Fig. 1. Curve A is from some experimental data of Wagner[9] on oiled paper, while Curve B is an empirical curve made to fit Curve A as nearly as possible in order that some numerical computations could be made. The equation of Curve B is

$$e = \frac{175\, i}{1 + 0.1\, i^2} \qquad (1)$$

where e is kv. per cm.
and i is milliamperes per sq. cm.

Referring to Curve B of Fig. 1, it is seen that at low-current densities, *i. e.*, when $0.1\, i^2$ is negligible in comparison to unity, the current is proportional to the voltage. At higher current densities, the current increases faster than the voltage and the curve takes the form shown. The equilibrium conditions are perfectly stable up to the maximum point of the characteristic, at which point rupture occurs. If some means be taken to prevent an excessive current, however, it is possible to maintain stable equilibrium in the dielectric even though it be operated beyond the maximum point of the volt-ampere characteristic. By using a high-resistance, mosaic electrode, Wagner was able to determine experimentally the Curve A of Fig. 1.

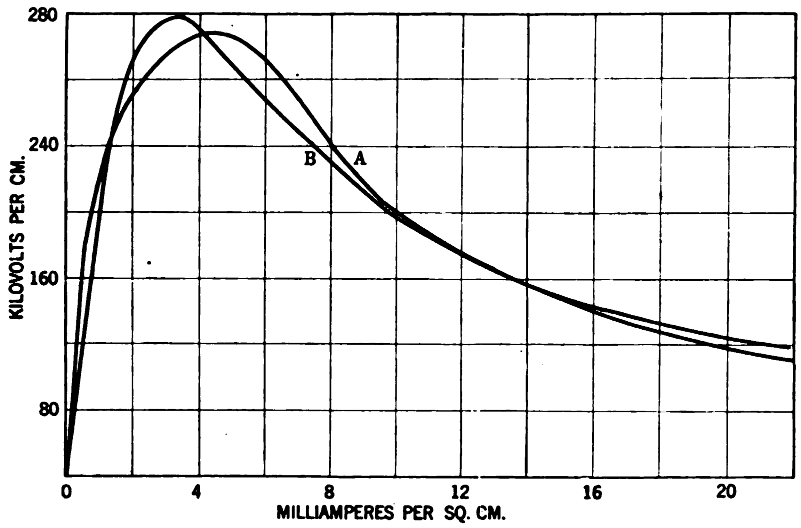

FIG. 1—VOLT-AMPERE CHARACTERISTICS
A. From data of Wagner (Oiled Paper)
B. $e = \frac{175\, i}{1 - 0.1\, i^2}$

CABLE BREAKDOWN

If a cable is constructed of an insulating material having a volt-ampere characteristic similar to those of Fig. 1, it follows that at low current densities the current will be proportional to the voltage. At higher current densities and voltages, when the inner layers begin to be overstressed, the current through these layers will begin to increase more rapidly than the voltage across

9. K. W. Wagner, Loc. Cit. See also Electric Cables, by W. A. Del Mar, p. 79.

these layers. Ultimately, the inner layers will be operating at a point beyond the maximum of the volt-ampere characteristic, but the outer layers, not being overstressed, will prevent complete rupture of the cable.

The possibility of such an analysis by means of the volt-ampere characteristic was recognized and suggested by Peaslee.[10] It is the purpose of the remainder of this paper to carry the analysis still further and to compare the results with certain experimental data.

In the appendix of the complete paper it is shown that the voltage across a cable made from a material with a volt-ampere characteristic given by equation (1), Curve B of Fig. 1, will be

$$E = \frac{175\, I}{4\,\pi} \operatorname{Log}\left(\frac{0.1\, I^2 + 4\,\pi^2 R^2}{0.1\, I^2 + 4\,\pi^2 r^2}\right) \tag{2}$$

Where

E = Total voltage in kv.

I = Milliamperes per cm. length of cable

R = Outer or sheath radius (cm.)

r = Inner or conductor radius (cm.)

$$\operatorname{Log}\left(\frac{0.1\, I^2 + 4\,\pi^2 R^2}{0.1\, I^2 + 4\,\pi^2 r^2}\right)$$

$$= \frac{0.8\,\pi^2 I^2 (R^2 - r^2)}{(0.1\, I^2 + 4\,\pi^2 R^2)\ (0.1\, I^2 + 4\,\pi^2 r^2)} \tag{3}$$

From equations (2) and (3), the puncture voltage of the various cables can be calculated. Fig. 3 shows curves of puncture voltage plotted as a function of the ration r/R and obtained in this way. Curve A is for cables with a constant-conductor radius of 0.158 cm.; Curve B is for cables with a constant sheath radius of 5.03 cm.; and Curve C is for cables with a constant insulation thickness of one cm.

In Fig. 4 are curves plotted from data obtained experimentally by various observers. Curves A and B resemble the A and B curves of Fig. 3. Curves B' and B'' resemble B of Fig. 3, except for the tendency to droop at small values of r/R. The five points in the center of the plot, numbered 1, 2, 3, 4, and 5, are from data by Fernie and correspond to a constant insulation thickness. The points are so erratic in their positions that no representative curve can be drawn.

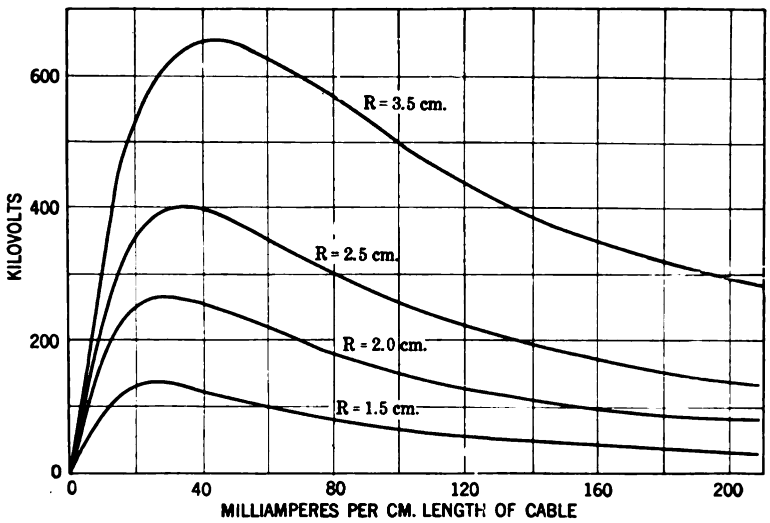

Fig. 2—Volt-Ampere Characteristics for Cables
Inner radius 1 cm.

From equation (2), the volt-ampere characteristics of cables of this material can be plotted. Fig. 2 gives the volt-ampere characteristics for cables of inner radius of one cm. and with various outer radii. These characteristics have the same general shape as those of Fig. 1. This, of course, is to be expected, and it is seen that the cable insulation as a whole increases in conductivity as the current increases. The insulation, however, remains stable regardless of the stress relations in the inner layers until the maximum point of the particular cable characteristic is reached. This point can be found by setting the derivative of equation (2) equal to zero, or,

10. W. D. A. Peaslee, Discussion, Journal of the A. I. E. E., Vol. 41, p. 620, 1922.

They indicate, however, a rough agreement with Curve C of Fig. 3.

These experimental checks are hardly sufficient to establish the theory as developed positively, but the agreement is certainly sufficiently good to warrant further study.

It is of interest to investigate the question of voltage gradient in various parts of the cable insulation on the basis of this theory. The gradient is given by

$$e = \frac{2\,\pi\, 175\, r\, I}{4\,\pi^2 r^2 + 0.1\, I^2} \tag{4}$$

(See appendix of complete paper.)

Fig. 5 gives the gradients in kv. per cm. at various distances from the axis for two cables, when the im-

pressed voltage is equal to the breakdown voltage. It is seen that the maximum gradient is at some point near the center of the wall of insulation and is not at the surface of the conductor, as is ordinarily assumed. In fact, the gradient at the conductor is less than that at any other point in the insulation.

To emphasize this point and to show the change in gradient distribution with increasing voltage, the curves of Fig. 6 are given. It is seen that, for low voltages, the maximum gradient is located at the core and that the gradient practically follows the logarithmic law. At higher voltages, and hence higher current densities, the gradient departs from the logarithmic law and has the form shown by the curves. It is seen that the gradient never exceeds a certain definite maximum. This maximum value is determined by the volt-ampere characteristic, Fig. 1, and for the case illustrated is 178 kv. per cm. The position of this point of maximum gradient moves gradually from the surface of the conductor towards the sheath, but puncture occurs before the sheath is reached.

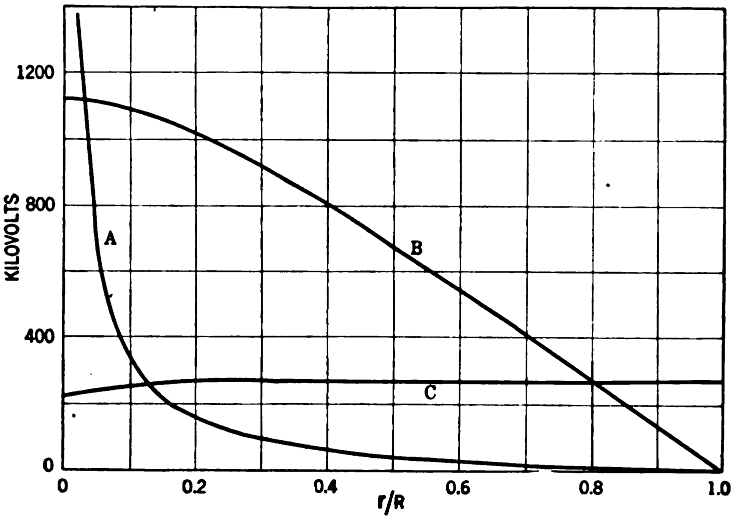

FIG. 3—PUNCTURE VOLTAGE OF SINGLE-CONDUCTOR CABLE VS. r/R

A. r = Constant
B. R = Constant
C. $R - r$ = Constant

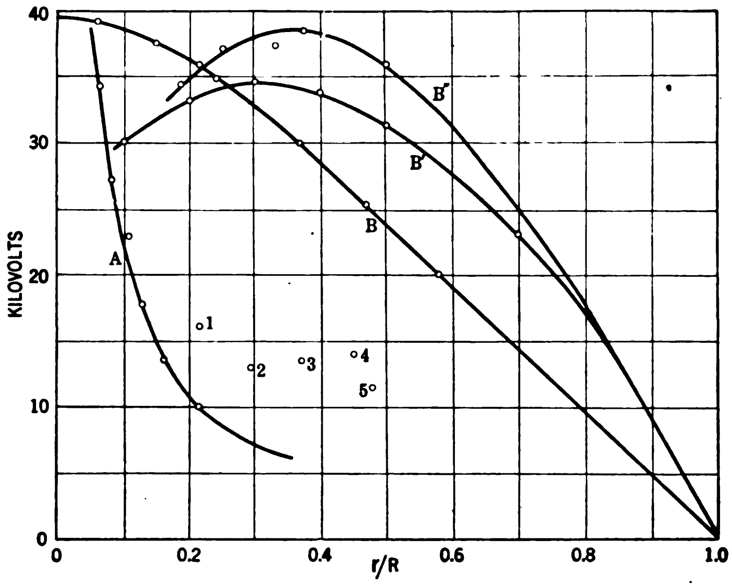

FIG. 4—PUNCTURE VOLTAGE VS. r/R

A, B and B' from Middleton, Dawes and Davis; B'' from Wiseman. Points 1, 2, 3, 4, and 5 from Fernie. (Multiply ordinates by 10 for Fernie's data.)

It is important at this time to investigate the stress-strain relations in the dielectric. It seems evident that stress is given by the voltage gradient and strain by the polarization or probably by the current density. We have then the stress proportional to the strain for low stresses, but for higher stresses the strain increases faster than the stress. Finally, the ultimate strength is

exceeded and the strain increases indefinitely even with a decrease in stress. The analogy with the stress-strain relations of mechanics is obvious, the only difference being that the elastic limit and the ultimate strength in dielectrics are probably not as definite as they are in mechanics.

The elastic limit may therefore be defined as in mechanics as that stress at which the stress-strain diagram begins to deviate from a straight line, the ultimate strength likewise being defined as the stress at the maximum point of the stress-strain diagram. The stress-strain diagram of a dielectric is its volt-ampere characteristic.

From the foregoing it appears that in cables operating

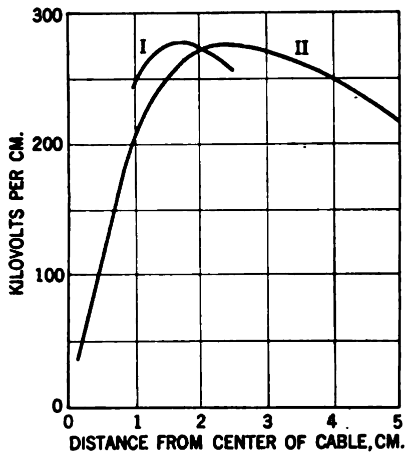

FIG. 5—GRADIENT DISTRIBUTION IN SINGLE-CONDUCTOR CABLES AT THE BREAKDOWN VOLTAGE

I $r = 1.0$ cm.
$R = 2.5$ cm.
II $r = 0.16$ cm.
$R = 5.03$ cm.

at high stresses, the logarithmic formula fails completely to give the correct gradient distribution. Furthermore, it seems that stress or voltage gradient is not the best criterion to use in judging the quality of various insulations when they are operating beyond the elastic limit. Strain is obviously the factor that is of utmost importance when once the elastic limit is passed. Consequently, in comparing various cable insulations, the strain at the core should be used rather than the stress at the core, the strain being given by the current density. This concept is thought to be very important.

There is, however, when alternating currents are used, some question as to whether the total current or simply the in-phase current should be used to determine the strain. The polarization of the dielectric determines the quadrature current and the conductivity and energy loss determine the in-phase current. So long as both of these two components increase uniformly with the stress, the total current will increase uniformly with stress. As soon as one of the components begins to deviate from a linear relation, however, the total current will correspondingly deviate from a linear relation with stress. Furthermore, if a stress is reached where either component of the current increases indefinitely with no further increase of stress, then the total current must likewise increase indefinitely. Consequently it seems immaterial whether the total current or simply the in-phase current is used in determining the strain in the dielectric and it is not evident at this time which of the two will give the best indication of the true strain in the dielectric.

The one outstanding effect that has not been explained is the drooping of the curves B' and B'' in Fig. 4. In these two cases, the sheath radius was kept constant and the conductor was made of smaller and smaller radius. There seems to be a point where further decrease of conductor radius not only fails to increase the puncture voltage but actually diminishes it. It hardly seems possible that an increase in insulation thickness should decrease the breakdown voltage, but such seems to be the case so far as these particular data are concerned.

Osborne's[11] theory explains this effect by assuming ". . . that a solid dielectric, when overstressed, is not disrupted uniformly, but that the material is affected as though it had been pricked by a number of needlepoints."

The ends of these needlepoint ruptures then become points of very high stress and therefore cause rupture of the entire dielectric. Considerable evidence exists supporting the needlepoint theory but little is known as to the origin, nature, and effects of these needlepoint ruptures. Their general character would suggest a high frequency discharge and this suggestion seems to be borne out by further analysis.

Much has been written on corona in oils and in

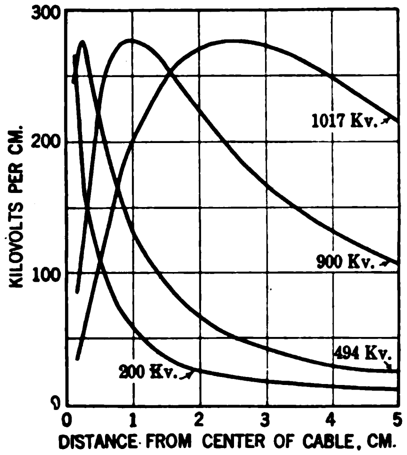

FIG. 6—GRADIENT DISTRIBUTION IN SINGLE-CONDUCTOR CABLE

Breakdown voltage = 1017 kv.
$r = 0.16$ cm. $R = 5.03$ cm.

solids, but there is still cause for considerable speculation as to the fundamental nature of the phenomenon. It probably is a high-frequency rupture. An experimental arrangement designed to show the nature and effects of corona in oils is illustrated in Fig. 7. Voltage was applied between the brass rod and the

11. H. S. Osborne, Loc. Cit., p. 1577.

water sheath. At about 20 kv., numerous discharges took place between the brass rod and the inside of the glass tube A. The apparatus, being transparent, afforded opportunity for visual observations. It was noticed that the discharges resembled ordinary spark discharges except that near the interface between the oil and the glass the spark discharge, or corona, spread out over considerable area; that is, the spark is not strictly radial but seems to consist of streamers that spread throughout an appreciable volume of the oil. Although corona in oil thus consists of disruptive discharges, there is some question as to their needle-like character. In fact, it seems as if these discharges are propagated outward and get thinner and thinner as they go. A somewhat analogous case would be a lightning bolt discharging a cloud by numerous streamers extending throughout the volume of the cloud but uniting to form a single bolt to earth.

The mechanism of these corona discharges in oil is readily understood when we recall the physical picture

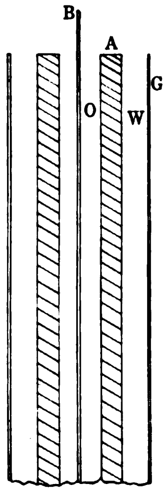

Fig. 7—A, Glass Tube; B, Brass Rod; C, Transformer Oil; W, Water Electrode; G, Glass Tube

of a kinetic equilibrium between the mobile ions and the molecules when the oil is under electric stress. If the oil is under high stress, near or beyond the breakdown point, there will be a comparatively great number of ions free to move, for the molecular bonds will be practically broken. Ions of one polarity will tend to move toward the outer electrode and those of the opposite polarity will move toward the inner electrode. The glass tube prevents any concentration of the ions that are moving toward the outer electrode but from the inner electrode sparks or corona discharges will radiate outward and discharge a finite volume of the ionized dielectric. Heterogeneity of the oil accounts for the concentration of the ion flow and the resulting spark discharge, rather than a more uniform corona glow.

Nevertheless, regardless of the nature of these discharges in the oil, considerable damage is done to the dielectrics. The oil is decomposed, gases being evolved quite rapidly, and the inner surface of the glass tube is badly cracked and chipped. Fig. 8 is an enlarged photograph of a glass tube after a few minutes' application of voltage. The various markings are chips and cracks along the surface of the inner bore of the tube. This tube did not puncture, although some of the cracks extend fully half-way through the wall of the tube.

This chipping and cracking of the glass tube may be due to a rather high temperature locally, or it may be

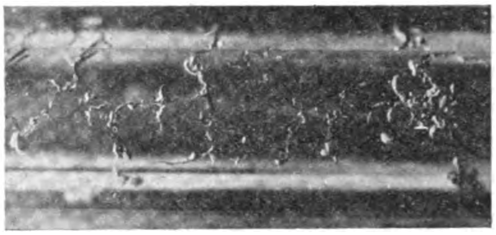

Fig. 8

due to the high-frequency character of the discharges. Peaslee[13] has obtained somewhat similar effects in porcelain. He, however, superimposed high-frequency pulses on the 60-cycle voltage and therefore knew definitely the cause of the phenomena which he observed.

In order to check up on the corona effect in solids, glass thermometer tubes were used. Mercury formed the inner electrode, which was 0.2 mm. in diameter, and water was used for the outer electrode. The ratio of R/r was 33. This tube was known to puncture between 35 and 40 kv., so that 34 kv. was applied and held for half an hour. During this interval nothing happened. There were no visual signs of stress or other effects to indicate that the tube was operating near the breakdown voltage. Due to the large ratio of R to r, the inner layers must have been strained far beyond their breakdown point.

Upon increasing the voltage gradually during 30

Fig. 9

seconds to 37 kv., the tube punctured. Examination showed that there were three distinct places where the tube punctured. Furthermore, throughout the length of the tube the inner wall was chipped and cracked. Figs. 9 and 10 are magnified photographs of parts of the tube. Fig. 9 shows two of the three breakdown points, one at division 26 and one at division 32. The third was at division 50. In Fig. 10 is shown a portion of the tube that was not punctured, but the chips and cracks along the inner bore of the tube are plainly

seen. This effect is undoubtedly a high-frequency phenomenon. There is some question, however, as to whether the high-frequency surges are a consequence of breakdown or are the actual cause of breakdown.

The high-frequency character of the phenomenon is suggested by the fact that several distinct ruptures were observed and also by the numerous chips and cracks along the inner bore of the tube. It is difficult to conceive of this chipping and cracking being due to a simple release of the stress but on the other hand a rapid alternation of stress would very likely result in cracking due to mechanical strains set up as a result of the rapid change in the polarization of the dielectric.

These experiments indicate that corona does not occur in solid dielectrics even when they are operated beyond the elastic limit. Thus the low mobility of the molecules and ions in the solid dielectric tends to prevent the formation of corona and likewise increases the stability of the insulation even when it is operated beyond the elastic limit. This extreme stability probably will not be found, even in solids, if there is any appreciable nonhomogeneity of the dielectric. For this reason composite or laminated insulations are particularly subject to corona phenomena, *i. e.*, internal discharges, when the weaker dielectric is over-strained. The complexities introduced by composite insulation are so numerous that they will not be discussed at this time.

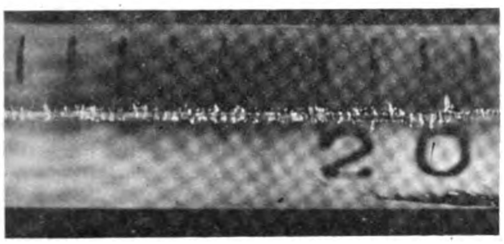

FIG. 10

The drooping of the Curves B' and B'' in Fig. 4 is explained, therefore, by assuming that the inner layer of insulation could not have been homogeneous. In both of these cases very small conductors were used, less than one mm. in diameter. With these very small conductors, it was, no doubt, impossible to get uniform vulcanization of the rubber insulation or uniform solidification of any insulating material. The resulting heterogeneity of the dielectric would cause internal discharge within the inner layers and thus the stability of the dielectric as a whole would be decreased; that is, the puncture voltage would be lower than would be the case if there were no internal discharges.

In this connection, however, it is well to mention some work by Kennelly and Wiseman[15] where they found that for varnished cambric there was a diminution of 14.8 per cent in puncture voltage when an 18.1-sq. cm. electrode was used in place of a 1.13-sq. cm. electrode. However, if sixteen of the smaller electrodes were connected together so as to have the same total area as the larger electrode and if some resistance was inserted between the different small electrodes, the puncture voltage for the combination was the same as for a single small electrode. On the other hand, if the small electrodes were connected by a low resistance as by fastening them into a brass plate, the puncture voltage was practically the same as with a single large electrode. It was suggested at the time that this effect might be due to high-frequency surges, the resistance serving to damp them out and thus give a higher puncture voltage. It would seem that in this case the high-frequency surges took place just before breakdown and were the cause of breakdown taking place at a lower voltage than otherwise would be the case.

13. W. D. A. Peaslee, *Insulation Failures under Transient Voltages*, JOURNAL of the A. I. E. E., Vol. 35, p. 1187.

15. A. E. Kennelly and R. J. Wiseman, The Apparent Dielectric Strength of Varnished Cambric, *Electrical World*, Vol. 70, p. 1138.

CONCLUSIONS

The mechanism of breakdown is not a simple phenomenon. The one fundamental concept is that in the dielectric there is a kinetic equilibrium between the mobile charges and the molecules. However, if there is any appreciable heating effect due to the conduction current or to dielectric losses, the equilibrium conditions will be changed. Therefore, in the complete analysis of the phenomena, the thermal effect must be considered. Then again, if the field is not uniform or if the dielectric is composite or heterogeneous, there is the possibility that part of the insulation will be over-strained and internal discharges are then likely to initiate high-frequency effects that disturb the stability of the dielectric as a whole. All of these three effects are undoubtedly present in every breakdown, but in many cases one or even two of them may be negligible. Experiments can be designed to show any one effect by reducing to a minimum the effects of the other two. It seems that in the past this tri-fold nature of the phenomenon has not been fully appreciated and has been the cause of much confusion. The term tri-fold may be misleading, for they are not three separate effects, but three manifestations of essentially the one phenomenon of kinetic equilibrium between the ions and the molecules of the dielectric.

The author is indebted to the members of the Electrical Engineering staff of the Harvard Engineering School, and especially to Professors H. E. Clifford and A. E. Kennelly, for suggestions in the preparation of this paper. The work has been done at the Harvard Engineering School under the auspices of the Cable Research Committee, which is a sub-committee of the appropriate committees of the National Electric Light Association, the American Institute of Electrical Engineers, and the Association of Edison Illuminating Companies.

Abridgment of

The Rectification of Alternating Currents with Steel Enclosed Mercury Arc Power Rectifiers and their Auxiliary Devices

BY OTHMAR K. MARTI*

Synopsis.—*Recently many publications have been issued on mercury arc rectifier installations in this country and in Europe, as well as on the theory of their voltage and current performances. Nevertheless, it seemed that it might be of interest to give a condensed paper dealing with the most important theoretical treatments, as well as a description of a steel enclosed rectifier of modern design.*

The fundamental theory of these rectifiers is discussed, touching only slightly upon the physical phenomena, but treating particularly of the theory involved in the practical applications. The effects of various factors on the rectifier characteristics and operation are dealt with, and the methods used for calculating the relations of voltages, currents, transformer ratings, etc., are given and tabulated. Moreover, there are mentioned the latest developments of the rectifier proper, as well as the auxiliary devices. Included in this is the design of the transformers from a mechanical point of view, making them rigid enough to stand the mechanical stresses forced upon the windings under abnormal operating conditions; and from an electrical point of view, giving the characteristics of connections such as zig-zag windings, special polyphase windings, and the introduction of reactance absorption coils in the neutral connections of the transformer. Special attention is paid also to the anodes and their cooling equipment, and to the seals, several ingenious points being brought out in their construction.

The vacuum question also is considered one of the most important, not only from the standpoint of producing and maintaining the vacuum, but also from the standpoint of measuring it. The importance of properly measuring the degree of vacuum, as well as the amount of mercury and other vapor present in the cylinder, is brought out, since it was found that the well-known devices for measuring a vacuum, such as McLeod's vacuum gage, did not give the actual conditions existent in the cylinder, but only a relative indication, namely, the pressure of the perfect gases. A new vacuum-measuring gage of novel design, which only very recently has been developed to its present state of perfection, is described in detail and its operation explained. This gage makes it possible to measure and record the absolute pressure of the gases and vapors contained in the rectifier cylinder.

The preparation of the rectifiers for service and their operation are described, and special attention is given to the numerous advantages secured by the use of rectifiers in substations. To simplify operation and to assure continuity of service, a simple and reliable method of ignition and excitation had to be developed. Without touching upon the two methods formerly employed, i. e., d-c.—a-c. ignition and excitation, a new method, lately developed, which proved to be extremely serviceable in practise, is described and illustrated in detail.

The simplicity of starting and operation, the ease of control and the adaptability to full automatic operation, as well as the high efficiencies of these rectifiers, are dealt with and all the advantages are recapitulated at the end. A somewhat exhaustive bibliography, which might be of value to future investigators, is also appended.

* * * * *

Introduction

MUCH information on mercury arc phenomena was published during the period 1892-1911, referring, however, to the mercury arc in glass bulbs only, while the theory of single-phase rectification was especially treated by Steinmetz and Cooper Hewitt. Over 20 years ago, the latter was actually constructing the first rectifier of a practical design which was received with much interest for a time, especially in this country. Steinmetz even gave a theoretical treatment of the two-phase rectifier and discussed the internal phenomena with the help of oscillograms. After a comparatively long period of inactivity, this problem of rectification by means of the mercury arc valve was again taken up, but this time in Europe. The large power rectifier was made possible to a great extent by the construction of an ingenious seal for use with steel tanks. Up to this time only glass vessels could be made sufficiently air-tight.

Inasmuch as in Europe alone several hundred rectifiers are already in successful operation (some of them for nearly 15 years), it may be seen that the steel-enclosed, mercury arc rectifier is equal in its state of development to the rotary converter. Of course, there are still many developments possible, especially in increasing the d-c. voltage. The latest tests in this direction promise results which as yet cannot even be foreseen. The highest d-c. voltage rectifier commercially used,—*i. e.*, 4000 volts,—has been in successful operation for over a year and a half, and tests have been made with as high as 8000 volts. Such high-voltage rectifiers, having an over-all efficiency of over 98 per cent, possess their greatest interest when considered with respect to railway electrification. Later on it will be seen that among the chief advantages of these rectifiers are not only their high efficiency, especially at partial load, but also the decrease in the cost of maintenance and operation.

Although the physical phenomena involved in the operation of the mercury arc rectifier are not fully understood, the quantitative relations upon which rectifier design is based are well established. These relations are given herein particularly with a view to their practical applications, leaving out factors which would only complicate the treatment and do not affect the final results of the computations to any great extent.

The presentation of the theory is based largely on a paper by Daellenbach and Gerecke (see Bibliography).

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Theory

The underlying principle of operation of the mercury arc rectifier is the valve action of the mercury arc in vacuum, which permits the flow of current in one direction only, from the anode to the mercury cathode.

The fall of potential in the mercury arc is constituted of three parts, a drop of 5.7 volts at the cathode surface, a drop of 6.3 volts at the anode surface, and the drop in the arc proper which is 0.1 to 0.4 volts per centimeter of arc length. Provided the current density in the arc is not too great, the fall of potential in the arc is independent of the current and the voltage of the electrodes and depends only on the nature of the vacuum and on the nature of the electrodes. The voltage drop in a mercury arc is reduced slightly by the presence in close proximity of another arc in which the current is changing. For this reason, in polyphase rectifiers, where this condition exists during the period of overlapping of two consecutive phases, the anodes should be arranged in cyclic order so that the arc passes from anode to anode without skipping.

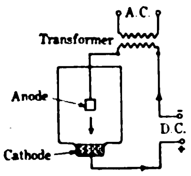


Fig. 1—Single-Anode Rectifier

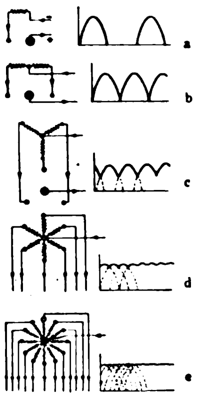


Fig. 2—Single-Phase and Polyphase Rectifiers

When connected to the secondary of a transformer and an external circuit as shown in Fig. 1, current will flow in the direction indicated when the potential of the anode is positive with respect to the cathode. When a single anode is used, Figs. 1 and 2A, current will flow only during one-half of the cycle. By using two anodes with the midpoint of the secondary of the transformer as the negative d-c. pole, Fig. 2B, current will flow over one anode during the first half of the cycle and over the other anode during the second half of the cycle. The full voltage wave is thus utilized and with a sinusoidal pulsating alternating voltage on the a-c. side a continuously flowing pulsating direct current is obtained on the d-c. side. In polyphase rectifiers with more than two anodes, Fig. 2C-E, the current will flow over the anode with the momentarily highest potential and the arc will travel from anode to anode describing a cone with its apex at the cathode.

It is seen from Fig. 2 that the larger the number of phases the better the form of the direct-current wave. However, as will be shown later, the number of phases used is limited by practical considerations. The frequency of pulsation of the direct-current wave is equal to the product of the a-c. frequency and the number of phases. These pulsations can be reduced to a negligible value by means of a choke coil in the cathode circuit.

In considering the current and voltage relations of a rectifier, the following simplifying assumptions will be made: (1) The direct-current wave is assumed to be a straight line. (2) The voltage drop in the arc is assumed to be constant at all loads. (3) The rectifier transformer ratio is assumed to be 1:1. (4) The magnetizing current of the transformer is neglected.

With these assumptions, the current and voltage relations of the rectifier will be derived: First, *neglecting the resistance and reactance of the transformer and line;* Second, *the effect of the reactance of the transformer secondary will be considered.*

Symbols. Following is a list of the symbols used and their explanations:

A Effective value of anode current
E Effective value of phase voltage, primary and secondary
E_d Average value of d-c. voltage
I Constant direct current
I_p Effective value of primary current
L Inductance per phase of transformer secondary
P Average d-c. power
P_1 Rating of transformer primary
P_2 Rating of transformer secondary
$X = 2\pi f L$ Reactance per phase of transformer secondary
$P.F.$ Power factor in line
a_1, a_2, etc. Instantaneous values of anode currents
e_1, e_2, etc. Instantaneous values of phase voltages
e_d Instantaneous value of d-c. voltage
f Frequency of a-c. supply
i_1, i_2, etc. Instantaneous values of transformer primary currents
p Number of secondary phases = number of anodes
t Time
u Angle of overlap
$x = \omega t = 2\pi f t$

1. *Voltage and Current Relations with Zero Transformer Reactance.* We shall consider the general case

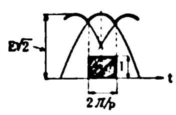


Fig. 3—Anode-Current and D-C. Voltage Waves of a p-Phase Rectifier, Neglecting Transformer Reactance

of a p-phase rectifier, delivering a constant direct current. I. The transformer is assumed to have zero reactance. The anodes then burn in sequence, one at a time, and each anode delivers the current I for an interval of $2\pi/p$. The anode current has the rectangular shape

shown in Fig. 3. Its average value is I/p and its effective value

$$A = \sqrt{\frac{1}{2\pi} \cdot \frac{2\pi}{p} I^2} = I/\sqrt{p} \tag{1}$$

The d-c. voltage, including the drop in the arc and the cathode choke coil, is equal to the voltage between the transformer neutral and the momentarily burning anode. Since the reactance drop is assumed to be zero, the d-c. voltage wave has the form shown in heavy outline in Fig. 3, and its average value

$$E_d = \frac{1}{2\pi/p} \int_{-\pi/p}^{+\pi/p} E\sqrt{2} \cos x \, dx = \frac{E\sqrt{2} \sin \pi/p}{\pi/p} \tag{2}$$

The average d-c. power

$$P = E_d I = E I \sqrt{2} \frac{\sin \pi/p}{\pi/p} \tag{3}$$

The rating of the transformer secondary windings

$$P_2 = p E A = E I \sqrt{p} = \frac{\pi/p \sqrt{p}/\sqrt{2}}{\sin \pi/p} . P \tag{4}$$

For a given transformer connection, the transformer

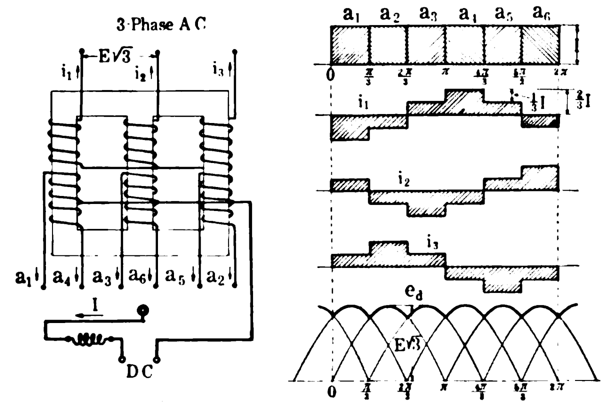


Fig. 4—Anode and Transformer Primary Currents of 3-Y/6-Phase Rectifier, Using the Diametrical Connection of Secondaries

primary and line current waves can be constructed from the anode currents. The effective values of the currents as well as the transformer primary ratings can then be computed.

For illustration we shall compute the voltages, currents, and transformer ratings of a six-phase rectifier with a 3-Y/6-phase transformer using the diametrical connection of secondaries.

Six-Phase Rectifier with Three-Phase, Y-connected Transformer Primary. Fig. 4 shows a 3-Y/6-phase transformer connected to a six-phase rectifier. The numeral subscripts of the anode currents correspond to the order in which the anodes will burn. With the assumption of zero magnetizing m. m. f., the sum of the m. m. f's. around a closed magnetic path in the transformer core is zero. With an assumed 1:1 transformation ratio, we can write:

$$i_1 + a_1 - a_4 + a_6 - a_3 - i_2 = 0 \tag{5}$$

$$i_1 + a_1 - a_4 + a_2 - a_5 - i_3 = 0 \tag{6}$$

Also by Kirchoff's first law

$$i_1 + i_2 + i_3 = 0 \tag{7}$$

Solving the above equations simultaneously for i_1, i_2 and i_3 we obtain

$$i_1 = -\frac{2}{3} a_1 - \frac{1}{3} a_2 + \frac{1}{3} a_3 + \frac{2}{3} a_4 + \frac{1}{3} a_5 - \frac{1}{3} a_6 \tag{8}$$

$$i_2 = \frac{1}{3} a_1 - \frac{1}{3} a_2 - \frac{2}{3} a_3 - \frac{1}{3} a_4 + \frac{1}{3} a_5 + \frac{2}{3} a_6 \tag{9}$$

$$i_3 = \frac{1}{3} a_1 + \frac{2}{3} a_2 + \frac{1}{3} a_3 - \frac{1}{3} a_4 - \frac{2}{3} a_5 - \frac{1}{3} a_6 \tag{10}$$

From these expressions the primary current curves have been constructed in Fig. 4. From equations (**1**) and (**2**) and from the diagram of Fig. 4,

$$A = I/\sqrt{p} = I/\sqrt{6}$$

$$E_d = E\sqrt{2} \frac{\sin \pi/p}{\pi/p} = E\sqrt{2} \frac{\sin \pi/6}{\pi/6} = \frac{3\sqrt{2}}{\pi} E$$

$$I_p = \sqrt{\frac{1}{\pi} \cdot \frac{\pi}{3} \left[\left(\frac{1}{3} I\right)^2 + \left(\frac{2}{3} I\right)^2 + \left(\frac{1}{3} I\right)^2 \right]}$$

$$= \frac{\sqrt{2}}{3} I$$

$$P = E_d I = \frac{3\sqrt{2}}{\pi} E I$$

$$P_2 = p E A = E I \sqrt{6} = \frac{\pi}{\sqrt{3}} P$$

$$P_1 = 3 E I_p = E I \sqrt{2} = \frac{\pi}{3} P$$

$$P.F. = \frac{P}{P_1} = \frac{3}{\pi} = 0.955$$

For other transformer connections the values of currents, voltages and transformer ratings can be computed similarly. These values for various transformer and rectifier connections are given in Fig. 8. Although computed on the assumption of zero transformer reactance and several other simplifying assumptions, *the values of this table are sufficiently accurate for most practical purposes.*

From Fig. 8, it is seen that the primary and secondary of the rectifier transformer have different ratings and that the relation between alternating- and direct-currents and voltages depend on the number of phases and the connections used. *The requirement of transformers of special design is therefore evident.*

Absorption Reactance Coil. The last two columns in

Fig. 8 deal with rectifiers having an absorption reactance coil. The absorption reactance coil, Fig. 5, consists of two windings having a common core. One terminal of each winding is connected to one side of the split transformer neutral. The other terminals are connected together to the negative d-c. pole. The polarity of the windings is such that their m.m.f's. oppose each other.

This arrangement produces a strong choking effect causing both sections of the transformer secondary to deliver currents simultaneously. The effect is that the six-phase rectifier is converted into two parallel working three-phase sections, each section delivering one-half of the direct current.

As a result, the effective values of the transformer currents and the transformer ratings are reduced as seen from Fig. 8, and the regulation of the rectifier is improved as will be shown later.

Effect of Reactance in Transformer Secondary. We shall return to the general case of a p-phase rectifier.

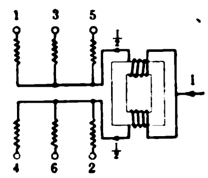


Fig. 5—Absorption Reactance Coil

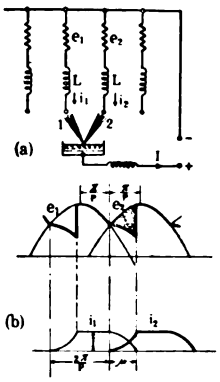


Fig. 6—Anode Current and D-C. Voltage Waves of a p-Phase Rectifier, Considering Reactances of Transformer Secondary

However, each phase of the transformer secondary now has an inductance L. Due to this inductance the anode currents can no longer build up and die down instantly as previously assumed, but the currents of two consecutive phases overlap. Two adjoining anodes, therefore, have their arcs going simultaneously for a short interval, constituting an electrical connection between the open ends of the windings of the overlapping phases. This condition is shown in Fig. 6A.

Anode 1 carries the full current I until the point of intersection of the voltage waves e_1 and e_2, when anode 2 strikes its arc. The instant of this occurrence will be used as the time origin for the expression of the voltages and currents.

Applying Kirchoff's second law to the closed circuit formed by phases 1 and 2, Fig. 6A,

$$e_1 - L\frac{d\,i_1}{d\,t} + L\frac{d\,i_2}{d\,t} - e_2 = 0 \qquad (11)$$

(Since the voltage drops in the two arcs are equal, they cancel each other and therefore do not enter into the above expression.)

Also

$$i_1 + i_2 = I \qquad (12)$$

$$e_1 = E\sqrt{2}\cos(\omega\,t + \pi/p)$$

$$e_2 = E\sqrt{2}\cos(\omega\,t - \pi/p)$$

Substituting for e_1 and e_2 in (11) and solving (11) and (12) simultaneously for i_1 and i_2 we obtain,

$$i_1 = I - \frac{E\sqrt{2}\sin\pi/p}{X}(1-\cos\omega\,t) \qquad (13)$$

$$i_2 = I - i_1 = \frac{E\sqrt{2}\sin\pi/p}{X}(1-\cos\omega\,t) \qquad (14)$$

Where $X = \omega\,L$

The form of the anode current waves during the period of overlapping as determined by expressions (13) and (14) is shown in Fig. 6B. The overlapping of the currents lasts until i_1 has become 0, since the valve action of the arc prevents it from ever having a negative value.

The angle of overlap u can be determined by equating to zero the expression for i_1 with $\omega\,t$ replaced by u.

$$i_1 = I - \frac{E\sqrt{2}\sin\pi/p}{X}(1-\cos u) = 0$$

from which

$$\cos u = 1 - \frac{I\,X}{E\sqrt{2}\sin\pi/p} \qquad (15)$$

From (15),

$$\frac{E\sqrt{2}\sin\pi/p}{X} = \frac{I}{1-\cos u}$$

Substituting in (13) and (14) and replacing $\omega\,t$ by x we obtain

$$i_1 = I\left(1 - \frac{1-\cos x}{1-\cos u}\right) \qquad (16)$$

$$i_2 = I\,\frac{1-\cos x}{1-\cos u} \qquad (17)$$

The effective value of the anode current may be computed by means of the diagram in Fig. 6 and expressions (16) and (17).

$$2\,\pi\,A^2 = \int_0^u i_2^2\,d\,x + I^2\left(\frac{2\,\pi}{p} - u\right) + \int_0^u i_1^2\,d\,x$$

from which

$$A = \frac{I}{\sqrt{p}}\sqrt{1 - p\,\psi(u)} \qquad (18)$$

where

$$\psi(u) = \frac{(2+\cos u)\sin u - (1 + 2\cos u)\,u}{2\,\pi\,(1-\cos u)^2}$$

Compare (18) with (1)

$$P_2 = p\,E\,A = E\,I\sqrt{p}\sqrt{1 - p\,\psi(u)} \qquad (19)$$

The d-c. voltage, *i. e.*, the voltage between the transformer neutral and burning anode, is now reduced by the drop in the inductance of the transformer secondary (see Fig. 6) which is equal to:

$$L \frac{d\, i_2}{d\, t} = \frac{\omega\, L\, I \sin x}{1 - \cos u} = \frac{I\, X \sin x}{1 - \cos u}$$

The average value of this drop

$$d = \frac{1}{2\, \pi / p} \int_0^u \frac{I\, X \sin x}{1 - \cos u}\, d\, x = \frac{I\, X}{2\, \pi / p} \qquad (\mathbf{20})$$

The average d-c. voltage considering the reactance drop is determined from equations (**2**) and (**20**)

$$E_d = \frac{E \sqrt{2} \sin \pi / p}{\pi / p} - \frac{I\, X}{2\, \pi / p} \qquad (\mathbf{21})$$

$$P = E_d\, I = \frac{E\, I \sqrt{2} \sin \pi / p}{\pi / p} - \frac{I^2\, X}{2\, \pi / p} \qquad (\mathbf{22})$$

The transformer primary and line current waves can be constructed from the anode currents as was done previously. For a 3-Y/6-phase transformer the primary current wave can be constructed from the anode currents using equations (**8**), (**9**) and (**10**). The effective value of the primary current and the rating of the transformer primary can be calculated then.

Regulation. Equation (**21**) expresses the d-c. current-voltage characteristic of the rectifier. The first term in the expression represents the d-c. no-load voltage. The second term shows the variation of the voltage drop with load. It is seen that the larger the number of phases the greater is the voltage drop and, therefore, the poorer the regulation. It also explains how the absorption reactance coil improves the regulation. The reactance divides the six-phase transformer into two three-phase transformers having the characteristics of two three-phase transformers in parallel. By converting the six-phase rectifier into two parallel working three-phase sections, the voltage drop is reduced both on account of reduction in the number of phases and the current delivered by each section.

The transformer primary and line reactances have the same effects as the transformer secondary reactance, as far as the d-c. voltage, anode current, and transformer secondary rating are concerned, and could be replaced by an equivalent (not equal) reactance in the transformer secondary. The effect of the primary and line reactances on the transformer-primary current and rating depend on the type of primary connection used and the magnitude of the reactance.

Rectifier Transformers and Their Connections

The transformers used in connection with mercury arc rectifiers are employed not only to step-down the a-c. voltage so that a d-c. voltage of a desired value is obtained at the rectifier terminals, but they serve several other purposes as well, and, therefore, their design and connections differ from standard transformers. The factors involved in the design of rectifier transformers are given below.

The treatment under "Theory" showed that it is essential from certain points of view to have a large number of phases and anodes, respectively (see Fig. 2), in order that the voltage on the d-c. side may be practically constant. Moreover, it could be seen that the rating for which a rectifier transformer must be designed is higher than the d-c. output which is desired from the rectifier. In designing the secondary winding, consideration must be given to the fact that the root-mean-square value of the anode current is considerably higher than the total current divided by the number of anodes. Furthermore, it is essential to keep in mind that in case of a short circuit on the d-c. side, the transformer connected to the rectifier is under more severe stresses than when connected to a rotary converter under similar conditions.

The rating of the transformer for a particular rectifier can be found under "Theory," and also in Fig. 8. Its mechanical construction has to be such that the high electric dynamic forces produced between the anode currents in the windings by a short circuit in the d-c. system are taken care of satisfactorily. Although it is not easy to meet these abnormal conditions, on account of the heavily unbalanced loads which occur, resulting in axial stresses on the coils, these conditions are admirably met in the transformer described below. The coils are always kept under a certain pressure by means of a specially designed support. It is composed of pressure rings of cast steel placed above and below the windings and held together by long bolts and spiral springs, thus forming a solid unit. In order to distribute the axial pressure evenly between the low- and high-voltage windings, an auxiliary ring is placed between the steel-pressure ring and the end-distance pieces of one of the windings, making possible a proper adjustment by means of screws.

The bushings are fastened to a common terminal frame so that the cover of the tank can be removed without taking off the terminals. Reference will also be made to the electrical design of the rectifier transformer in connection with regulation and parallel operation. The voltage regulation depends entirely upon the transformer design, or upon both the transformer and the auxiliary apparatus; since the rectifier itself has no regulating properties, the connections of the windings of rectifier transformers are therefore important. In Fig. 17 A, B, C, D are illustrated various transformer connections; the open terminals of the secondary windings lead to the rectifier anodes.

The term "regulation of the rectifier" refers to the voltage drop between full load and no load at the d-c. side and for several transformer connections usually employed the regulation performance is given below:

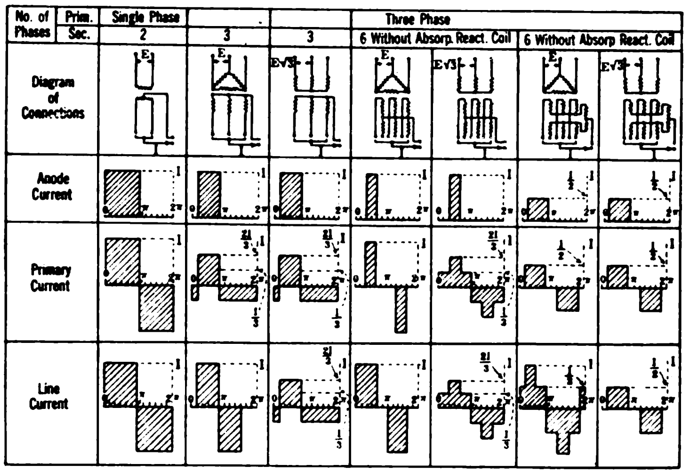
Double six-phase connection, primary three-phase,

Y or delta, usually used with an absorption reactance coil, see Figs. 8 and 17A, has a regulation of about 10 to 12 per cent without and about 4 to 5 per cent with absorption coil;

Polygon connection, primary three-phase-Y regulation about 6 per cent;

Zig-zag connection, primary three-phase-Y, regulation as for polygon connection;

Double zig-zag connection, primary three-phase Y, (used for 12-anode rectifiers or two six-anode rectifiers in parallel) regulation as for the two preceding connections.



No. of phases	Prim.	Single-phase	Three-phase: Delta	Star	Delta	Star	Delta	Star
	Sec.	2	3	3	6 without absorp. react. coil		6 with absorp. react. coil	
Anode current	Maximum	I	I	I	I	I	$\frac{I}{2}$	$\frac{I}{2}$
	Average	$\frac{I}{2}$	$\frac{I}{3}$	$\frac{I}{3}$	$\frac{I}{6}$	$\frac{I}{6}$	$\frac{I}{6}$	$\frac{I}{6}$
	Effective	$\frac{I}{\sqrt{2}} = \frac{I}{1.41} = 0.71\ I$	$\frac{I}{\sqrt{3}} = \frac{I}{1.73} = 0.58\ I$	$\frac{I}{\sqrt{3}} = \frac{I}{1.73} = 0.58\ I$	$\frac{I}{\sqrt{6}} = \frac{I}{2.45} = 0.41\ I$	$\frac{I}{\sqrt{6}} = \frac{I}{2.45} = 0.41\ I$	$\frac{I}{2\sqrt{3}} = \frac{I}{3.46} = 0.29\ I$	$\frac{I}{2\sqrt{3}} = \frac{I}{3.46} = 0.29\ I$
Primary current, effective value		I	$\frac{I\sqrt{2}}{3} = \frac{I}{2.12} = 0.47\ I$	$\frac{I\sqrt{2}}{3} = \frac{I}{2.12} = 0.47\ I$	$\frac{I}{\sqrt{3}} = \frac{I}{1.47} = 0.58\ I$	$\frac{I\sqrt{2}}{3} = \frac{I}{2.12} = 0.47\ I$	$\frac{I}{\sqrt{6}} = \frac{I}{2.45} = 0.41\ I$	$\frac{I}{\sqrt{6}} = \frac{I}{2.45} = 0.41\ I$
Line current, effective value		I	$I\sqrt{\frac{2}{3}} = \frac{I}{1.23} = 0.82\ I$	$\frac{I\sqrt{2}}{3} = \frac{I}{2.12} = 0.47\ I$	$I\sqrt{\frac{2}{3}} = \frac{I}{1.23} = 0.82\ I$	$\frac{I\sqrt{2}}{3} = \frac{I}{2.12} = 0.47\ I$	$\frac{I}{\sqrt{2}} = \frac{I}{1.41} = 0.71\ I$	$\frac{I}{\sqrt{6}} = \frac{I}{2.45} = 0.41\ I$
Power factor in line		$\frac{2\sqrt{2}}{\pi} = \frac{1}{1.11} = 0.90$	$\frac{3\sqrt{3}}{2\pi} = \frac{1}{1.21} = 0.83$	$\frac{3\sqrt{3}}{2\pi} = \frac{1}{1.21} = 0.83$	$\frac{3}{\pi} = \frac{1}{1.05} = 0.955$	$\frac{3}{\pi} = \frac{1}{1.05} = 0.955$	$\frac{3}{\pi} = \frac{1}{1.05} = 0.955$	$\frac{3}{\pi} = \frac{1}{1.05} = 0.955$
D. C. voltage		$\frac{2\sqrt{2}}{\pi} E = \frac{E}{1.11} = 0.90\ E$	$\frac{3\sqrt{6}}{2\pi} E = \frac{E}{0.855} = 1.17\ E$	$\frac{3\sqrt{6}}{2\pi} E = \frac{E}{0.855} = 1.17\ E$	$\frac{3\sqrt{2}}{\pi} E = \frac{E}{0.74} = 1.35\ E$	$\frac{3\sqrt{2}}{\pi} E = \frac{E}{0.74} = 1.35\ E$	$\frac{3\sqrt{6}}{2\pi} E = \frac{E}{0.855} = 1.17\ E$	$\frac{3\sqrt{6}}{2\pi} E = \frac{E}{0.855} = 1.17\ E$
Transformer rating	Sec.	$\frac{\pi}{2} P = 1.57\ P$	$\frac{\pi\sqrt{2}}{3} P = 1.48\ P$	$\frac{\pi\sqrt{2}}{3} P = 1.48\ P$	$\frac{\pi}{\sqrt{3}} P = 1.81\ P$	$\frac{\pi}{\sqrt{3}} P = 1.81\ P$	$\frac{\pi\sqrt{2}}{3} P = 1.48\ P$	$\frac{\pi\sqrt{2}}{3} P = 1.48\ P$
	Prim.	$\frac{\pi}{2\sqrt{2}} P = 1.11\ P$	$\frac{2\pi}{3\sqrt{2}} P = 1.21\ P$	$\frac{2\pi}{3\sqrt{2}} P = 1.21\ P$	$\frac{\pi}{\sqrt{6}} P = 1.28\ P$	$\frac{\pi}{3} P = 1.05\ P$	$\frac{\pi}{3} P = 1.05\ P$	$\frac{\pi}{3} P = 1.05\ P$
	Aver.	$1.34\ P$	$1.35\ P$	$1.35\ P$	$1.55\ P$	$1.43\ P$	$1.26\ P$	$1.26\ P$

FIG. 8—VOLTAGE AND CURRENT RELATIONS FOR VARIOUS RECTIFIER CONNECTIONS, NEGLECTING TRANSFORMER REACTANCE AND RESISTANCE DROPS

Construction and Mechanical Details of Power Rectifiers

A cross-section of a Brown Boveri rectifier of recent design is shown in Fig. 10 and described below, although reference will be made to other makes when these differ in some essential point from the above mentioned make.

The large number of different types developed during the years of experimenting have now been condensed into three commercial types. The main differences between these are the difference in the sizes of the various parts, the spacing of the anodes and cathode, and the method of anode cooling. The foundation is very light compared to that required for rotary converters. A special earthquake-resisting foundation has also been developed, which successfully keeps the vacuum piping and other delicate parts intact, even in the countries most frequently subject to seismic disturbances. Six insulating feet, resting on the cast-iron foundation ring, support the rectifier proper. If for any reason it is impossible to lift the rectifier into position, the foundation ring is provided with casters, see Fig. 11, which enable the rectifier to be moved to the desired position. The casters are provided with means for raising the rectifier off the floor while moving it and for lowering it to the floor when it has been put into place.

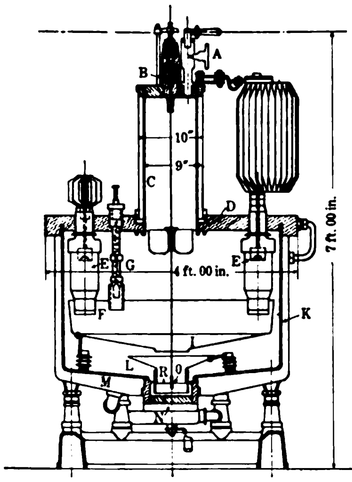


Fig. 10—Cross-Section of a Rectifier

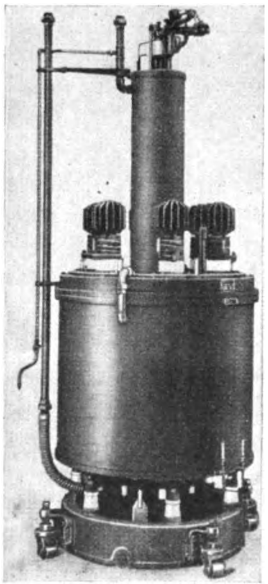


Fig. 11—General View of a Rectifier

Cylinder. In Fig. 10 the cylinder K, made of welded steel, is closed by the anode plate D, which supports the main anodes E, the excitation anodes G, and condensing cylinder C, at the top of which is mounted the ignition device. The cathode consists of a quantity of mercury in the receptacle R. From this the electrons travel through the openings in the funnels L and I, through the so-called arc guide F, to the anode E. The funnels L and I are insulated from each other and from the rest of the rectifier by means of special insulators, visible in the drawing. The arc guide F, shown in detail in Fig. 12, has baffle plates so arranged that no secondary high-vacuum phenomena at the cathode can influence the performance of the anode.

The cooling water enters the rectifier at N, cooling the cathode and the main cylinder, which is specially treated to resist the action of the water for an indefinite period of time. The water then passes upward, through the anode plate D, into the jacket surrounding the condensing cylinder C, whence it is discharged.

The condensing cylinder C serves to cool the mercury vapor so that it becomes liquid and flows down along the walls of the cylinder into a trough, from which it is brought to a point near the wall of the main cylinder K, but outside the aprons L and I, and thence flows back into the cathode receptacle at the bottom of the main cylinder. To the top of the condensing cylinder is attached the ignition plunger, with its solenoid B, which in starting the rectifier acts upon the small iron piece just above it. The pipe to the vacuum pump also leaves the top of the condensing tower, being sealed in the same way as the current conductors.

Anodes. The main anodes are insulated with special porcelain bushings, the shape of which depends upon the voltage for which the rectifier is to be used. The shape of the anodes themselves is shown by the dotted lines. They are made of specially treated steel which has been found, after exhaustive tests, to be best suited to this purpose. The design of the anode cooling system for rectifiers to be used with voltages up to 1600 volts is shown on the right-hand side of the illustration, while the construction of the anodes for voltages as high as 3000 volts is shown on the left-hand side.

The difference in the cooling devices for the two types of rectifiers can easily be understood by taking into consideration the fact that the voltage drop of a rectifier is practically constant for all voltages. It follows, therefore, that while the heat losses in a 200-volt, 200-kw. rectifier are about 20-kw., in a 2000-volt, 200-kw. rectifier they are only about two kw. or about one-tenth of the low-voltage rectifier losses.

The excitation anode with its arc guide is shown on

the left-hand side of the drawing—its function is explained later on.

Like the inner surface of the cylinder K, and all other metal parts inside the cylinder, the anode surfaces are treated in such a way that all occluded air and other gases can easily be removed. This shortens appreciably the time required for forming the rectifiers (about which more is said later on) before they can be put into service. The spacing of the anodes, their shape, and the special manner of treating them, make the rectifier insensible to momentary short circuits, as well as to heavy overloads, which would be disastrous in the case of rotary converters.

Sealing. The seals in the above mentioned make of rectifier are secured by means of mercury, and hence they are not only perfectly air-tight, but they also are not sensitive to the action of the mercury vapor and other gases which are developed in the cylinder. Furthermore, they can be equipped with a visible indicating device.

The Allgemeine Elektrizitats Gesellschaft of Berlin employs a composite packing of aluminum and lead, the former dealing with the high vacuum while the latter forms the seal against the atmosphere. An intermediate space is provided between the aluminum and lead seals which is itself evacuated, and serves to distribute the pressure in such a way that each seal has to deal only with a part of the total pressure difference. For inspection and testing purposes, however, it is necessary to fit each seal with a vacuum pipe, and in case of a leaky cylinder each vacuum pipe of the series must be connected to the gage in turn until the faulty seal has been discovered. Moreover, thorough investigation revealed the fact that mercury vapor and other gases will affect such metal seals to a certain extent, and unless iron is used, an amalgam is formed which may destroy the seals in a very short time. Furthermore, these investigations showed that due to aging of the metals, all inner elasticity is lost after a year or two and that repeated tightening after successive intervals will not remedy the trouble.

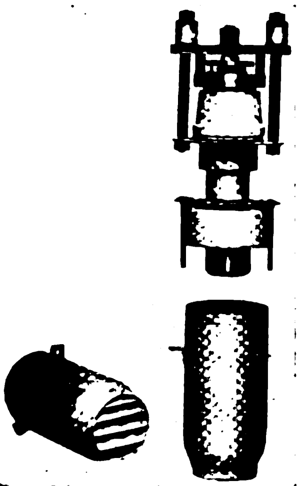


Fig. 12—Anode with Arc Guide

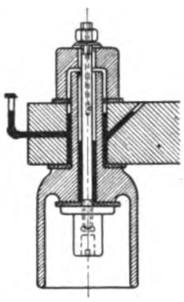


Fig. 13—Mercury Seal with Indicating Gage.

The General Electric Company's glass seal which was recently mentioned in an article on rectifiers may prove to be very effective, and it will be interesting to learn how it stands up in practise. The description of it given in the article did not contain enough information to permit a thorough discussion of it. However, the disadvantage of these seals seems to be that there is no possibility of detecting any leakage, and that when the anodes are removed the seals are destroyed.

The construction of the Brown Boveri seal is shown in detail in Fig. 13. The joints are first fitted with special elastic washers, and thorough investigation, carried on for an extended period, showed that an asbestos washer (double cross-hatched shading) was most suitable. The mercury (solid shading) is then poured into the annular spaces between the anode plate and the insulating bushing, and the insulating bushing and the central conductor, respectively, thus sealing the vacuum, while the asbestos keeps the mercury from flowing into the cylinder.

One of the most important features of the mercury seal is the fact that in case any mercury should filter past the asbestos packing it would only find its way to the mercury cathode at the bottom of the cylinder, doing absolutely no harm. At the same time the leak would be indicated at the mercury gage with which each seal is equipped. The gage, therefore, makes it possible to check instantly the condition of each seal, and if necessary the bolts can be tightened before the vacuum is broken.

Ignition and Excitation. The ignition of the arc is accomplished by means of a small plunger, O, usually located, as in Figs. 10 and 14, within a few millimeters of the surface of the mercury cathode in the receptacle R and connected to a special metal rod extending from the top of the condensing cylinder. This plunger is controlled by the solenoid B, located at the top of the condensing cylinder, which pulls the plunger into the mercury cathode against the action of a spring. As soon as the plunger touches the mercury, the solenoid is de-energized and the plunger is withdrawn. In a fraction of a second an arc is drawn between the mercury cathode and either the excitation or the main anodes, provided the vacuum in the cylinder is sufficiently high and a load is connected to the d-c. circuit.

When working at very light loads the main arc has a tendency to become unstable, and may be extinguished. Therefore, when the d-c. demand is highly fluctuating, as in traction systems, rolling mills, etc., where the current might drop below the value which is necessary to maintain the arc, the cylinders are equipped with excitation anodes. A cross-section through such an anode G is shown in Fig. 10 and it is indicated in Fig. 14, where it is denoted by A_e. The construction of it is similar to that of the main anode, and it is located at about

three-quarters of the total distance between the cathode and the main anode. Much investigation had to be done in order to find the proper location and shape of the excitation anodes so as to prevent condensation of mercury at the main anodes in case the main arc should be extinguished for a considerable length of time. The latest development in this line is the recently developed pure *a-c. ignition device*, by which means the necessity for a special ignition converter is obviated. Trial tests in two Swiss installations demonstrated

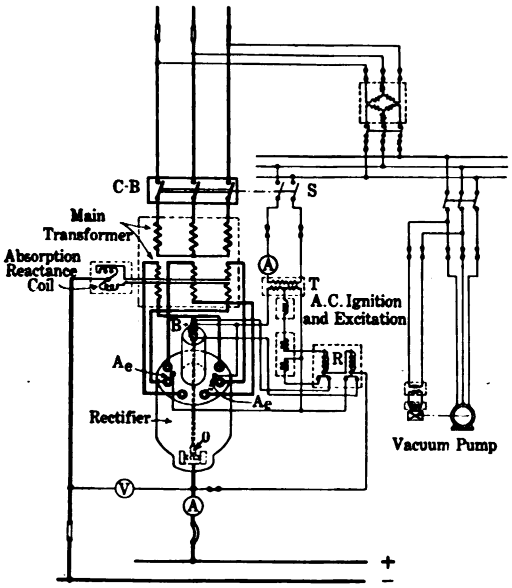


FIG. 14—TYPICAL DIAGRAM OF CONNECTIONS, SHOWING A NOVEL TYPE OF IGNITION AND EXCITATION EQUIPMENT

the superiority of this novel method which is of the utmost importance in connection with fully automatic substations. A full description of a plant equipped with such an ignition and excitation apparatus is given below under "Operation."

AUXILIARY DEVICES

On a rectifier equipment of the simplest form there is only one important auxiliary provided, namely, the vacuum pump and measuring gages illustrated in Fig. 16A. A high vacuum is absolutely essential to the satisfactory operation of the plant.

The pumps used are of special design, and very efficient, so that there is no difficulty in producing a high vacuum in a properly sealed rectifier cylinder. There are several types of vacuum pumps in use, but owing to the scope of the subject, a description of them will not be given here. Just as essential as the pump for producing the vacuum is the device for measuring it. An improvement of the utmost importance has recently been made in this line, which will be described below.

The familiar McLeod mercury column gage used in connection with rectifiers and in laboratory work has been superseded by a direct-reading hot-wire vacuum gage which in size and purpose is similar to the shunt of a precision millivoltmeter.

It may be recalled that McLeod's gage is based upon the fact that the pressure of a perfect gas times its volume is always constant. This law of Boyle's holds true, however, only for perfect gases, and therefore the use of the above gage furnishes no information about the other gases and the vapors of water, mercury, etc., which the cylinder might contain. Another disadvantage of this gage is the fact that it is not direct reading, and cannot be used for automatic station control.

The development of the new direct-reading gage, therefore, made it possible for the first time to study scientifically several phases of the mercury arc rectifier and the influence of the degree of vacuum upon its operating conditions. The latest improvements in the operation of rectifiers are a direct result of the increased ability, made possible by this instrument, to measure high vacuums.

Novel Hot-Wire Vacuum Gage. The arrangement of the direct-reading measuring device as shown in Fig. 16A and B consists of the following important parts: a hot-wire sealed-vacuum gage 1, illustrated by Fig. 16A, a resistance 4, a shunt 5, and a precision moving coil voltmeter 6. The connection to the vacuum piping of the rectifier is shown at *E*.

The working principle of the hot-wire vacuum gage is based upon the fact that the thermal conductivity of gases depends upon the gas pressure. If two bodies at different temperatures are placed opposite to one

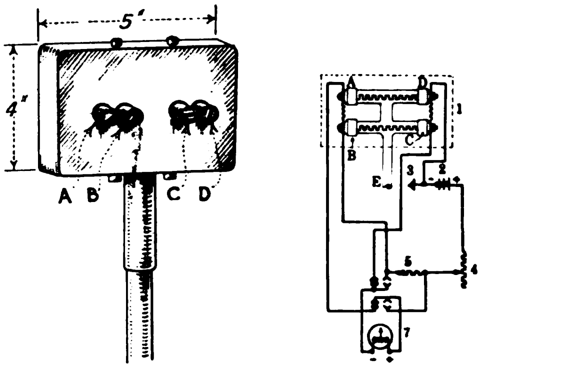


FIG. 16A—NOVEL ELECTRIC HOT-WIRE VACUUM GAGE
B—DIAGRAM OF CONNECTIONS FOR GAGE AND RECORDING INSTRUMENT

another, a heat transfer takes place from the warmer to the colder body, partially by radiation and partially by conduction. It must be kept in mind that (1) the radiation is independent of the gas pressure existing between the two bodies, and that (2) the heat conductivity depends mainly upon the respective pressures. In an absolute vacuum the latter are zero. At first the conductivity rises in proportion to the increasing gas pressure, while the latter approaches asymptotically a constant limit of value. In the range of small pressures,

the thermal conductivity is, therefore, a measure of the gas pressure.

The gage consists of four resistance wires connected together like a Wheatstone bridge. The wires stretched between the terminals *B C* and *A D* are located in the vacuum, while the wires *A B* and *C D* are exposed to the atmosphere, as shown in Fig. 16B. They are electrically heated with a constant current of about 100 milliamperes. When the branches *B C* and *A D* of the bridge are heated, their ohmic resistance and the pressure difference between the points *A* and *C* increase in proportion to the vacuum. Since this potential difference varies with the degree of vacuum, the deflection of the meter varies in proportion, giving a continuous indication of the vacuum in the rectifier cylinder. On account of the special bridge connection, fluctuations of the room temperature have practically no influence on the reading of the vacuum gage. For the safe operation of the voltmeter, the lead from terminal *D* is grounded at 3.

The millivoltmeter is designed as a contact voltmeter with two adjustable contacts which are set for predetermined low and maximum values of the vacuum, and, therefore, can be used for the automatic control of the air-pump set, making possible a full automatic control of a mercury arc rectifier substation.

The hot-wire vacuum gage is connected to the vacuum piping by means of a flange and a high-vacuum stuffing box. When connecting the apparatus, the vacuum gage is first fitted with the stuffing box, after which both parts are connected to the vacuum piping, and finally the stuffing box filled with the sealing mercury. This is essential in order to prevent the outer and inner parts of the vacuum gage from coming into contact with the mercury or the mercury vapor.

The arrangement with the battery 2 furnishing the direct current for the bridge has been superseded by an arrangement allowing the use of alternating current taken from the normal control circuit of the plant. The principle upon which the measuring device is based is the same, but this arrangement does away with the battery and makes the apparatus very simple and consequently fool-proof.

Next in order would be mentioned the ignition converter providing an independent source of current to start the arc. But recently made improvements on the Brown Boveri type rectifier made such a converter unnecessary, and, as can be seen under the next heading, starting is accomplished by means of alternating current furnished from the control circuit.

Cooling. In order to carry off the heat produced by the arc, the rectifier cylinders are usually cooled by means of water, as described above. In case fresh water of sufficient quantity and purity is available near the plant, no auxiliary device is necessary; otherwise, a small pump is required. This pump, usually electrically driven, continuously circulates the water through a recooling system, which consists of radiators mounted near the rectifier installation.

Another auxiliary of importance is the absorption or regulation reactance coil placed in the neutral point of the main transformer, its function being to limit the inherent regulation of the complete plant to a reasonable figure—usually of the order of five per cent from full to approximately no load. Without this coil the regulation may be as high as 10 to 12 per cent unless special transformer connections are used. Further details are given under "Theory" and "Transformers."

Operation of Rectifiers: Single, in Groups, and with Rotary Converters

Before a mercury arc rectifier can be placed in service, a certain "forming" process has to be carried out. The forming itself consists of expelling the gases occluded in the metal parts of the rectifier, chiefly in the anodes. To be able to conduct this process intelligently, it is essential to have a measuring gage which indicates not only the pressure of the perfect gases, but also the pressure of other gases and vapors present. Some of the late t improved methods along this line have to be credited to the hot-wire vacuum gage previously described.

In order to shorten the forming process, it is important that all moisture and humidity be removed from inside the tank beforehand. This is done by the application of high heat, either by passing current through the rectifier, or by circulating hot water. If an electric current is used, it is gradually increased from a low value until the anodes are brought to maximum heat. At the same time the vacuum pump exhausts the gases liberated from the anodes. Various schemes were tried out to faciliate and hasten this preparation for the forming process. This preparation is of the utmost importance in that the gases occluded in the metals can otherwise not be expelled at all, or only very slowly, when the cy inder is being finally evacuated.

Forming is usually started by treating each anode individually, the d-c. energy being dissipated in a small grid resistance. This is followed by six-phase forming, during which t me the rectifier may be connected to a commercial load. The time spent in forming at the factory varies between two and three days, and generally a similar procedure is carried out during erection at the power plant or substation. The forming process should be continued day and night with as few interruptions as possible, and therefore needs careful attention. It is understood that during this process the pumps have to be in operation continually, and also for a further length of time after the rectifier has been placed in service. Both processes have been very carefully worked out in every detail, and their successful application is a direct result of long and elaborate experimenting.

One of the difficulties that had to be overcome in connection with the satisfactory operation of the mer-

cury arc rectifiers, both during forming and in actual service, was internal flashing-over or back-firing. Such internal disturbances, which paralyze the valve effect, were overcome after years of investigation. They have occurred sometimes when the forming process was not carefully carried out, or because of neglect in properly checking the material, especially that used for the anodes. However, if the proper precautions are not taken, such disturbances can occur during the forming process even now.

Ignition and Excitation Control of Novel Design. A typical diagram of connections is given in Fig. 14, which shows all the auxiliary gear of a rectifier controlled and operated in an ingenious way. The outstanding feature is that the controlling, starting, etc., are accomplished by means of alternating current, which is taken from the usual control circuit, fed from the high-voltage line through an auxiliary transformer. No direct current is needed to strike the arc nor to control the ignition anode. The fact that it was possible to dispense with the d-c. source, usually a specially designed converter set, and the development of a simple control arrangement for both ignition and excitation, account for the very simple layout of such a plant, which can be made fully automatic by merely adding two special relays.

The rectifier starts automatically as soon as the circuit-breaker *C B* on the high-voltage side connects the main transformer to the high-voltage line. This breaker is mechanically coupled to the switch *S*, which connects the excitation transformer *T* to the a-c. control circuit. As soon as the switch *S* is closed, the ignition solenoid *B*, see also Fig. 10, is energized, and the ignition anode consisting of plunger *O* is immersed in the mercury cathode, thereby closing another circuit through the right-hand secondary winding of the excitation transformer *T* and the two relay coils *R*. The right-hand relay, as soon as it is energized, in turn opens the ignition coil circuit, and the ignition anode is withdrawn from the mercury cathode by the action of the spring, thus striking an arc and enabling the rectifier to pick up load on the d-c. side at once. Should it happen that the polarity is not correct, the arc is immediately extinguished and the right-hand relay deenergized again, thus causing a repetition of the ignition process until the arc has the correct polarity. As soon as the excitation anodes are working the ignition circuit is broken by the action of the left-hand relay *R*.

The time which elapses from the moment the circuit-breaker relay receives an impulse to close the circuit breaker to the moment the rectifier is able to handle load is usually less than two seconds. The value of such a simple and quick operation cannot be appreciated enough in connection with automatic substations, as well as in other ways. For instance, in substations equipped with rotary converters, it is possible to have a rectifier as a spare set which can instantly be placed into service to take care of peak loads of such short duration that the rotary converters as reserve units would miss them because of the time involved in starting them.

The d-c. voltage is controlled either by step-by-step regulation from the primary side of the transformer or by an induction regulator, hand or automatically operated. The arrangement with the induction regulator is decidedly preferable for lighting supplies, as the voltage can be varied smoothly and to any extent. For the case of traction supplies, and where the question of regulation is not of primary importance, the rectifier can be given a shunt characteristic with a four- or five-per cent rise of pressure with falling load, by the use of specially designed transformers or an *absorption reactance coil* connected in the neutral of the main transformer; see Figs. 5 and 14. Reference to the latter arrangement has already been made under "Theory" and further details of these two methods will be given below.

Parallel Operation. It is possible to feed two rectifier cylinders from one main transformer and in such a case it is essential that each cylinder takes its proper share of the total load. Moreover, a number of rectifiers, all fed from the same primary supply, must be able to operate in parallel with each other. Furthermore, a rectifier might be added to an existing d-c. plant, and have to operate in parallel with existing rotary converter or mercury arc rectifier units. In all these cases certain conditions must be fulfilled in order that the units may supply power to the same bus-bars without interfering with each other, and that each may take a proportionate share of the total load. In considering the conditions necessary for satisfactory parallel operation of rectifiers, it has to be kept in mind that the rectifier cannot feed back to the a-c. line, and also that the inherent load characteristics of rectifiers are somewhat different from those of other converters. Some of the essential considerations relative to these facts are given below.

For all practical applications of rectifiers it can be assumed that the voltage drop in the arc in vacuum decreases with increasing current, and the load characteristic is therefore similar to that of an over-compounded d-c. generator. From the above, it can easily be seen that rectifiers feeding the same bus-bars and connected in parallel to the same source of alternating current may not operate satisfactorily. To meet this condition, a sufficiently large inductance has to be inserted in the anode circuit of each rectifier so as to obtain a suitable load characteristic which assures satisfactory parallel operation of each cylinder over a given range of load. For instance, a correctly dimensioned choke coil can be used to obtain such an inductance. Incorporating the arrangement of the connections shown in Fig. 17B, the inductance or the flux set up in the choke coil can be limited to that part produced by the difference in the anode currents. The same

effect can be obtained by utilizing that part of the main transformer inductance which corresponds to the stray field, by using either a separate transformer for each rectifier, or a double six-phase arrangement, as given in Fig. 17A and C, respectively. However, the inductance set up in this way must be large enough to impress such a high voltage across the electrodes of a rectifier working in parallel with others but not taking a share of the load which will force it to pick up some of the load. The actual arc voltage, therefore,

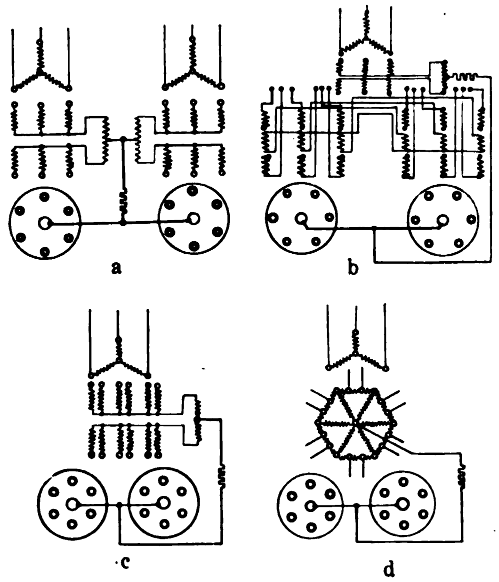


FIG. 17 A, B, C, D,—DIAGRAMS OF CONNECTIONS OF TWO RECTIFIERS IN PARALLEL

is less than the ignition voltage, and when several rectifiers are operating in parallel the unit having the lowest ignition voltage consequently picks up the load before the others. The voltage drop necessary for the operation outlined above cannot efficiently be obtained by means of ohmic resistance, and therefore methods such as those mentioned above for inserting an inductance into the anode circuit had to be developed so as to produce a satisfactory characteristic. As soon as all the rectifier units are taking their share of the load, their parallel operation is subject to the general conditions already stated. For comparison, all the methods of connection used to effect the desired characteristic for rectifier plants with more than one cylinder are given below, and are illustrated in Fig. 17A, B, C, D. In Fig. 17A, the effect is produced by making use of the leakage field of the main transformer; in Fig. 17B, by inserting a choke coil; in Fig. 17C, by means of the leakage field of the secondary winding only; and finally, in Fig. 17D, by doubling the number of phases on the secondary side.

As already pointed out, it is also essential that each unit take a proportionate share of the load when working in parallel. Two units are assumed to have falling-load characteristics E_1 and E_2, illustrated in Fig. 18. In can easily be seen that the distance between the two points of intersection of any horizontal straight line with the characteristics of the two sets gives the total current, I, supplied. The distance from the middle vertical line to the points of intersection gives the currents supplied by sets No. 1 and No. 2, respectively. The voltage of the two parallel working units is indicated by E. From this curve it is evident that an increase of the total load will be distributed according to the slope of the load characteristic.

It is sometimes desirable to have a rectifier working in parallel with rotary converters or motor generators. The efficiencies of the two latter types of converters are lower at overloads and at partial loads than the efficiency of the rectifier. In order to obtain, therefore, a good annual average efficiency for the plant, it is desirable to design these two types of converting devices for such load characteristics that in parallel operation the rotary converter or motor generator is always working at practically full load, while the fluctuating peaks are taken care of by the mercury arc rectifiers. Assuming that the load characteristic of the motor generator is shown on the right-hand side of Fig. 18, and the load characteristic of the mercury arc rectifier on the left-hand side, it is evident from the figure that the rectifier will take by far the larger share of a given increase in load.

Efficiency and Power Factor. Apart from other considerations, the outstanding electrical characteristic of the rectifier is its efficiency, which remains nearly constant at all loads; but to obtain the true commercial efficiency we must include all losses between the high-tension terminals of the transformer and the d-c. busbars. These losses are the losses in the transformer, excitation equipment, vacuum pump, and reactance coils. The constant efficiency of the rectifier alone is due to the drop in the arc being approximately constant

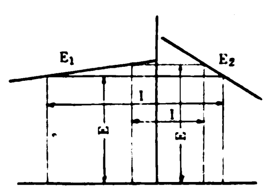


FIG. 18—PROPORTIONATE SHARE OF THE TOTAL LOAD BETWEEN A RECTIFIER AND A MOTOR GENERATOR

under all load and pressure conditions. This drop varies roughly between 16 and 23 volts according to the size of the rectifier, and is influenced by the vacuum to which it is directly proportional. The actual amount of watts dissipated in the rectifier is, therefore, simply the total drop multiplied by the current for any particular load, which gives a constant efficiency under all conditions. Thus when operating at 500 volts, direct current, the efficiency of the rectifier is represented by

$$\frac{500}{500 + 20} = 95.5 \text{ per cent.}$$

These indications show that the higher the d-c. voltage, the better will be the efficiency. For voltages up to 8000 volts, efficiency curves are plotted in Fig. 19A.

The over-all efficiency over the whole working range for 600-, 1500-, 300-, and 500-volt rectifiers of standard types is shown in Fig. 19B.

In general the power factor varies between 90 and 95 per cent. Reference was made to this under

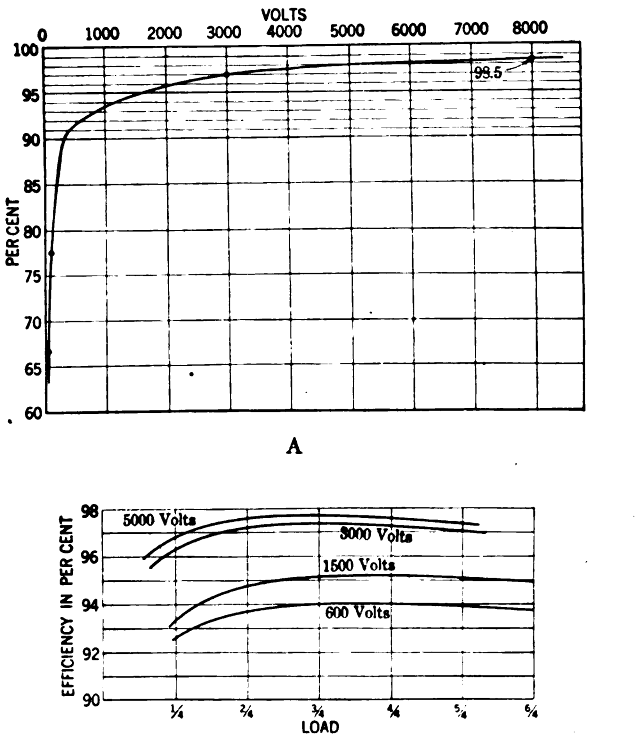


FIG. 19A,-B—OVER-ALL EFFICIENCIES OF RECTIFIERS FOR VARIOUS VOLTAGES

"Theory" and since it depends to a great extent on the external circuit further considerations are omitted.

Overloads. It is the very high momentary overloads that the rectifier can deal with that makes it preeminently suited for traction conditions where the average load is below full load. The consequence of this is that rather smaller normally rated sets can be employed than if, for instance, rotary converters were used.

Traction rotaries must necessarily be amply rated; otherwise commutator trouble will be experienced under very heavy overload or short-circuit conditions. Sometimes this measure does not do, and some special schemes of load protection have to be employed.

Extensive load and short-circuit tests on rectifiers showed that practically any overload can be handled for a certain time with a complete absence of any bad effects on the rectifier proper.

As there are no moving nor wearing parts, the life of the rectifier is still unknown as none of the rectifiers installed more than 12 years ago have shown any signs of deterioration as yet. The arc takes place in a vacuum, and therefore there is not any appreciable chemical effect on the anode or on the cylinder. No change either in the size or the shape of the anodes or of the inside surface of the cylinder that would in any way affect the operation of the rectifier could be observed. On the contrary, experience has shown that the longer the rectifier is in operation the better are its efficiency and its overload characteristic. The vacuum pump runs for such brief periods of time, and so infrequently, that the wear on its moving parts is negligible, while the development of the a-c. ignition has done away with any other rotating parts.

ADVANTAGES OVER ROTARY CONVERTERS

The floor space usually occupied by rectifiers is about the same as that required for rotary converters for d-c. voltages up to about 600 volts. Above that, the space required is considerably less. Special foundations are not required for any voltages except what is needed to bear the stationary weight. For this reason, and due to the fact that the operation of the rectifier is noiseless, new substations need only be of the lightest

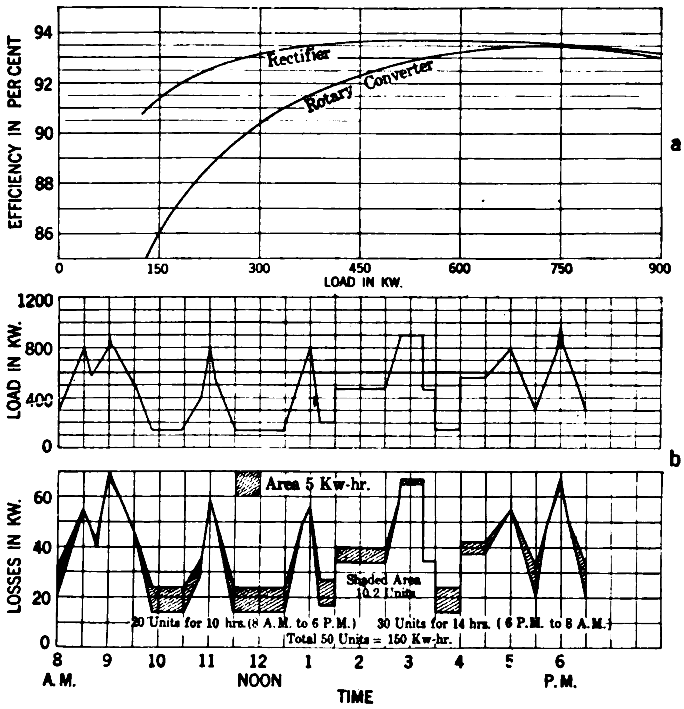


FIG. 21A—EFFICIENCY OF A 600-VOLT 600-KW. ROTARY CONVERTER AND MERCURY ARC RECTIFIER

B—LOAD CHART AND REDUCTION IN LOSSES BY THE USE OF MERCURY ARC RECTIFIERS INSTEAD OF ROTARY CONVERTERS

construction, and substations can, therefore, often be placed in locations that would not be at all suited for the installation of rotating machinery because of the vibration and noise.

Starting. Among the most striking advantages of the mercury arc rectifier over the rotary converter is the simplicity of the starting procedure. It takes a few seconds only to ignite the arc and put the rectifier

into service. This makes it preeminently adapted to automatically controlled substations. Since a rectifier has no standby losses, like a rotary converter, it can be generally left connected to the high-voltage supply, and in case of a short circuit at the primary side of the transformer, the rectifier disconnects itself from the network at the moment the arc extinguishes, and it will pick up the load as soon as the a-c. voltage is restored. However, even in manually operated substations, the attendance is greatly reduced, as will be explained at length later on.

Efficiency. To illustrate what the superiority of the rectifier efficiency really means, especially the efficiency at partial loads, a typical case of an actual railroad in the United States has been taken and the annual saving effected worked out on the basis of the daily-load curve. The curve in Fig. 21A shows the comparative efficiency of mercury arc rectifiers and rotary converters for 600-volt direct current. The conservative efficiency curves do not alter the comparative losses of the two classes of equipment nor the saving effected. The difference in the losses for the two sets is represented by the shaded area between the two lower curves of Fig. 21B and if this is averaged over 24 working hours it will be found that the losses of the rotary converter exceed those of the rectifier by about 125 kw-hr., representing, at a current cost of one cent per kw-hr., an annual saving of approximately $450 for a 600-kw-hr. mercury arc rectifier substation which represents half the interest on the investment required for such a substation.

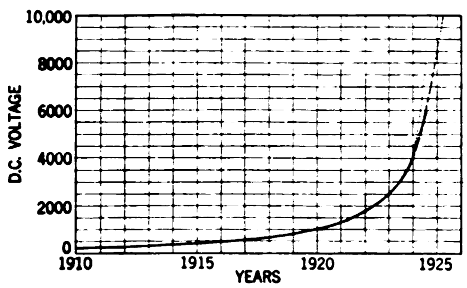


FIG. 22—MAXIMUM D-C. VOLTAGES OF RECTIFIER INSTALLATIONS IN SERVICE AND IN LABORATORY TESTS

As shown in Fig. 19A, the efficiency of a rectifier increases with the voltage; so these savings would increase appreciably at the high voltages. But even at the comparatively low voltage for which the above figures were computed the saving is worth considering. For a d-c. voltage of 1500 volts the annual saving would be over $1000.

As d-c. motors for terminal pressures of 2000 volts can be built to operate with perfect satisfaction, there is no reason why d-c. line pressures of 4000 volts cannot become widely adopted for railway service. In fact, the Torino-Lanzo-Ceres Railway in Italy has already been using that voltage for some time, and has obtained the best kind of service from its rectifier.

Needless to say, such voltages would be impracticable with rotary converters. The increase in the voltages on the d-c. side successfully used with rectifiers during the past 15 years is shown by the heavy line in Fig. 22, while the broken line shows the voltages which have been tested successfully at long trial tests, and the light dotted line, the voltages obtained during short laboratory tests. Following the extension of the voltage curve, it may be concluded that the next few years will possibly give us rectifiers furnishing direct current at pressures suitable for high-power transmission.

Another advantage of note is the fact that for the parallel operation of rectifiers there is no elaborate synchronizing procedure required. Since polarity indicators are also not needed, another possible source of trouble is eliminated. These facts again decrease the amount of special equipment necessary for an automatically or remotely controlled substation, while in a manually operated substation the attendant's duties are further reduced.

Automatic Control. The equipment for the full automatic operation of mercury arc rectifier substations costs less than half as much as for a rotary converter substation of the same capacity. Not only is the equipment cheaper, but because it is also simpler a better operation is assured.

The automatic operation of the vacuum pump is likewise an important advantage of the rectifier equipment. The vacuum gage previously described opens and closes the pump-motor circuit independently of the operation of the rectifier set itself, and always maintains the vacuum at the proper stage for immediate starting.

Making allowance for interest, depreciation, and taxes on the additional investment required for full automatic control of rectifier substations, and taking into consideration the salaries for high grade inspectors to look after the automatic equipment periodically, there will be effected a saving of $500 per year even in a small substation of only 600-kw. capacity.

Another great advantage accruing from the use of mercury arc rectifiers is the fact that changes in voltge can be made without any change in the rectifier. For instance, a railroad equipped for using 600-volt direct current can be changed to 1200-volt direct current merely by changing the connections of the transformers, and making no changes whatever in the rectifiers. Needless to say, this could not be done with rotary converters. Furthermore, the additional traffic that can be handled by making this change would represent another great advantage, all without any extra cost except the slight additional expense of having the transformers equipped with taps for making the change in the connections. As mentioned before, these rectifiers are able to withstand short circuits for a few moments without any harm, and can stand the severest overloads, taking instantaneously currents of even three times the normal value.

As an example of the short-circuit current one of the high-voltage rectifiers is capable of dealing with, it may be mentioned that a rectifier the normal capacity of which is 1800 volts and 400 amperes successfully passed a momentary current of 8700 amperes and was able to resume operation immediately upon clearing the short circuit. Sixty similar short circuits were applied within two days, after which the rectifier was opened and found to be in precisely the same condition as when sealed prior to these tests. In another instance, 10 short circuits were applied at one-minute intervals, and again there were no deleterious effects.

As mentioned under "Operation," the wear on the rectifiers is practically negligible.

The author gratefully acknowledges the valuable suggestions and assistance of Mr. Harold Winograd.

Abridgment of

Law of Magnetization

BY S. L. GOKHALE[1]

Member, A. I. E. E.

Synopsis.—*The purpose of the study which constitutes the subject matter of this paper was to investigate the reliability of Frolich's law of magnetization near saturation.*

For the last forty years, Frolich's law has been accepted as the most reliable expression representing the relation of magnetizing force to the magnetic induction produced thereby in ferro-magnetic materials. In the course of the study it was found that the law is not as reliable as it is generally believed to be, particularly for purpose of computation of saturation value. It was also found in the course of the same study that this part of the curve follows the law,

$$B - H = S\,(1 - b\,e^{-aH}) \quad . \; . \; . \; (\textit{equation } \mathbf{30\text{-}2})$$

more closely than any other law yet formulated. This law and Frolich's law are both in harmony with Weber's theory of molecular orientation. (See equations **24, 25, 26**).

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1. Purpose of the Investigation and Plan of Presentation of Results

The progress of scientific and industrial development of production, distribution, and control of electrical energy depends very largely on the knowledge and understanding of the laws representing the relation of electric current to magnetism. During the last hundred years, various attempts have been made to obtain correct information about these laws. The analytical study and experimental work which constitutes the subject of this paper is one more effort toward the same goal; it is limited to a study of the law of magnetization for flux density in the neighborhood of saturation. Stated symbolically, the subject of this investigation is the equation,

$$B = F\,(H) \qquad (\mathbf{1})$$

and the problem in hand is the determination of the form of the function $F\,(H)$ and its properties. For reasons to be explained later, the form of the problem is slightly modified in the course of the study. (See § 3, equation **4**, and § 9, equation **23**.)

The plan of presentation of results which is followed in this paper is:

Nomenclature and symbols, with illustrative curves. Attention is directed to characteristic peculiarities of curves which occupy an important place in the subsequent argument.

Study of Ewing's conception of intrinsic induction, and of Weber's theory of molecular orientation, as a ground work for formulating a law of magnetization. (§ 3, 4; equations **4**, **6**).

Presentation of Frolich's law as a hypothesis in relation to Weber's theory. (§ 5, equation **7**.)

Study of different forms of Frolich's law, with a view to formulate some crucial equations whereby the validity of Frolich's law can be tested. (§ 5, 6, 7, 20; equations **7**, **9**, **11**, **12**, **17**, **32** and **33**.)

Further study of Weber's theory, as groundwork for equation of progress near saturation. (§ 8, 9; equations **22**, **23**).

Presentation of Frolich's law, as a hypothetic equation of progress. (§ 10, equation **24**.)

Experimental study of a curve of incremental permeability and reluctivity. It will be shown that the form of the observation curves does not support Frolich's law, but that on the contrary, its indications are in favor of Lamont's equation of progress. (§ 11, Fig. 3-1, equation **26**.)

(Supplement, § 20, Fig. 3-3, -4, equations **32**, **33**).

Law of latent induction ($\log \gamma = f - g\,H$) is derived as a corollary to Lamont's equation of progress. (§ 11, equation **29**.) This leads to the equation of magnetization, $B - H = S\,(1 - b\,e^{-aH})$, referred to in the synopsis. (Equation **30-2**.)

Study of saturation value and of $\beta\,H$, $\beta\,\mu$ and $H\,D$ curves for standard sheet steel. A study of these curves shows, first, that the magnetization curve for this material does not follow Frolich's law, and second, that for the part of the curve above $H = 300$, it follows the law $\text{Log}\ \gamma = f - g\,H$. (§ 12, 13, 14.)

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1. General Engineering Laboratory, General Electric Co., Schenectady, N. Y.

Presented at the Annual Convention of the A. I. E. E., at White Sulphur Springs, W. Va., June 21-25, 1926.

Study of H ρ curve. The apparent straightness of the H ρ curve seems at first sight to support Frolich's law, but a closer study of the curve reveals that this is due to its insensitive character, and proves that it has no evidential value (§ 15, equation **31-2**).

Corroborative evidence from tests on other typical samples (§ 16).

Further corroborative evidence from tests at the Bureau of Standards. (§ 17, Fig. **12-2, -4.**)

Practical application of both laws for purpose of extrapolation beyond the limits of test (§ 18).

Summary of conclusions.

Tables of data and curves.

The scheme of numbering the tables and curves is such that all figures with a common group number refer to tables with the same group number. The sub-numbers have no significance; they are used merely as a convenient mark for subdivision of the group. In view of the difficulties due to the large number of figures necessary to illustrate the various points of the argument, a few curves are selected for publication. Other curves will be available in the form of blue prints, for anyone who desires to study the results farther than they are given in this paper.

Necessary references to all curves, including those that are not published, will be found in the tables. References to published curves only are given in the body of the text, each in its proper place.

2. Nomenclature and Symbols

The following symbols are used in this paper:

B Total induction, or flux density (gausses).

β Intrinsic induction, or flux density (gausses).

H Magnetizing force, (gilberts per cm.: briefly g).

H Spatial induction, (gausses, See par. 3, note 1).

S Saturation value, *i. e.*, limiting value of β.

γ Latent induction, ($= S - \beta$). (See §4, 8).

μ Intrinsic permeability ($= \beta/H$, not $= B/H$).

ρ Intrinsic reluctivity ($= H/\beta$).

D Distribution ratio ($= \beta/\gamma$).

μ' Transformation rate ($= - d\gamma/dH$, or $d\beta/dH$); also called incremental permeability.

ρ' Incremental reluctivity, ($dH/d\beta$).

i_1 First inflection of β μ or H ρ curves.

i_2 Second inflection of β μ or H ρ curves.

a Coefficient of permeability ($= \mu/\gamma$) when used with reference to Frolich's law in its various forms (equations **7**, **8**, **9**, **12**, **16**, etc.).

a Coefficient of incremental permeability ($= \mu'/\gamma$) when used with reference to Lamont's equation of progress, and other equations derived from it. (Equation **27**).

σ Coefficient of reluctivity ($= 1/S$).

α Initial reluctivity ($\alpha = \rho - \sigma H$). This quantity is also defined as $\alpha = 1/aS$. (See equations **10** and **11**).

h Coefficient of magnetic hardness ($h = 1/a$) when used with reference to Frolich's law (see equation **13**).

Curves are designated by joint use of the variables involved, for example, β H, β μ, H ρ curves; when one of the variables is logarithmic, a comma is inserted, for example H, log γ curve.

For illustration of these symbols see Fig. 1.

NOTES: The symbol H is used in two senses but this ambiguity does not lead to any inconvenience or mis-

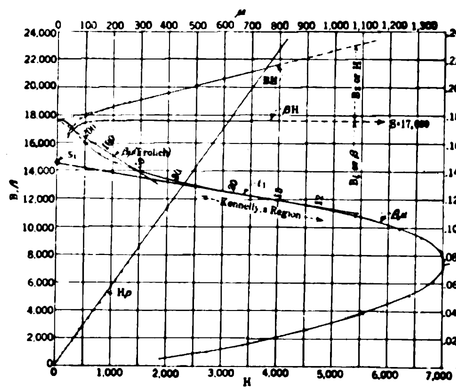

FIG. 1-1—SILICON STEEL (SAMPLE NO. R437-6)

understanding, as the context is clear in all cases. The same remark applies to the symbol a.

The symbol μ, in the usual sense of B/H, is not used in this paper.

The symbol ρ, in its original sense of H/B, is not used in this paper.

The numerical figures on the β μ curve refer to the

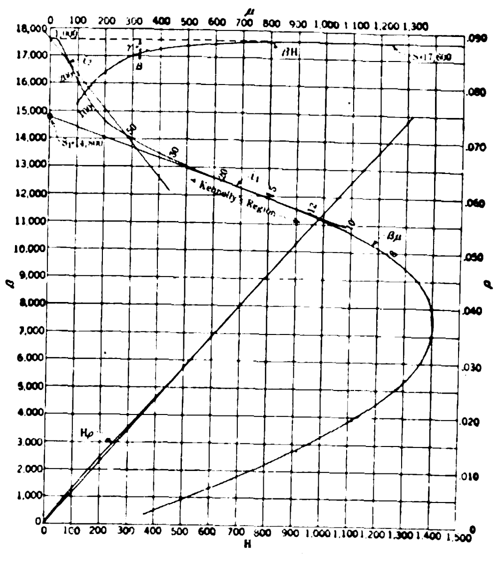

FIG. 1-2—MAGNIFIED SECTION OF FIG. 1-1

values of H for the corresponding points. The straight line drawn in relation to the β μ curve is a hypothetic β μ curve for Frolich's law, that is, the β μ curve which would be represented by this straight line if the material followed Frolich's law, within the limits indicated. (Fig. 1-1, -2, -3.)

In relation to the reluctivity curve, the straight line passing through the origin is the ideal reluctivity curve,

that is, a curve for a hypothetical sample of material having the same saturation value as the test sample but having no magnetic hardness, so that the material is supposed to be saturated from the s art. (Fig. 1-1, -2, -3.)

In studying the various curves, the following characteristics should be noted; their significance will be explained later.

(a) The β H curve has the appearance of a hyperbola, asymptotic to the saturation line (Fig. 1-1, -2, -3).

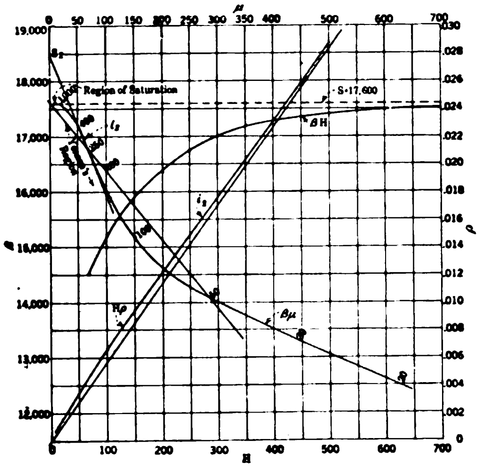

FIG. 1-3—MAGNIFIED SECTION OF FIG. 1-2

It will be shown later that the curve is not truly hyperbolic.

(b) For values of H above a certain limit, ($H = 50$ approx.), the H ρ curve appears to be almost a perfect straight line (Fig. 1-1, -2, -3). Even below $H = 50$, the curvature is scarcely noticeable.

(c) For corresponding values of H, the β μ curve is not straight. It contains three straight sections, *viz.*, regions of Kennelly, Yensen, and saturation. (Fig. 1-1, -2, -3.) For further discussion on this point, see §14.

(d) The H D curve is not straight; it has the appearance of an exponential curve. The corresponding logarithmic curve is comparatively straight; in the particular case selected for illustration, the logarithmic curve seems to be made up of two separate straight lines, with a seemingly abrupt bend at $H = 370$ (Fig. 1-6).

3. EWING'S CONCEPTION OF INTRINSIC INDUCTION

Prior to the year 1890, the various laws of magnetization propounded by several physicists were equations of the form $B = F(H)$ or other equations derived therefrom. In 1890, Prof. Ewing showed that the induction in all ferro-magnetic material could be conceived as made up of two components, each following its own characteristic law.

$$B = B_s + B_i \quad (2)$$

where

$$B_s = F_1(H) = H$$

and

$$B_i = F_2(H)$$

NOTES: B_s is the spatial induction, that is, induction in the space as a magnetic property of the space irrespective of the magnetic character or condition of the material occupying that space. It is supposed to follow the very simple law $B_s = H$. (See Fig. 1-1).

B_i is the intrinsic induction which depends on, and is an undetermined function of, H; it is signified by the symbol β in this paper. (See Fig. 1-1.)

B is the resultant induction in the magnetic material. Using the notation of §2, Ewing's conception is

$$B = H + \beta \quad (3)$$

The problem of determining the law of magnetization is thus reduced to a determination of the equation,

$$\beta = F(H) \quad (4)$$

In view of the fact that Ewing's conception is now generally accepted, it is considered necessary to revise the laws of Lamont, Frolich, etc., and regard them as referring to β, although in their original form they referred to B.

4. WEBER'S THEORY OF MAGNETIZATION, AND CONCEPTION OF LATENT FLUX

According to Weber's theory, as modified by Ewing, all magnetic material consists of molecular magnets; the question regarding the cause of magnetism of the molecules is irrelevant for our present purpose, and is therefore left out of consideration in this paper.

The process of magnetization is merely a process of orientation of the molecules.

In the non-magnetized condition the molecules form a large number of small groups, each group making a small but complete magnetic circuit.

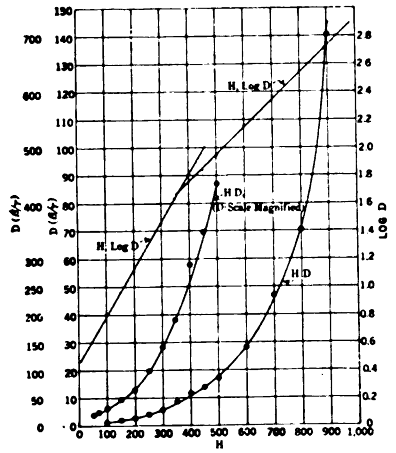

FIG. 1-6—H D AND H LOG D CURVES

The molecules in each group are held in their place by magnetic forces which originate in the molecular magnets of that group as well as of neighboring groups.

When a magnetizing force is applied to the magnetic material, each molecular magnet acting as a compass needle tends to turn around and place itself in a line parallel to the magnetizing force. This tendency is partly opposed by the counteracting magnetic forces of the neighboring molecules.

The function of the magnetizing force is therefore merely to determine the configuration of the molecules. For each configuration there is a certain magnitude of H necessary to produce it.

The total flux of the oriented molecules across any section of the magnet is the manifest flux, and this flux, divided by the area of that cross-section, is the manifest induction; it is represented by the symbol β.

The total flux of the unoriented molecules across the same cross-section is the latent flux; it is made up of two groups of flux lines in opposite directions making an algebraic total of zero lines. The total number of these lines reckoned without consideration of direction is the latent flux, and this flux divided by the sectional area of the whole magnet is the latent induction; it is represented by the symbol γ.

The total intrinsic flux in a magnet across any section is the aggregate of flux lines of all molecules irrespective of the direction of the lines. This is a constant quantity not dependent on the magnetizing force, being determined only by flux in each molecule and by the total number of molecules in the plane of the cross section; it is represented by the symbol S.

The function of the magnetizing force is to establish a

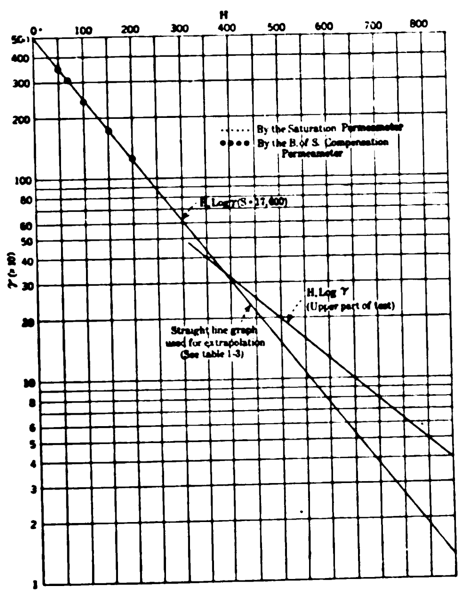

FIG. 1-7—H γ CURVE

configuration of the molecules and therefore the distribution of S into its two components β and γ. (See Fig. 1-2.)

Weber's theory may therefore be stated analytically by the equations,

$$\beta + \gamma = S \tag{5}$$

and

$$\beta / \gamma = F\,(H) \tag{6}$$

the form of the function H being undetermined for the present.

5. FROLICH'S LAW: HYPOTHETIC EQUATION OF DISTRIBUTION RATIO

We have seen that according to Weber's theory $\beta/\gamma = F\,(H)$, the form of the function being yet undetermined. If at this point we assume that the distribution ratio is not only a function of H but is directly proportional to H, we arrive at the equation,

$$\beta/\gamma = a\,H \tag{7}$$
$$= H/h$$

where $h = 1/a$,

or

$$D = a\,H = H/h \tag{7-2}$$

This equation may be called Frolich's hypothesis be-

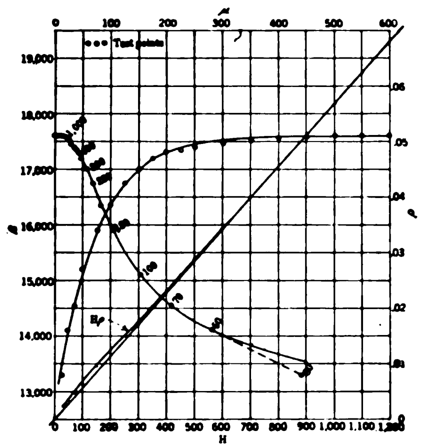

FIG. 1-8—RECONSTRUCTION OF CURVES BY LOGARITHMIC LAW

cause it is implied in Frolich's law. It has not been explicitly stated in this form by Dr. Frolich or by any one else. Substituting for γ its equivalent $S - \beta$, we get

$$\beta/\gamma = a\,H$$

$$\therefore \beta/(S - \beta) = a\,H \tag{8}$$

$$\therefore \qquad \beta = S\,.\,a\,H/(1 + a\,H) \tag{9}$$

$$= S - S/(1 + a\,H) \tag{9-2}$$

This is Frolich's law (*E. T. Z.*, 1886, p. 164).

Equation (**9**) can also be expressed as

$$\beta = \frac{H}{\dfrac{1}{a\,S} + \dfrac{H}{S}}$$

$$= \frac{H}{\alpha + \sigma\,H} \tag{10}$$

where

$$\alpha = 1/a\,S, \text{ and } \sigma = 1/S.$$

This is another form of Frolich's law (*E. T. Z.*, 1882, p. 71).

From equation (**10**) we obtain

$$H/\beta = \alpha + \sigma\,H$$

or

$$\rho = \alpha + \sigma\,H \tag{11}$$

or

$$\rho = (H + h)/S \tag{11-2}$$

This equation is known as Kennelly's law. It was formulated first by Prof. Fleming, who derived it as a corollary to Frolich's law, (J. I. E. E. *Trans.*, 1886, p. 569); second by Dr. Kennelly, who derived it independently of Frolich's law, empirically from a study of the published data of Ewing, Rowland and Du Bois, (A. I. E. E. TRANS., 1891, p. 503-517); and third by Dr. Steinmetz, who derived it also as an empirical law from the study of data published by Dr. Corsepious, (*E. T. Z.*, 1892, p. 203).

From equation (**8**) we also obtain directly

$$\beta/H = a\,(S - \beta)$$

or

$$\mu = a\,(S - \beta) \tag{12}$$

or

$$\mu = \gamma/h \tag{12-2}$$

This is Bosanquet's law, (*Electrician* 1886, p. 247). Equation (**12**) may also be derived directly from equation (**11**) by purely algebraic process involving no other equations except the defining equations,

$$\mu = \beta/H$$
$$\rho = H/\beta$$
$$\alpha = 1/a\,S$$

and

$$\sigma = 1/S$$

The relation of equation (**12**) to equation (**11**) is not dependent on their relation to equation (**7**) or (**8**) or to any other hypothesis. From this it follows that if any part of the $H\ \rho$ curve is straight, the corresponding part of the $\beta\ \mu$ curve must also be straight.

Again, starting with equation (**9**)

$$\beta = S\,.\,a\,H/(1 + a\,H)$$

and using a symbol $h = \dfrac{1}{a}$ (see equation **7-2**), we get

$$\gamma = S\,h/(H + h) \tag{13}$$
$$\beta = S\,.\,H/(H + h) \tag{14}$$
$$= S - S\,h/(H + h) \tag{15}$$

NOTE: The relation of equations (**7-2**), (**9**), (**11-2**), (**12-2**), (**13**), (**14**), (**16**) and (**17**) can be easily demonstrated geometrically with the help of Fig. 2-1. For example,

$M\,P/P\,N = O\,M/N\,Q$ or $\beta/\gamma = H/h$, equation (**7-2**).

Again $M\,P/O\,S = O\,M/S\,Q$, or $\beta/S = H/(H + h)$, equation (**14**).

Equations (**13**), (**14**) and (**15**) are equations for Frolich's law in its analytical form. They lend themselves easily to computation of β and γ for any value of H. Equation (**15**) is preferred in this paper in the preparation of the several tables. For example, see Table II. The several equations given above lead us to expect that

1. If Frolich's law be true for the entire curve above any value of H, the corresponding parts of the $H\ \rho$, $\beta\ \mu$ and $H\ D$ curves should be straight lines, as the corresponding equations are all of the first degree. (See equations **7-2**, **11** and **12**. Fig. 2-1.)

2. If Frolich's law be true only between certain limits and not true above and below that limit, the $H\ \rho$ and $\beta\ \mu$ curves should be straight between those limits, but the $H\ D$ curve should not be straight even between those limits if the true saturation value determined by measurement be used as a basis of computation, unless the value of S indicated by the straight part of the $H\ \rho$ or $\beta\ \mu$ curve happens to be the true saturation value. No concrete instance of such exceptional coincidence has yet been observed.

3. In no case is it possible to find a particular part of the $H\ \rho$ curve straight unless the corresponding part of the $\beta\ \mu$ curve is also straight.

These three curves, *viz.*, the $\beta\ \mu$, $H\ \rho$ and $H\ D$ curves, are therefore three practical tests whereby the truth of Frolich's law for any part of the $\beta\,H$ curve may be

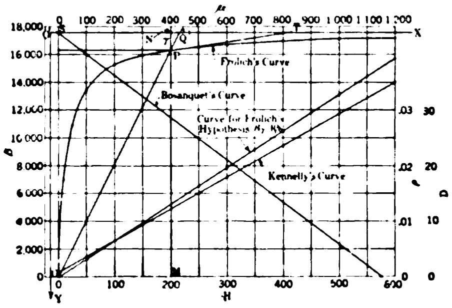

FIG. 2-1—FROLICH'S LAW AND COGNATE CURVES

The $\beta\ H$ curve is an equilateral hyperbola with asymtotes $O'\,X$, $O'\,Y$

$\beta = M\,P$	Then	$\beta/H = S/(H + h)$	Frolich's Law
$\gamma = N\,P$		$\beta/H = \gamma/h$	Bosanquet's Law
$H = O\,M = S\,N$		$H/\beta = (H + h)/S$	Kennelly's Law
$S = O\,S$		$\beta/\gamma = H/h$	Frolich's Hypothesis
$h = O'\,S = N\,Q$		$\beta/S = H/(H + h)$	
$H + h = O'\,N = N\,T = S\,Q$		$d\beta/d\,H = P\,N/N\,T$	
		$= r/(H + h)$	
		$= r^2/S\,.\,h$	Frolich's Equation of Progress

tested; two other practical tests will be described later. (See §6 and 20.)

6. FROLICH'S EQUATION OF PROGRESS AND EMERY'S LAW

By differentiation of equation (**12**), we obtain,

$$\mu' = \frac{a}{S}\,(S - \beta)^2 \tag{16}$$

$$= K\,(S - \beta)^2 \tag{17}$$
$$= \gamma^2/S\,h$$

where

$$K = a/S = 1/S\,h.$$
$$\therefore \mu = \gamma/H + h) \tag{17-2}$$

(See equation **13**.)

This is Frolich's equation of progress of magnetization. (*E. T. Z.*, 1886, p. 164.) By reintegration of equation (**16**), we get

$$\beta = S\,(a\,H + c\,S - 1)/(a\,H + c\,S) \tag{18}$$

or

$$\beta = S - S/(a\,H + c\,S) \tag{19}$$

where c is an undetermined constant of integration. This is Emery's law. (A. I. E. E. TRANS., 1892, pp. 209, 215.) In equation (**18**) or (**19**), if $c = 1/S$, the equation reduces itself to the form

$$\beta = S \,.\, a\, H/(1 + a\, H) \tag{9}$$

or

$$\beta = S - S/(1 + a\, H) \tag{9-2}$$

This is Frolich's law.

From Emery's law we have,

$$\beta/\gamma = a\, H + c\, S - 1 \tag{20}$$

According to Emery's law the distribution ratio expressed as a function of H is a straight line not passing through the origin except in the particular case where $c\, S - 1 = 0$ in which case Emery's law becomes Frolich's law; in either case it is a straight line. Equation (**16**) is an equation of first degree for μ' and second degree for β. Therefore, if Frolich's law be true, the corresponding curve should be a parabola with the vertex at the point S on the axis of β, and with its directrix parallel to the axis of β.

7. Study of Equations of Distribution Ratio (Equations 7 and 20)

We have seen that Frolich's law in all its forms, and even Emery's law, involves the hypothesis that the distribution ratio is a linear function of H. Such an assumption has no justification either theoretical or empirical. Fig. 1-6 shows the curve for distribution ratio for a selected sample of silicon steel.. This curve is certainly not a straight line. On the theoretical side we have against it the negative fact that no reason has yet been given to explain why the ratio β/γ should be a simple linear function of H. It is true that there is nothing inherently absurd in the assumption that the ratio of the components β and γ is proportional to magnetizing force; it does not conflict with Weber's theory, but neither is there anything in Weber's theory to justify or even to suggest that assumption; in fact even the form of the general equation (**6**), that is, $\beta/\gamma = F\,(H)$, does not express the fundamental nature of the phenomenon which would be better expressed by a differential equation of the form,

$$d\,\beta/d\,H = F\,(\beta, \gamma)$$

although the final result may be expressed in any convenient form, including the form,

$$\beta/\gamma = F\,(H)$$

NOTE: We have seen that the curve β/γ as a function of H is not straight, but has the appearance of an exponential curve corresponding to the equation $\beta/\gamma = e^{H}$. (See §2 par. d.) If this conjecture be correct, the curve for log β/γ should be a straight line. This expectation is found to be partly justified by Fig. 1-6. This point will be discussed more fully later. (See §13, equation **30-4**.)

8. Equation of Progress According to Weber's Theory

According to Weber's theory, the values of β and γ for any value of magnetizing force depend on the configuration which has been reached under the influence of that force, and which is therefore determined by the condition of equilibrium between the internal and external magnetic forces when that configuration is established. The internal forces are those due to the interaction of the magnetic poles of the molecules, from which it follows that the forces which oppose the change of configuration at any step in the process of magnetization are determined by the configuration itself. According to this conception, the process of magnetization is a progressive process made up of changes of configuration in successive steps, and is, at each step, accompanied by a transformation of a small part of the latent induction $d\,\gamma$ into an equal amount of manifest induction $d\,\beta$, under the influence of the incremental magnetizing force $d\,H$. The fundamental law of magnetization should therefore be an equation of the form,

$$d\,\gamma/d\,H = -\,F\,(\beta, \gamma) \tag{21}$$

or

$$d\,\beta/d\,H = F\,(\beta, \gamma) \tag{22}$$

Equations (**21**) and (**22**) are identical, being merely the negative and positive aspects respectively of the same transformation process. In formulating this conception, the transformation ratio $(d\,\gamma/d\,H)$ is expressed as a function of β and γ, but not as a function of H; this is because, according to the conception under discussion, the transformation of $d\,\gamma$ into $d\,\beta$ is brought about by the operation of the increment $d\,H$, not by the whole magnetizing force H. The function of the magnetizing force H is to establish the corresponding configuration by counteracting the opposing internal forces, and when that configuration has been reached the function is exhausted. Any further change in the value of β and γ is brought about by the incremental component of force $d\,H$, and the magnitude of this component necessary for unit change in γ and β is determined by the component of internal force which it has to oppose and overcome. This component of internal force is the result of, and therefore some mathematical function of, the configuration itself, that is, a function of β and γ; it follows therefore that the rate of transformation $d\,\gamma/d\,H$ must be fundamentally a function of β and γ but not of H. But since β and γ are themselves functions of H, it also follows that $d\,\gamma/d\,H$ is capable of being expressed as a function of H, although such an equation would not be the fundamental equation.

9. Equation of Progress Near the Saturation Limit

We have seen that $d\,\gamma/d\,H$ is a function of β and γ. (See equation **21**.) At this point, we can introduce a further simplification by limiting the problem to the part of the curve near saturation. As saturation approaches, the manifest component of flux β becomes practically constant. The corresponding oriented molecules are now practically in the final stage of orientation; their influence in opposing any change of configuration is

now practically constant irrespective of how great or how small that influence happens to be; this makes the transformation ratio depend on the γ component of S only, which is now practically the only variable in the function.

Thus we have the equation,

$$d\,\gamma/d\,H = -\,F\,(\gamma) \qquad \textbf{(23)}$$

the form of the function $F\,(\gamma)$ being yet undetermined; the determination of the function $F\,(\gamma)$ now becomes the main problem.

10. Study of Frolich's Equation of Progress

At this point we might make some assumption as to the form of the function $F\,(\gamma)$. If we assume $F\,(\gamma) = K\,\gamma^2$, we have

$$d\,\gamma/d\,H = -\,K\,\gamma^2 \qquad \textbf{(24)}$$

or

$$d\,\beta/d\,H = K\,(S - \beta)^2 \qquad \textbf{(25)}$$

This is Frolich's equation of progress (see equation **17**) wherein K represents the ratio of Frolich's constants, a/S, (see §6, equation **16**). The status of Frolich's law depends on the validity of the assumption

$d\,\beta\,d\,H = \dfrac{a\,(S-\beta)^2}{S}$. On the theoretical side no justification for this assumption has been given by Dr. Frolich or by any one else. On the empirical side, there is no experiment on record to demonstrate that the curve for incremental permeability as a function of β is a parabola such as is represented by the equation in question.

11. Form of Curve for Incremental Permeability and Equation of Latent Induction

In order to ascertain the validity of Frolich's assumption (Equation **16** or **24**), a sample of standard

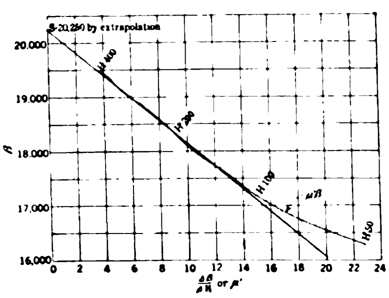

Fig. 3-1—Standard Sheet Steel Ring Curve of Incremental Permeability

steel in the form of a toroid ring was tested by the differential method. For details of test and result of measurement see Table III, Fig. 3. The curve plotted from test has certainly no resemblance to the parabola

representing the equation $d\,\beta/d\,H = \dfrac{a\,(S-\beta)^2}{S}$. Incidentally, we observe that the observation curve, though not perfectly straight, is very nearly a straight line for magnetizing forces above $H = 100$, and still more straight above $H = 200$. The test stops at $H = 400$; extrapolation of the curve indicates a saturation value of $S = 20{,}250$. (For true value of S, see next paragraph.) We might therefore follow the

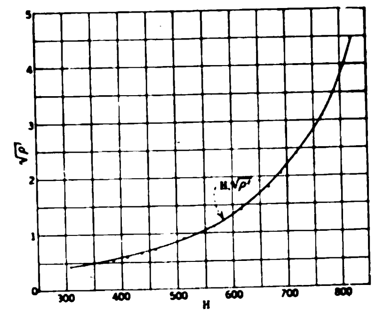

Fig. 3-3—Standard Sheet Steel Ring Curve of Incremental Reluctivity H as a Function of $\sqrt{\rho'}$

suggestion of this experiment and assume that the function $F\,(\gamma)$ in equation (**23**) is $a\,\gamma$.

This leads to the equations

$$d\,\gamma/d\,H = -\,a\,\gamma \qquad \textbf{(26)}$$

or

$$d\,\beta/d\,H = a\,(S - \beta) \qquad \textbf{(27)}$$

This is Lamont's hypothetical equation of progress. By integrating either of these, we have

$$\log_e \gamma = C - a\,H \qquad \textbf{(28)}$$

where C is an integration constant,

or

$$\log_{10} \gamma = f - g\,H \qquad \textbf{(29)}$$

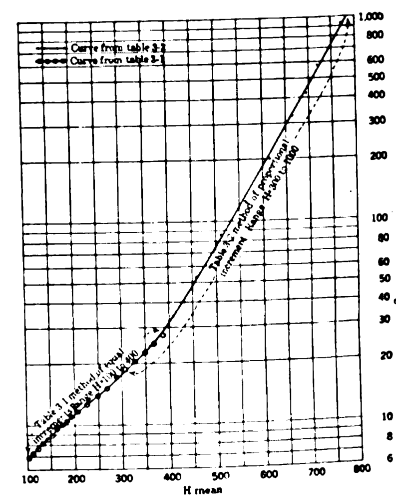

Fig. 3-4—Curve of Incremental Reluctivity H as a Function of Log ρ'

From equation (**28**), we get

$$\beta = S\,(1 - b\,e^{-aH}) \qquad \textbf{(30)}$$

where $b = e^c/S$,

or

$$B - H = S\,(1 - b\,e^{-aH}) \qquad \textbf{(30-2)}$$

This is the law of magnetization referred to in the synopsis.

Equation (**30**) is the same as Lamont's equation in form, but differs from it in the limitations which are implied in equations (**26**) and (**30**) but not recognized by Lamont, *viz.*, that the equation is true for parts of curve near saturation only (See par. 9). Lamont assumes that the equation is true for all values of H including $H = 0$, which makes $b = 1$; Lamont's equation therefore takes the form,

$$\beta = S\,(1 - e^{-aH}) \qquad \textbf{(30-3)}$$

This equation has no experimental support.

12. Law of Magnetization for Standard Sheet Steel

In order to ascertain the reliability of the extrapolation method based on the assumption $d\,\gamma/d\,H = -\,a\,\gamma$, the ring referred to in the last paragraph was unwound and rewound for higher magnetizing force reaching up to $H = 1000$, if possible. (For details of test and result of measurement, see Table IV, Fig. 4). The sample seems to be saturated at $H = 650$, reaching the saturation value of $S = 20{,}200$, which is in very close agreement with that indicated by extrapolation,

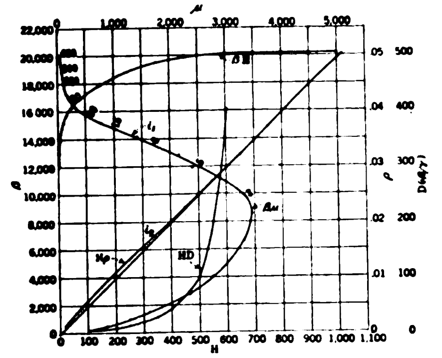

Fig. 4-1—Standard Sheet Steel Ring

viz., 20,250 (See Fig. 3). For magnetizing forces above $H = 300$, the observation curve is in very close agreement with the reconstruction curve representing the law, $\log\gamma = f - g\,H$; (see Fig. 4-4); it is not in as good agreement with the law $\beta = S\,a\,H/(1 + a\,H)$. (See Fig. 4-5.)

13. Curve of Distribution Ratio for Standard Sheet Steel

According to the equation (**7**), ($\beta/\gamma = a\,H$), the curve for distribution ratio should have been a straight line. The observation curve is certainly not straight, (Figs. 1-6, 4-1). On the contrary, the curve seems to be exponential, as it ought to be if equation (**30**) represented the true law of magnetization; for,

$$\beta = S\,(1 - b\,e^{-aH}) \qquad \textbf{(30)}$$

Then

$$\gamma = S\,.\,b\,e^{-aH}$$

Then

$$\beta/\gamma = (1 - b\,e^{-aH})/b\,e^{-aH}.$$

$$= \frac{1}{b\,e^{-aH}} - 1$$

$$= \frac{1}{b\,e^{-aH}} \text{ approximately as saturation approaches,}$$

or

$$D = e^{aH}/b \qquad \textbf{(30-4)}$$

or $\text{Log}_{10} D = p\,H + q$ (making due allowance for change of base). The corresponding observation curve

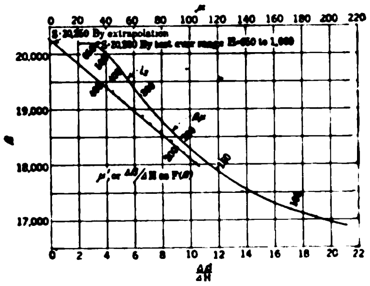

Fig. 4-2—Magnified Section of $\beta\mu$ Curve, Fig. 4-1 $\mu'\rho$ Curve from Fig. 3-1 Reproduced for Comparison

is approximately straight, showing that the distribution ratio is not a linear function of the magnetizing force as is required by Frolich's law, but nearly an exponential function as is required by the law of equations (**29**) and (**30**).

14. The Permeability and Reluctivity Curves

According to Frolich's law, equation (**12**), ($\mu = a\,(S - \beta)$, the $\beta\,\mu$ curve should be a straight line

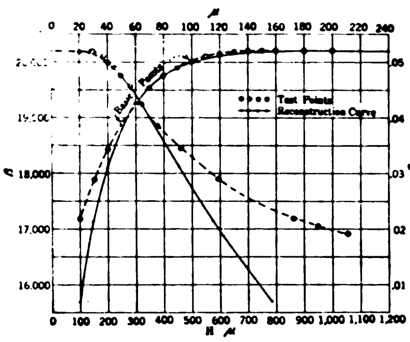

Fig. 4-4—Reconstruction of Curves by Log Law

intersecting the axis of β at the point S. The observation curve does not seem to fulfill this condition, (see Fig. 4-1, -2). For magnetizing forces above $H = 300$, the curve seems to follow very closely the law $\log\gamma = f - g\,H$. The complete $\beta\,\mu$ curve is not straight, but it has three straight regions.

1. First straight region, associated with the first inflection i_1 (Kennelly's region; see Figs. 1-1, 4-1).
2. Second straight region, associated with the second inflection i_2 (Yensen's region; see Figs. 1-3, 4-2).
3. Region of saturation.

The work of Dr. Kennelly was limited mostly to that part of the βH curve which corresponds to the first straight region, (see Fig. 5-2); and the work of Dr. Yensen was limited to the second straight region, (see Fig. 5-1). From the form of the $\beta \mu$ curve it is obvious that Frolich's law should hold true within the corresponding limits of H for each of these regions, but not for the whole curve above the first or even above the second region. The first and second regions can be

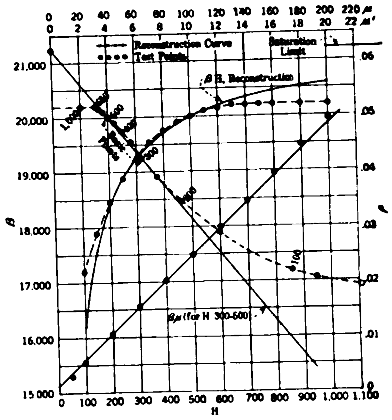

FIG. 4-5—RECONSTRUCTION OF CURVE BY FROLICH'S LAW ON THE BASIS OF YENSEN'S REGION

represented by the equations, $\mu = a_1 (S_1 - \beta)$, and $\mu = a_2 (S_2 - \beta)$, respectively, (see Figs. 1-1, -3), but it must be remembered that neither S_1 nor S_2 represent necessarily the true saturation value. In all cases observed thus far, S_1 is always less, and S_2 always greater, than S. (See Figs. 1-1, -2, -3; S_1 = 14,800, S_2 = 18,430, S = 17,600.) The curve for reluctivity as a function of H, *i. e.*, $H \rho$ curve, possesses all the characteristics of the $\beta \mu$ curve, but they are not so easily noticeable in the $H \rho$ curve, (see Figs. 1-1, -2; for points i_1 and i_2, see Figs. 1-3, 4-1, -2). The $H \rho$ curve seems to be almost a perfect straight line; in some cases, it seems to resolve itself into two straight lines connected by an apparently abrupt bend; in either case, the straightness is only apparent and misleading.

15. INSENSITIVE CHARACTER OF RELUCTIVITY ($H \rho$) CURVE

It has long been recognized that the reluctivity curves are always almost perfectly straight over a wide range although the corresponding parts of the $\beta \mu$ curves are not straight. (Kennelly: A. I. E. E., 1891, p. 531.) Theoretically, the $\beta \mu$ curve and the $H \rho$ curve are so related that if one of them be straight, the other must be straight also; the straightness of the $H \rho$ curve over a wide range is therefore anomalous, being mathematically impossible when the corresponding part of the $\beta \mu$ curve is not straight. The explanation of the anomaly lies in the insensitive character of the $H \rho$ curve in comparison with the $\beta \mu$ curve. The insensitive character of the $H \rho$ curve is inherent in the form of the function irrespective of the law of reluctivity.

This may be seen from the following analysis:

The insensitiveness of the reluctivity curve may also be demonstrated graphically by choosing for comparison two samples of magnetic material of nearly identical character. (See Table XII-III.) The differences between the two $\beta \mu$ curves are then easily noticeable, but the corresponding $H \rho$ curves are practically indistinguishable except near the upper end of the curves. Fig. 5-1 is a concrete example of insensitivity of the $H \rho$ curve. The data for this curve are taken from an experiment by Dr. Yensen (A. I. E. E. TRANS., 1920, p. 821). In the data as originally published, there appears to be a typographical error which becomes manifest in the βH and $\beta \mu$ curves but is scarcely noticeable in the $H \rho$ curve.

16. MAGNETIZATION CURVES FOR MAGNETIC METALS AND BINARY FERRIC ALLOYS

In view of the importance of the conclusions reached in the foregoing pages, it seemed advisable to extend the experiment to a variety of samples. The following list contains a few samples selected for purpose of demonstration; only toroid ring samples are included in this list.

1. Pure iron, electrolytic vacuum fused and vacuum annealed.
2. Pure nickel, 99.5 per cent nickel.
3. Pure cobalt, percentage not specified.

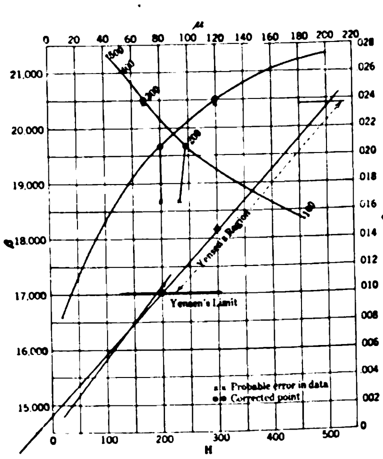

FIG. 5-1—YENSEN'S CURVE FOR 2 *N i* 204

NOTE: This sample was used by Mr. J. D. Ball in his well-known experiment: G. E. *Review*, 1916, p. 379.

4. Iron nickel alloy, 72 per cent nickel.
5. Iron cobalt alloy, 20 per cent cobalt.

For details of test and results of measurement see tables and curves in appendix.

A study of the curves shows that:

1. In all cases except cobalt, the samples are saturated well within the limits of test.
2. In all cases the complete $\beta \mu$ curve above the point of maximum permeability is not straight, but has all the peculiarities mentioned in par. 14, *viz.*, the two inflections and the three straight regions. In the case of

cobalt, the curve is incomplete but it demonstrates the first two straight sections.

3. The curve of distribution ratio is not straight as required by Frolich's hypothesis, but has the appearance of an exponential curve.

4. The βH curve by measurement is in closer agreement with the reconstruction curve according to the logarithmic law than with the reconstruction curve by Frolich's law. The same remark applies to the other derived curves, such as the $\beta \mu$ curve.

5. Below the second inflection, the βH curve does not follow the logarithmic law; according to the theory outlined above, this disagreement should be expected, for the rate of transformation is no longer capable of being represented by the simpler equation, $d \gamma / d H = - a \gamma$, but must be a more complex function involving both β and γ. (See equation **21.**)

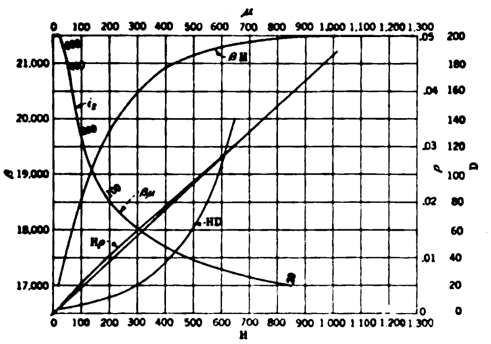

FIG. 12-2—ELECTROLYTIC IRON MAGNIFIED SECTION—TEST BY BUREAU OF STANDARDS

By way of further evidence in support of item (4), I may refer once more to Fig. 1, which has been obtained by the saturation permeameter. In this case also the βH curve is in closer agreement with the logarithmic law than with Frolich's law, (Fig. 1-8). Tests by the saturation permeameter run into several hundred samples. It is obviously not practicable to include them all in this paper, and I must therefore limit myself to the bare statement that in all cases the observation curve follows the logarithmic law much more closely than Frolich's law.

17. CORROBORATIVE EVIDENCE FROM TESTS AT THE BUREAU OF STANDARDS

Further evidence in support of the above findings will be found in the data from tests at the Bureau of Standards (See Table XII, Fig. 12). In this case the material under test was a group of samples of electrolytic iron carefully prepared by Dr. T. D. Yensen. The tests were made at the Bureau of Standards; both the material and the test results are of the highest order of reliability. The curves speak for themselves and need no further explanation.

18. PRACTICAL APPLICATION OF THE LAW LOG $\gamma = f - g H$

As a practical application of these conclusions, let us complete by extrapolation the incomplete βH curve for cobalt; the whole procedure is as follows:

19. SUMMARY OF CONCLUSIONS

We have found that:

1. According to Weber's theory of molecular orientation, the process of magnetization should be expressed fundamentally by an equation of progress of the form

$$d \gamma / d H = F_1 (\beta, \gamma)$$

and in its ultimate effect by the equation of distribution ratio of the form

$$\beta / \gamma = F_2 (H)$$

2. For the part of the curve near saturation, the equation of progress should be of the simpler form

$$d \gamma / d H = - F_1 (\gamma)$$

3. Frolich's law involves the assumption, fundamentally, that

$$d \gamma / d H = - K \gamma^2$$

and in ultimate effect that

$$\beta / \gamma = a H$$

This assumption has no theoretical justification or empirical support.

4. In the case of a toroid ring of standard sheet steel, it was found that for magnetizing forces $H = 200$ to 400, the progress of magnetization followed, approximately, the equation

$$d \beta / d H = a (S - \beta)$$

5. From the above equation, it follows that as saturation approaches, the magnetization should be expected to follow approximately the equation

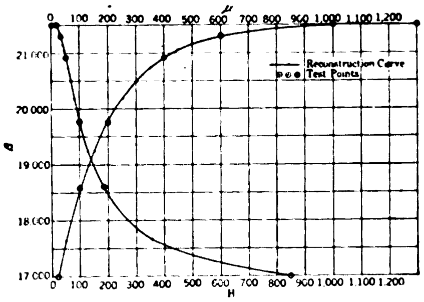

FIG. 12-4—RECONSTRUCTION OF CURVE BY LOG LAW

$$\log \gamma = f - g H$$

This expectation has been justified by subsequent verification (see next item).

6. For magnetizing forces above the second inflection of the permeability curve, the βH curve follows the law $\log \gamma = f - g H$ more closely than any other law yet formulated.

7. The part of the $\beta \mu$ curve above the point of

maximum permeability is not straight, but it contains three straight regions, *viz.*,

(a) The region of first inflection (Kennelly's region).

(b) The region of second inflection (Yensen's region).

(c) The saturation region.

8. It follows from this observation that a magnetization curve does not follow Frolich's law except in the first two regions mentioned above. The corresponding parts of the βH curve are segments of equilateral hyperbola corresponding to the equations

$$\beta = S_1 a_1 H/(1 + a_1 H)$$

and

$$\beta = S_2 a_2 H/(1 + a_2 H)$$

where S_1 and S_2 are the indicated saturation values corresponding to the two inflection regions. S_1 is always less, and S_2 always greater, than the true saturation values.

9. The part of the $H \rho$ curve above the point of minimum reluctivity appears to be very straight. The straightness of the $H \rho$ curve has been generally regarded as a conclusive evidence in favor of Frolich's law, but it has now been demonstrated that the straightness of this curve is only a geometric illusion, being caused by the insensitive character of the reluctivity function. The insensitiveness of the $H \rho$ curve has been proved analytically and demonstrated graphically. It follows therefore that the straightness of the $H \rho$ curve is misleading, and that the curve is therefore not reliable for purpose of drawing any conclusion as to the nature of the law of magnetization or for extrapolation of the βH curve. The $\beta \mu$ curve is a more reliable criterion, and the curvature of a $\beta \mu$ curve between any limits demonstrates conclusively the unreliability of Frolich's law for the corresponding range of the βH curve.

20. Incremental Reluctivity (Supplement)

In paragraph 11, reference is made to an experiment for determination of the incremental permeability $d\beta/dH$ as a function of β. The test stops at $H = 400$; all attempts to extend the test to $H = 1000$ have been unsuccessful. By slightly modifying the test procedure, it has become possible to determine the curve for ρ' or $dH/d\beta$ as a function of H for a range of $H = 400$ to 800. Differentiation of equations (9) and (29) leads respectively to equations of form

$$\sqrt{\rho'} = H + q, \text{ for Frolich's law} \quad \text{(32)}$$

$$\log \rho' = H + q, \text{ for logarithmic law} \quad \text{(33)}$$

From these equations it follows that for any range of H,

(a) If Frolich's law be true, the curve $H, \sqrt{\rho'}$ should be straight,

(b) If the law $\log \gamma = f - g H$ be true, the curve $H \log \rho'$ should be straight.

Figs. 3-3 and 3-4 represent graphically the result of a test and demonstrate that for the range $H = 400$ to 800, the $H, \sqrt{\rho'}$ curve is not straight, and that the $H \log \rho$ curve is straight, proving thereby that near saturation the βH curve follows the law $\log \gamma = f - g H$ far more closely than Frolich's law. For further details see complete pamphlet form.

TABLE I

4 per cent Silicon Steel: Sample No. R-437-6 (Ref. G. L. 39705-39, -41)

Note: This is a very unusual sample selected for purpose of illustration only because it combines in a single sample all the characteristic peculiarities that call for a demonstration. The sample is not a representative of the grade of steel to which it nominally belongs. Tests above H-200 are made by Saturation Permeameter and below $H = 200$ by the B of S. method.

Table 1-1: test by the Saturation Permeameter (Not reliable below $H = 1000$)

H	β	B	μ (β/H)	ρ (H/β)	γ $(S = 17600)$	D (β/γ)	Log D
4000	17,600	21,600	4.40	0.2273			
3000	17,600	20,600	5.87	0.1705			
2500	17,600	20,100	7.04	0.1421			
2000	17,600	19,600	8.80	0.1136			
1500	17,600	19,100	11.73	0.0852			
1300	17,600	18,900	13.54	0.0739			
1200	17,600	18,800	14.66	0.0682			
1100	17,600	18,700	16.00	0.0625			
1000	17,600	18,600	17.60	0.0568	0		
900	17,575	18,475	19.53	0.0512	25	702.	2.896
800	17,550	18,350	21.94	0.0456	50	352.	0.546
700	17,525	18,225	25.03	0.03995	75	234.	0.370
600	17,475	18,075	29.12	0.03434	125	139.7	0.145
500	17,400	17,900	34.8	0.02874	200	87.0	1.940
450	17,350	17,800	38.60	0.02595	250	69.4	0.842
400	17,300	17,700	43.25	0.02312	300	57.7	0.761
350	17,200	17,550	49.15	0.02035	400	43.0	0.633
300	17,000	17,300	56.66	0.01765	600	28.3	0.452
250	16,750	17,000	67.00	0.01493	850	19.7	0.294
200	16,350	16,550	81.75	0.01224	1250		
150	15,800	15,950	105.30	0.00949	1800		
100	15,100	15,200	151.0	0.00662	2500		
50	13,900	13,950	278.0	0.00360	3700		

TABLE I—(*Continued*)

Table 1-3: Reconstruction of βH and $\beta \mu$ curves according to the law $\log \gamma = f - g H$

Note: The values of γ for required values of H are read from the graph γH (Fig. 1-7), for range of H 50 to 400, and by extrapolation up to H 1200. The value of S taken from test, (Table 1-1).

H	γ	S	β	μ	ρ
30	4080	17,600	13,520	450.7	0.00222
50	3500		14,100	282.0	0.003548
70	3050		14,550	208.0	0.00481
100	2480		15,120	151.2	0.00662
150	1740		15,860	105.7	0.00946
200	1220		16,380	81.9	0.01221
250	870		16,730	66.9	0.01495
300	600		17,000	56.7	0.01764
350	425		17,175	49.1	0.02038
400	300		17,300	43.3	0.02310
450	210		17,390	38.7	0.02585
500	150		17,450	34.9	0.02866
600	70		17,530	29.2	0.03425
700	35		17,565	25.1	0.03984
800	20		17,580	21.9	0.04569
900	10		17,590	19.5	0.0513
1000	0		17,600	17.6	0.0568
1100	0		17,600	16.0	0.0625
1200	0		17,600	14.7	0.06805

TABLE II

Hypothetic curve for Frolich's law and cognate equations

$$\beta = S - \gamma = S - S\,h/(H + h) \text{ Frolich's law} \qquad \text{(equation 15)}$$
$$\mu = S/(H + h) : \rho = (H + h)/S;$$
$$D = H/h = a\,H$$
$$d\,\beta/d\,H = \gamma/(H + h)$$

Note: In the following computations, the value of S is taken from Table 1; the value of h is so selected as to give for $H = 200$ the same value of β as in Table 1.

(1) Determination of constants.

H	β	S	γ	μ	a	h	$S.h$
200	16,350	17,600	1250	81.75	.0654	15.29	269,000

(2) Computation of β and other cognate quantities.

H	$H + h$	$S.h$	γ $(S\,h/H + h)$	S	β	μ	ρ	D (β/γ)	$d\,\beta/d\,H$ $=(\gamma/(H + h)$
0	15.3	26,900	17,600	17,600		1150.	0.000869	0.	
10	25.3		10,630		6,970	697.	0.001435	0.656	420
25	40.3		6680		10,920	437.	0.002290	1.635	166.
50	65.3		4120		13,480	270.	0.00371	3.27	63.1
100	115.3		2330		15,270	152.7	0.00655	6.54	20.2
150	165.3		1630		15,970	106.5	0.00939	9.82	9.87
200	215.3		1250		16,350	81.75	0.01225	13.08	5.81
250	265.3		1015		16,585	66.3	0.01508	16.35	3.90
300	315.3		855		16,745	55.8	0.01792	19.63	2.71
400	415.3		650		16,950	42.4	0.02360	26.17	1.565
500	515.3		520		17,080	34.15	0.02920	32.7	1.010
600	615.3		440		17,160	28.6	0.03500	39.25	0.715
700	715.3		375		17,225	24.6	0.04065	45.80	0.526
800	815.3		330		17,270	21.58	0.04635	52.34	0.405
900	915.3		295		17,305	19.23	0.05200	58.9	0.322
1000	1015.3		265		17,335	17.33	0.05770	65.4	0.261

TABLE III

Curve for transformation ratio for standard steel for range $H = 50$ to 400

Method of Test

1. **Material:** Several rings were punched from a single sheet of standard sheet steel .014 in. From these punchings several rings were made of the same weight, and similarly wound for preliminary test. Two rings were selected having as nearly as possible the same magnetization curve.

2. Windings: The two selected rings were now wound for the differential test; the potential coils were wound next to the iron and were of about 500 turns of fine wire uniformly wound, each ring having the same number of turns. The magnetizing coil was made of a cable of twenty conductors, connected in series, with a tap at each joint. This scheme of winding permits a change of magnetizing value from any predetermined value to higher values in small and definite equal steps.

3. Scheme of wiring: The two magnetizing coils of the two rings were connected in series; the two potential coils were also connected in series. In all respects the scheme of wiring was the same as the usual scheme for tests on toroids. Two dial switches were provided for control of number of windings. One of the rings was used for measurement and the other for compensation. The potential coil of the compensating ring was provided with a supplementary potential coil of few turns and a fractionizing shunt for exact adjustment of the compensating interlinkage. (For wiring diagram, See Fig. 3-0.)

4. Test procedure for magnetization curve: The magnetization coils of the compensating ring and the test ring are tested alone according to the usual procedure. The galvanometer is calibrated to read 100 gausses per millimeter. Assuming that an error in reading the galvanometer cannot exceed half millimeter, it follows that the relative error does not exceed 50 gausses.

5. Test procedure for differential test: The galvanometer is calibrated to read a flux density of one gauss per millimeter of deflection. The dial switches of both rings are set at 10 each; the magnetizing current is adjusted to give $H = 50$, 100 or 200. On reversing the magnetizing current, there should be no deflection, that is, if the two rings are exactly alike; but as there is always a slight difference, a small deflection is produced in all cases, which can be eliminated by a careful adjustment of the supplementary coil and fractionizing shunt. The dial switch of the test coil is now set at No. 11. On reversing the current, a deflection is produced which represents the increment of flux density in the test ring. Other details of test procedure are too obvious to need explanation.

6. Limits of error: The relative error of any individual point in relation to the whole curve does not exceed 0.5 gauss (corresponding to half millimeter of deflection) and is probably much less for small deflection, which is capable of being read correctly to 1/5 of a millimeter. The whole curve may, however, be in error by any amount not exceeding 50 gausses.

In interpreting the curve, it is permissible to assume the curve to be straight enough for extrapolation, and yet the error in the indicated value of S may be as high as 50 gausses, even though the plotted curve were strictly a straight line.

Note: The original measurements were made in terms of H and apparent B; the true value of B was computed by making correction for space factor.

TABLE III—(*Continued*)

Ring, standard sheet steel 0.014 in.
Diameter 3.5 in., 2.7 in.; mean diameter 3.1 in. = 7.885 cm.
Sectional area 1.245 sq. cm.
Table 3-1: test for incremental permeability

H_t	$H\,a$	$\Delta\,H$	β mean	$\Delta\,\beta/\Delta\,H$
400	380	20	19491.5	3.61
380	360	"	19419.0	4.01
360	340	"	19335.5	4.41
340	320	"	19235.5	4.86
320	300	"	19130.5	5.26
300	280	"	19015.5	5.81
280	260	"	18888.0	6.61
260	240	"	18752.5	7.16
240	220	"	18602.0	7.86
220	200	"	18442.0	8.61
200	190	10	18316.0	9.06
190	180	"	18223.5	9.56
180	170	"	18125.5	9.96
170	160	"	18020.5	10.36
160	150	"	17913.0	11.16
150	140	"	17798.0	11.76
140	130	"	17678.0	12.36
130	120	"	17555.0	13.01
120	110	"	17425.0	13.66
110	100	"	17287.5	14.46
100	95	5	17170.0	15.06
95	90	"	17084.0	15.66
90	85	"	16997.0	16.26
85	80	"	16906.0	16.86
80	75	"	16810.0	17.66
75	70	"	16709.0	18.26
70	65	"	16622.0	19.26
65	60	"	16516.0	20.26
60	55	"	16387.0	21.26
55	50	"	16271.0	22.86

$S = 20250$ by extrapolation. (see Fig. 3-1)

TABLE III-II

Curve for Incremental Reluctivity for Standard Steel for Range H = 300 to 1000 g

This test is similar to that of test table 3-1, except that the increment ΔH is in each case one-twentieth part of H. The magnetizing coil of the test ring was made up of two parts of 700 turns, and 35 turns; the first section alone produces the magnetizing force H_1, and the two sections produce the force H_2. The compensating ring has the magnetizing coil of 700 turns, which also gives the magnetizing force H_1. The potential coils are connected as in test 3-1, giving the value ΔB. Each ring is also equipped with a compensative bakelite ring (see table 4-1) which gives the result in terms of $\Delta \beta$ instead of ΔB. The values ρ', log ρ' and $\sqrt{\rho'}$ are obtained by computation.

TABLE III-II—(*Continued*)

Ring same as in Table 3-1
Windings same as in Table 4
Scheme of wiring same as in Fig. 3-0

H_1	H_2	H mean	ΔH	$\Delta \beta$	μ'	ρ'	$\sqrt{\rho'}$
300	315.	307.5	15.	80	5.33	0.1785	0.433
325	341.3	333.1	16.25	79	4.62	0.2055	0.453
350	367.5	359.	17.5	71	4.057	0.2464	0.4967
375	393.7	384.	18.75	67	3.555	0.2813	0.5302
400	420.	410.	20.	59	2.951	0.3422	0.582
425	447.	435.5	21.25	53	2.494	0.4010	0.6334
450	473.	461.	22.5	42	1.867	0.536	0.7322
500	525.	512.5	25.	31	1.240	0.8064	0.898
550	578.	564.	27.5	22	0.800	1.250	1.117
600	630.	615.	30.	15	0.500	2.00	1.414
650	683.	666.	32.5	10	0.3077	3.25	1.802
675	709.	689.	33.75	8	0.237	4.22	2.055
700	735.	718.	35.	6	0.1714	5.834	2.413
750	788.	768.	37.5	4	0.1066	9.38	3.060
800	840.	820.	40.	2	0.0500	20.0	4.470
850	893.	871.	42.5	0	0	inf.	inf.
900	946.	922.	45.	0	0	"	"
950	998.	974.	47.5	0	0	"	"
1000	1050.	1025.	50.	0	0	"	"

Notes:

$$H_2 = H_1 \times 1.05$$
$$H \text{ mean} = H_1 \times 1.025$$
$$\Delta H = H_1 \times .05$$
$$\mu' = \Delta \beta / \Delta H$$
$$\rho' = \Delta H / \Delta \beta$$

TABLE III-II—(*Continued*)

Test data in Table 3-1; further computation to determine relation of ρ' to H

H	$H\,a$	ΔH	$\Delta \beta / \Delta H$	ρ' ($= \Delta H / \Delta \rho$)	H Mean	$\sqrt{\rho'}$
400	380	20	3.61	0.277	390	0.516
380	360	"	4.01	0.2493	370	0.499
360	340	"	4.41	0.2268	350	0.4765
340	320	"	4.86	0.2059	330	0.454
320	300	"	5.26	0.1890	310	0.435
300	280	"	5.81	0.1721	290	0.415
280	260	"	6.61	0.1513	270	0.389
260	240	"	7.16	Q.1396	250	0.3735
240	220	"	7.86	0.1272	230	0 357
220	200	"	8.61	0.1162	210	0.341
200	190	10	9.06	0.1104	195	0.332
190	180	"	9.56	0.1046	185	0.3235
180	170	"	9.96	0.1004	175	0.317
170	160	"	10.36	0.0964	165	0.3105
160	150	"	11.16	0.0896	155	0.2995
150	140	"	11.76	0.0850	145	0.2915
140	130	"	12.36	0.0809	135	0.2845
130	120	"	13.01	0.0768	125	0.277
120	110	"	13.66	0.0732	115	0.271
110	100	"	14.46	0.0691	105	0.263
100	95	5	15.06			
95	90	"	15.66			
90	85	"	16.26			
85	80	"	16.86			
80	75	"	17.66			
75	70	"	18.26			
70	65	"	19.26			
65	60	"	20.26			
60	55	"	21.26			
55	50	"	22.86			

S = 20,250 by extrapolation (see Fig. 3)

TABLE IV

Magnetization Curve for Standard Steel

The ring used for this test is the same as the test ring in Table 3, Fig. 3. The ring was unwound, and rewound with heavier wire to obtain a magnetizing force of H = 1000. In order to eliminate space factor error a compensative ring of bakelite of the same size as the test ring, and wound with the same number of turns of same size wire, was used as a companion ring. The two rings were then treated as a single ring and wound with a common magnetizing coil. During test, the two potential coils of the test ring and the compensative ring are connected in opposition; this arrangement compensates for the entire spatial flux inside of the potential coil of the test ring, and therefore serves the double purpose (1) of eliminating the space factor error and (2) of deducting the spatial flux in the magnetic material. With this arrangement, the galvanometer deflections indicate directly the intrinsic flux density. In testing for saturation value, this method of compensation has the further advantage that the measurement of β is not affected by errors in measurement of the magnetizing current; the adjustment of the current need not be accurate; this permits rapidity of measurement and prevents excessive heating. Without this facility, measurement of saturation value in toroid rings would have been impracticable except in the case of permalloy and other similar material of low magnetic hardness. The following is the result of the test:

TABLE IV—(*Continued*)

Ring Standard Sheet Steel
(Same ring as in Table 3)
Table 4-1: Test Data

H	β	μ	ρ	γ	D ($= \beta/\gamma$)
1000	20,200	20.2	0.0495	0	
900	20,200	22.4	0.04465	0	
800	20,200	25.3	0.0395	0	
750	20,200	26.9	0.03715	0	
700	20,200	28.9	0.03465	0	
650	20,200	31.1	0.03215	0	
600	20,150	33.1	0.02980	50	403
550	20,100	36.5	0.02748	100	201
500	20,000	40.0	0.02500	200	100
450	19,900	44.2	0.02260	300	66.3
400	19,750	49.4	0.02025	450	43.9
350	19,550	55.8	0.01767	650	30.05
300	19,250	64.2	0.01558	950	20.25
250	18,900	75.6	0.01323	1300	14.52
200	18,450	92.3	0.01084	1750	10.55
150	17,900	119.4	0.00838	2300	7.78
100	17,200	172.0	0.00581	3000	5.74
90	17,050	189.5	0.00528	3150	
80	16,900	211.0	0.00474	3300	
60	16,500	275.0	0.00364	3700	
50	16,300	326.0	0.00307	3900	
30	15,700	523.0	0.00191	4500	
20	15,200	760.0	0.001315		
15	14,800	986.0	0.001013		
10	14,200	1420.0	0.000704		
8	13,700	1712.0	0.000584		
6	12,900	2150.0	0.000465		
5	12,000	2400.0	0.0004165		
4	11,250	2817.0	0.0003555		
3	9900	3300.0	0.0003030		
2.5	8600	3440.0	0.0002905		
2.0	6600	3300.0	0.0003030		
1.5	4100	2735.0	0.000367		
1.2	2800	2335.0	0.000429		
1.0	1600	1600.0	0.000625		
0.8	1000	1250.0	0.000800		
0.6	500	833.0	0.001200		

TABLE IV—(*Continued*)

Table 4-2: Reconstruction curve according to Frolich s law on the basis of two points $H = 300$ & 500, (*i. e.* Yensen's region approximate)

(1) Determination of constants S and h.

H	β	μ	$\Delta\mu$	$\Delta\beta$	a	h	$(\gamma = h\,\mu)$	S	$S\,h$	$(\alpha = h/S)$
500	2000	40	24.17	750	.03224	31	1240	21,240	659,000	.00146
300	19,250	64.17					1990	21,240		

(2) Reconstruction of curve.

H	$H + h$	$S.h$	$\gamma = S\,h/(H + h)$	S	β	μ	ρ	$d\,\beta/d\,H = \gamma/(H + h)$
0	31							
50	81	65,900	8140	21,240	13,100			101.6
100	131		5040		16,200	162	0.00617	38.5
150	181		3640		17,600			29.1
200	231		2860		18,380			12.37
250	281		2350		18,890			8.37
300	331		1990		19,250			6.01
350	381		1730		19,510			4.54
400	431		1530		19,710			3.55
450	481		1370		19,870			2.85
500	531		1240		20,000			2.335
600	631		1045		20,195			1.66
700	731		900		20,340			1.232
800	831		790		20,450			0.951
900	931		710		20,530			0.762
1000	1031		640		20,600	20.6	0.04855	0.620
1200	1230		535		20,705			0.435
1500	1530		430		20,810			0.281
2000	2031		325		20,915			0.161
3000	3030		220		21,020			0.0703
4000	4040		165		21,075			0.0402

TABLE IV—(*Continued*)

Table 4-3: Reconstruction of curve according to Frolich's law with constants selected for agreement at $H = 200$, and infinity

(1) Determination of constants.

H	β	S	γ	μ	h	$S\,h$
200	18,450	20,200	1750	92.25	18.97	383,000

(2) Determination of β and cognate quantities.

H	$H + h$	$S\,h$	γ	β ($S = 20{,}200$)	μ	ρ	$d\,\beta/d\,H$ $\gamma/(H + h)$
0	18.97	38,300	20,200	0	1064	0.000939	1063
50	69.		5525	14,675	293.	0.00342	86.8
100	119.		3215	16,985	169.7	0.00589	27.0
150	169.		2265	17,935	119.6	0.00836	13.4
200	219.		1750	18,450	92.25	0.01085	7.99
250	269.		1425	18,775	75.1	0.01333	5.30
300	319.		1200	19,000	63.3	0.01579	3.76
350	369.		1037	19,165	54.8	0.01827	2.81
400	419.		914	19,285	48.2	0.02074	2.18
500	519.		728	19,470	38.9	0.02570	1.42
600	619.		619	19,580	32.6	0.03060	1.00
700	719.		533	19,665	28.1	0.03560	.742
800	819.		468	19,730	24.7	0.04050	.571
900	919.		417	19,785	22.0	0.04550	.454
1000	1019.		376	19,825	19.8	0.0504	.369
1200	1219.		314	19,885			.258
1500	1519.		252	19,950			.166
2000	2020.		190	20,010			
3000	3020.		120	20,070			
5000	5020.		74	20,125			

TABLE IV—(*Continued*)

Table 4-4: Reconstruction curve according to equation

$$\text{Log}\,\gamma = f - g\,H$$

On the basis of agreement for $H = 300$, 500 and infinity

(1) Determination of constants f and g

H	H	B	S	γ	Log γ	Δ Log γ	g	$g\,H$	f
300	200	19,250	20,200	950	2.9775	.6765	.003383	1.0149	3.9924
500		20,000		200	2.3010			1.6915	3.9925

(2) Determination of β

H	g	$g\,H$	f	Log γ	γ	S	β	μ	ρ
100	.003383	0.3383	3.9924	3.654	4510	20,200	15,690	156.9	.00637
150		0.507		3.485	3055		17,145	114.3	.00874
200		0.676		3.316	2070		18,130	90.7	.01103
250		0.846		3.146	1400		18,800	75.2	.01331
300		1.015		2.977	950		19,250	64.2	.01558
350		1.185		2.807	640		19,560	55.9	.01790
400		1.354		2.638	435		19,765	49.4	.02024
450		1.527		2.465	290		19,910	44.25	.02260
500		1.692		2.300	200		20,000	40.0	.02500
550		1.862		2.130	135		20,065	36.5	.02740
600		2.031		1.961	90		20,110	33.5	.02985
650		2.200		1.792	60		20,140	31.0	.03228
700		2.370		1.622	40		20,160	28.8	.03478
750		2.540		1.452	30		20,170	26.9	.03720
800		2.705		1.287	20		20,180	25.2	.03965
900		3.047		0.945	10		20,190	22.4	.04460
1000		3.382		0.610	0		20,200	20.20	.04950
1200		4.060		-1.830	0		20,200	16.8	.0594
inf.							20,200	0	

TABLE V

Insensitiveness of Reluctivity Curve

Table 5-1: Dr. Yensen's Experiment: A. I. E. E., 1920, p. 821

H	β	μ	ρ	
20	16,600	830	0.0012	
100	18,330	183.3	0.0055	
200	18,670	93.35	0.0107	Error in β, probably typographic
300	20,430	68.1	0.0147	Error in β, probably observational
400	21,030	52.6	0.0190	
500	21,310	42.6	0.0235	
200	19,670	98.35	0.01016	Corrected by guess
300	20,500	68.33	0.01463	Corrected by reference to β H curve

Table 5-2: Dr. Kennelly's Curve: A. I. E. E., 1891, p. 509

B	μ $(=B/H)$	H	β	ρ	μ (β/H)	
0	40					
100	50	2.	98	0.0204	49	
420	100	4.2	416	0 01010	99	
720	150	4.8	715	0.006712	149	
1100	200	5.5	1095	0.005028	199	
1500	225	6.6	1493	0.004465	224	
2080	200	10.4	2070	0.005025	199	
2500	150	16.66	2483	0.006708	149	
2960	100	29.6	2930	0.01010	99	
3500	70	50.0	3450	0.01450	69	
3920	50	78.4	3482	0.02040	49	
4500	32	146.0	4354	0.03353	29.8	H, β, ρ, and β/H incorrect
5000	22	227.0	4773	0.04756	21	
4500	32	140.6	4360	0.03225	31	H, β, ρ, and β/H corrected

TABLE VI

Electrolytic Iron: Sample E-B

Table 6-1: Test for β H Curve

Method of test same as in Table 4

H	β	μ	ρ	γ	D $(=\beta/\gamma)$	log D
1160	21,000	18.1	0.0552	0		
1000	21,000	21.1	0.0476	0		
900	21,000	23.3	0.0429	0		
850	21,000	24.7	0.0405	0		
800	21,000	26.3	0.0381	0		
750	20,980	28.0	0.03575	20	1050	3.021
700	20,950	30.0	0.0334	30	700	2.845
650	20,900	32.2	0.0311	100	209	2.320
600	20,850	34.7	0.0288	150	139	2.143
550	20,780	37.8	0.0265	220	95	1.978
500	20,650	41.3	0.0242	350	59	1.771
450	20,500	45.6	0.02195	500	41	1.613
400	20,300	50.7	0.0197	700	29	1.462
350	20,000	57.2	0.0175	1000	20	1.301
300	19,700	67.7	0.01525	1300	15.15	1.180
250	19,300	77.2	0.01295	1700	11.35	1.055
200	18,800	94.2	0.01065	2200	8.5	0.930
150	18,300	122.0	0.00820	2700	6.8	0.832
100	17,500	175.0	0.00572	3500	5.0	0.698
50	16,650	333.0	0.00300	4350	3.84	0.585
20	15,900	795.0	0.001258	5100	3.12	0.495
10	15,400	1540.0	0.000649	5600	2.75	0.440
3	14,250	4750.0	0.000211			
1.0	12,500	12500.0	0.0000800			
0.70	11,500	16400.0	0.0000608			
0.60	10,650	17750.0	0.0000563			
0.55	10,000	18200.0	0.0000550			
0.50	9250	18500 0	0.0000541			
0.45	8300	18450.0	0.0000542			
0.40	6950	17400.0	0.0000575			
0.35	5500	15700 0	0.0000636			
0.30	3800	12650.0	0.0000789			
0.25	2550	10200.0	0.0000980			
0.20	1450	7250 0	0 000138			

TABLE VI—(*Continued*)

Table 6-2: Reconstruction of curve (Table 6-1) by the law log $\gamma = f - g\, H$

Note: The values of γ are read from the straight line graph of Fig. 6-3.

H	γ	S	β	μ
50	7800	21,000	13,200	264
100	5500		15,500	155
150	3900		17,100	114
200	2750		18,250	91.25
250	1920		19,180	76.7
300	1350		19,650	65.5
350	960		20,040	57.3
400	680		20,320	50.8
450	480		20,520	45.6
500	340		20,660	41.3
550	240		20,760	37.7
600	170		20,830	34.7
650	120		20,880	32.1
700	85		20,915	29.9
750	60		20,940	27.9
800	40		20,960	26.2
850	30		20,970	24.7
900	20		20,980	23.3
1000	10		20,990	21.0
1100	0		21,000	19.1
1200	0		21,000	

TABLE VII

Nickel Pure: 99.5 per cent Nickel: Ring No. N-D

Test 7-1: test for β H curve

H	β	μ	ρ	γ	D (β/γ)
375	5810	15.5	0.0645		
270	5810	21.5	0.0465		
240	5810	24.2	0.0413		
210	5790	27.6	0.03625	20	289.5
180	5750	32.0	0.03122	60	95.8
150	5700	38.0	0.02631	110	51.8
120	5650	47.0	0.02129	160	35.3
105	5600	53.3	0.01875	210	26.68
90	5550	61.6	0.01625	260	21.34
75	5475	73.0	0.01370	325	16.85
60	5350	89.2	0.01121	460	11.63
45	5200	115.5	0.00866	610	8.52
30	5000	166.8	0.00600	810	6.17
15	4600	306.5	0.00326	1210	3.80
7.5	4100	547.0	0.00183	1710	2.41
6.0	3900	650.0	0.00154	1910	2.04
4.5	3600	800.0	0.00125	2210	1.63
3.0	3050	1015.0	0.000986	2760	1.11
2.5	2750	1100.0	0.000910		
2.0	2400	1200.0	0.000833		
1.5	1900	1267.0	0.000790		
1.0	1200	1200.0	0.000833		
.8	850	1060.0	0.000944		
.6	450	750.0	0.001333		
.4	225	560.0	0.001785		
.2	100	500.0	0.002000		

TABLE VII—(*Continued*)

Table 7-2: Reconstruction of curve (Table 7-1) by the law log $\gamma = f - g\, H$

Note: Values of γ are read from the straight line graph of Fig. 7-3.

H	γ	S	β	μ
20	860	5810	4950	247.5
40	620		5190	129.6
60	440		5370	89.5
80	320		5490	68.8
100	230		5580	55.8
120	160		5650	47.1
140	120		5690	40.6
160	80		5730	35.8
180	60		5750	31.9
200	45		5765	28.8
220	30		5780	26.2
240	20		5790	24.1
260	15		5795	22.3
280	10		5800	20.7
300	0		5810	19.35
320	0		5810	18.15
340	0		5810	17.10
360	0		5810	16.15
380	0		5810	15.3
400	0		5810	14.5

TABLE VIII

Cobalt Pure: (Percentage composition not specified. This ring is the same that was used by Mr. Ball in his well-known experiment published in G. E. *Review*, 1916, p. 379)

H	β	μ	ρ	
1600	13,000	8.13	0.1232	
1400	12,600	9.00	0.1111	
1200	12,100	10.08	0.0992	
1000	11,600	11.60	0.0862	
800	10,950	13.70	0.0730	
700	10,550	15.07	0.0664	
600	10,200	17.00	0.0588	
500	9700	19.40	0.0516	
400	9050	22.63	0.0442	
360	8800	24.45	0.0409	
320	8500	26.55	0.03775	
280	8200	29.30	0.03411	
240	7800	32.5	0.03075	
200	7300	36.5	0.02740	
160	6750	42.2	0.02370	
120	6000	50.0	0.02000	
100.	5550	55.5	0.01802	
80	4950	61.8	0.01618	
60	4200	70.0	0.01429	
40	3200	80.0	0.01250	
30	2500	83.3	0.01200	
20	1650	82.5	0.01213	
10	600	60.0	0.01666	
1200	12,130	10.1	0.0989	Corrected by reference to the β H curve
700	10,580	15.11	0.0662	

TABLE IX

Nickel—Iron Alloy. Ring No. R-309

Table 9-1: Test for β H curve

H	β	μ	ρ	γ	β/γ
346	12,250	35.4	0.02825		
277	12,250	44.2	0.02260		
208	12,250	58.9	0.01700		
173	12,210	70.6	0.01416	40	305
138.5	12,170	88.0	0.01136	80	152
104.	12,080	116.1	0.00860	170	71
90.	12,060	134.0	0.00746	190	63.4
79.5	11,900	149.8	0.00668	350	34
69.3	11,730	169.5	0.00590	520	22.5
62.3	11,550	185.5	0.00539	700	16.5
55.4	11,390	206.0	0.00485	860	13.2
48.5	11,080	228.5	0.00438	1170	9.46
41.5	10,690	258	0.00388	1560	6.85
34.6	10,250	296	0.00338	2000	5.12
27.7	9600	348	0.00287	2650	3.43
20.8	8830	425	0.00235	3420	2.58
17.3	8370	484	0.00207	3850	2.17
13.85	7820	564	0.001775	4430	1.76
10.4	7210	693	0.001442	5040	1.43
8.65	6780	784	0.001275		
6.93	6380	921	0.001085		
5.54	6020	1085	0.000921		
4.15	5630	1355	0.000738		
2.77	5120	1850	0.000540		
2.08	4780	2300	0.000435		
1.39	4370	3140	0.000318		
0.693	3730	5380	0.000186		
0.415	2950	7100	0.000143		
0.388	2820	7300	0.000137		
0.346	2610	7540	0.000133		
0.319	2330	7300	0.000137		
0.277	1870	6760	0.000148		
0.208	950	4560	0.000219		
0.139	170	1220	0.000820		

TABLE IX—(*Continued*)

Table 9-2: Reconstruction of curve by the law:

$\text{Log}\ \gamma = f - g\,H$

Note: Values of γ, are read from the straight line graph of Fig. 9-2.

H	γ	S	β	μ
10	5040	12,250	7210	721
15	4150		8100	540
20	3450		8800	440
30	2350		9900	330
40	1600		10,650	266
50	1100		11,150	223
60	760		11,490	191.5
70	530		11,720	167.4
80	360		11,890	148.6
90	240		12,010	133.4
100	165		12,085	120.8
110	110		12,140	110.4
120	80		12,170	101.4
130	55		12,195	93.8
140	35		12,215	87.3
150	25		12,225	81.6
160	17		12,233	76.2
170	10		12,240	72.0
180	0		12,250	68.1
190	0		12,250	64.5
200	0		12,250	61.2

TABLE X

Cobalt Iron Alloy: 20 per cent Cobalt

Table 10-1: Test for β H curve

H	β	μ	ρ	γ	D
1500	23,200	15.45	0.0646		
1350	23,200	17.18	0.0582		
1200	23,200	19.33	0.0517		
1050	23,200	22.1	0.0453		
900	23,200	25.8	0.0388		
750	23,170	30.9	0.0324	30	772
660	23,130	35.1	0.0285	70	331
600	23,100	38.5	0.0260	100	231
540	23,050	42.7	0.02342	150	153.5
510	23,000	45.1	0.02217	200	115
480	22,950	47.8	0.02092	250	92
450	22,880	50.8	0.01969	320	71.5
420	22,800	54.3	0.01842	400	55.7
390	22,700	58.2	0.01719	500	45.5
360	22,550	62.6	0.01596	650	34.7
330	22,350	67.7	0.01476	850	26.3
300	22,150	73.8	0.01355	1050	21.1
270	21,900	81.2	0.01233	1300	16.7
240	21,650	90.2	0.01109	1550	13.9
225	21,450	95.3	0.01050	1750	12.25
210	21,300	101.4	0.00986	1900	11.20
195	21,150	108.5	0.00922	2050	10.30
180	20,950	116.4	0.00859	2250	9.3
165	20,730	125.6	0.00796	2470	8.4
150	20,550	137.0	0.00730	2650	7.76
135	20,300	150.3	0.00665	2900	7.00
120	20,050	167.0	0.00598	3150	6.37
105	19,800	187.5	0.00530	3400	5.82
90	19,500	217.0	0.004615	3700	
67.5	19,050	283.0	0.0354	4150	
45.0	18,400	409.0	0.002445	4800	
30	17,750	592	0.00169		
24	17,450	727	0.001375		
18	16,950	942	0.001062		
15	16,550	1103	0.000906		
12	15,900	1325	0.000755		
9	14,850	1650	0.000605		
7.5	14,050	1875	0.000534		
6.75	13,350	1975	0.000505		
6.0	12,800	2130	0.000469		
5.4	12,100	2240	0.000446		
4.8	11,300	2355	0.000425		
4.5	10,850	2410	0.000415		
4.2	10,400	2475	0.000404		
3.9	9750	2500	0.000400		
3.6	9200	2555	0.000391		
3.3	8500	2575	0.000388		
3.0	7750	2580	0.000387		
2.7	6800	2520	0.000397		
2.4	6000	2500	0.000400		
2.1	4950	2360	0.000424		
1.8	3800	2110	0.000473		
1.5	2650	1765	0.000566		
1.2	1600	1330	0.000750		
0.9	800	890	0.001125		
0.6	350	585	0.001710		

TABLE X—(*Continued*)

Table 10-2: Reconstruction of curve by the law $\log \gamma = f - g H$

Values of γ read from straight line graph of Fig. 10-2

H	γ	S 23,200	β	μ
100	5100		18,100	181
150	3450		19,750	131.6
200	2300		20,900	104.6
250	1550		21,650	86.6
300	1050		22,150	73.8
350	700		22,500	64.3
400	470		22,730	56.8
450	320		22,880	50.8
500	210		22,990	45.7
550	140		23,060	41.9
600	95		23,105	38.5
650	65		22,135	35.6
700	45		22,155	33.1
750	30		23,170	30.9
800	20		23,180	28.95
850	13		23,187	27.25
900	10		23,190	25.8
1000	0		23,200	23.2
1100	0		23,200	21.1
1200	0		23,200	19.3

TABLE XI

Cobalt—(Table 8)

Reconstruction by the equation

$\operatorname{Log} \gamma = f - g H$

Table 11-1: Approximate determination of S according to equation $d\beta/d H = a \gamma$

H	β	$\Delta \beta$	ΔH	$\Delta \beta/\Delta H$	B Mean
1600	13,000				
		400	200	2.00	12,800
1400	12,600				
		470	200	2.35	12,365
1200	12,130				
		530	200	2.65	11,865
1000	11,600				
		650	200	3.25	11,275
800	10,950				
		370	100	3.70	10,765
700	10,580				
		380	100	3.80	10,340
600	10,200				

$S = 15{,}350$ by extrapolation; see Fig. 11-1

As the points for the curve β/H as functions of β do not form a very good straight line, the extrapolation is a matter of personal judgment.

TABLE XI—(*Continued*)

Table 11-2: Reconstruction of curve by the law $\operatorname{Log} \gamma = f - g H$, by graphic method

Values of γ read from graph of Fig. 11-2

H	γ	S	β
100	7600	15,300	7700
200	7000		8300
300	6500		8800
400	6000		9300
500	5500		9800
2000	1700		13,600
2500	1150		14,150
3000	770		14,530
4000	350		14,950
5000	160		15,140
6000	70		15,230
7000	30		15,270
8000	15		15,285
9000	5		15,295
10,000	0		15,300

TABLE XI—(*Continued*)

Table 11-3: Reconstruction of curve by the law $\log \gamma = f - g H$, by the analytical method

Determination of f and g

H	β	S	γ	$\operatorname{Log} \gamma$	$\Delta \operatorname{Log} \gamma$	g	$g H$	f
600	10,200	15,300	5100	3.7075	0.346	.000346	0.2076	3.9155
1600	13,000		2300	3.3615			0.5536	3.9155

Table 11-4: Reconstruction and extrapolation of the βH curve

H	g	$g H$	f	$\log \gamma$	γ	S	β	μ
100	.000346	0.0346	3.9155	3.8805	7600	15,300	7700	77
200		0.0692		3.8459	7010		8290	41.5
300		0.1038		3.8113	6480		8820	29.4
400		0.1384		3.7767	5980		9320	23.3
500		0.1730		3.7421	5522		9780	19.6
600		0.2076		3.7075	5100		10,200	17.0
700		0.2422		3.6729	4710		10,590	15.1
800		0.2768		3.6383	4350		10,950	13.7
1000		0.3460		3.5691	3708		11,592	11.6
1200		0.4152		3.4999	3160		12,140	10.1
1400		0.4844		3.4307	2695		12,605	9.0
1600		0.5538		3.3615	2300		13,000	8.13
2000		0.692		3.2231	1670		13,630	6.82
2500		0.865		3.0501	1125		14,175	5.67
3000		0.6038		2.8771	755		14,545	4.85
4000		1.384		2.5311	340		14,980	3.74
5000		1.73		2.1851	160		15,140	3.03
6000		2.075		1.8401	70		15,230	2.54
7000		2.422		1.4903	30		15,270	2.18
8000		2.768		1.1461	15		15,285	1.91
9000		3.115		1.8001	5		15,300	1.70
10,000		3.460			0		15,300	1.53
12,000		4.152			0		15,300	1.28

TABLE XI—(*Continued*)

Cobalt Pure (Table 8)

Table 11-4: Reconstruction of curve by Frolich's Law on the basis of two points at $H = 1200$ and 1600

(1) Determination of constant h and S.

H	β	μ	$\Delta \mu$	β	h	γ μh	S $(\beta + \gamma)$	γ	$S . h$
1600	13,000	8.125	1.985	870	438.3	3560	16,580	3560	7,260,000
1200	12,130	10.11				4430	16,560	4430	

(2) Reconstruction of β H curve.

H	$H + h$	$S . h$	γ	S	β
		7,260,000		16,560	
100	538		13,500		3060
200	638		11,380		5180
300	738		9840		6720
400	838		8670		7890
500	938		7740		8820
600	1038		7000		9560
700	1138		6380		10,180
800	1238		5860		10,700
1000	1438		5050		11,510
1200	1638		4430		12,130
1400	1838		3950		12,610
1600	2040		3560		13,000
2000	2440		2980		13,580
2500	2940		2470		14,090
3000	3440		2110		14,450
4000	4440		1635		14,925
5000	5440		1335		15,225
7000	7440		975		15,585
10,000	10,440		695		15,865
20,000	20,440		355		16,205
30,000	30,440		240		16,320
40,000	40,440		180		16,380

TABLE XII
Electrolytic Iron
Sample: Yensen-rod 1413-*A*
Test made at the Bureau of Standards
Table 12-1: (Test No. Tem. 41893)

Original data for *H* and *B* received through courtesy of Dr. T. D. Yensen, and computation of β, μ and γ made by S. L. Gokhale

H	*B*	β	μ	ρ	γ	*D*
0.2	460		2300.	0.000435		
0.4	4600		11500.	0.000087		
0.5	7300		14600.	0.0000685		
1.0	11,150		11150.	0.0000985		
2.0	14,230		7115.	0.000141		
4.0	15,770		3940.	0.000254		
20.0	17,020	17,000	850.	0.00118	4500	3.78
100.	18,700	18,600	186.	0.00537	2900	6.40
200.	19,960	19,760	99.	0.0101	1740	11.34
400.	21,320	20,920	52.3	0.0191	580	36.1
600.	21,900	21,300	35.5	0.0282	200	105.5
1000.	22,500	21,500	21.5	0.0465	0	
1500.	23,000	21,500	14.3	0.0700	0	
2000.	23,500	21,500	10.7	0.0935	0	
2500.	24,000	21,500	8.6	0.116	0	

TABLE XII—(*Continued*)
Table 12-2: Reconstruction of the curve by the Logarithmic law
Note: Values of γ read from the straight line graph of Fig. 12-3.

H	γ	*S*	β	μ
20	4500	21,500	17,000	850.
50	3850		17,650	353.
100	2930		18,580	185.8
150	2240		19,260	128.4
200	1710		19,790	98.95
250	1310		20,190	80.4
300	1000		20,500	68.3
350	760		20,740	59.3
400	585		20,915	52.3
450	450		21,050	46.8
500	340		21,160	42.3
600	200		21,300	35.5
700	115		21,385	30.5
800	70		21,430	26.8
900	40		21,460	23.85
1000	20		21,480	21.5
1100	10		21,490	19.5
1200	0		21,500	17.9
1500	0		21,500	14.3
2000	0		21,500	10.7
2500	0		21,500	8.6

TABLE XII—(*Continued*)
Electrolytic Iron (Yensen)
Table 12-3: Comparison of two samples of nearly identical magnetic character
Tests at Bureau of Standards
Test No. Tem. 41893

	Rod No. 1413-*A* (Annealed)				Rod No. 1413-*B* (Unannealed)			
H	*B*	β	μ	ρ	*B*	β	μ	ρ
2500	24,000	21,500	8.6	0.1162	24,100	21,600	8.64	0.1157
2000	23,500	21,500	10.7	0.0935	23,600	21,600	10.8	0.0926
1500	23,000	21,500	14.3	0.0700	23,100	21,600	14.4	0.0694
1000	22,500	21,500	21.5	0.0465	22,600	21,600	21.6	0.0463
600	21,900	21,300	35.5	0.02815	22,000	21,400	35.7	0.02800
400	21,320	20,920	52.3	0.01913	21,370	20,970	52.4	0.01910
200	19,960	19,760	99.0	0.01010	19,950	19,750	98.7	0.01013
100	18,700	18,600	186.0	0.00538	18,600	18,500	185.0	0.00541

TEMPERATURE AFFECTS RADIO SIGNAL STRENGTH

That temperature influences the strength of radio signals is the conclusion reached by L. W. Austin and Miss Wymore of the Bureau of Standards, Department of Commerce. This work is a part of the program of the International Union of Scientific Radio Telegraphy, which was adopted at Brussels in 1922 and is now being carried on in the various countries belonging to the Union.

Two years ago, Dr. Austin described a decided increase in the signals received at Washington from the Radio Corporation transatlantic stations at Tuckerton and New Brunswick, N. J., during the passage of severe cold waves over the eastern states. Further study now indicates that whenever the temperature rises along the signal path there is a tendency for the signal to drop; and conversely, a falling temperature tends to produce a stronger signal, though these temperature effects are often masked by other unknown influences.

Experiments on the relations existing between meteorological phenomena and radio transmission require preferably at least fairly uniform meteorological conditions between the sending and receiving stations. For this reason, stations between 125 and 190 mi. distant were chosen for the experiments, rather than stations at great distances. On the other hand, stations much less than 125 mi. distant would probably not have shown the influence of weather changes to so marked an extent.

There seems to be no doubt that the temperature changes influence the waves which are reflected or refracted from the Kennelly-Heaviside layer, 60 mi. or more above the earth's surface rather than the waves which glide along the ground, since no marked change is observed in signal intensity due to long continued rain or drought, the presence of snow, or the presence or absence of frost in the ground.

ELECTRICITY USED TO RUSH FLOWERS

Turning a dark cellar into a bright solarium and growing tropical plants in greenhouses 5000 mi. north of their native habitat are realizations. These things have been done with the aid of electric light. In an experimental greenhouse in Yonkers, N. Y., all sorts of weird results have been obtained by running a traveling crane up and down all night over the glass roof, flooding electric light in varying intensities over beds of plants and flowers from the four corners of the earth. About 100,000 candle power made sweet peas bloom five weeks ahead of their daytime schedule. Oriental clover that requires two years to bloom under natural conditions blossomed in two months under 24 hours of daily light. Orchids were produced at will and brought to fullest flower on certain fixed schedules, thus presaging strange doings in the horticulture of the future by electric agents.

Abridgment of

An Investigation of Transmission-System Power Limits

BY C. A. NICKLE[1] and F. L. LAWTON[1]

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Synopsis.—*Results of theoretical analysis, verified by miniature-system tests of the power limits of transmission systems, are discussed, among the major conclusions being the following:*

The criterion for stability under all conditions is the steady-state power limit.

The charging kv-a. exercises marked detrimental effects on stability.

The characteristics of synchronous terminal apparatus are of great importance.

Improvements can be made by modifying present apparatus design.

Automatic voltage regulators, suitable exciters, and fast relays are essential.

The mercury-arc rectifier, as an adjunct in excitation circuits, shows real advantages.

INTRODUCTION

THE subject of transmission-system power limits and related problems is one of utmost importance in present and future projects, as emphasized by recent papers.[2]

The present paper deals with the results of careful theoretical analysis and calculations, verified by extensive miniature-system tests, of the power limits of transmission systems. Theoretical studies have been checked by tests on a miniature system equipped with synchronous apparatus, lines of variable constants, exciters, regulators, etc., and so chosen that 2300 volts and 180 kilowatts corresponded to 220,000 volts and 15,000 kw. on the actual system. The work covered was planned and directed by Messrs. R. E. Doherty and H. H. Dewey, and to a large extent outlined by them in a recent paper before the Institute.[3]

In addition to investigations relating to a basic knowledge of power limits of systems, attention has been focused on methods of improving their stability—in other words, increasing the power limits. In this connection, careful analysis has been made of special types of synchronous equipment, voltage-regulation schemes, induction generators, use of static condensers for the compensation of line inductive reactance, and many other devices. The work has been paralleled throughout by studies of actual projects.

In the computation of power limits, a thorough knowledge of the theory of synchronous machines is essential. It can be shown that, for all practical purposes, it is unimportant whether salient-pole or cylindrical-rotor theory be used in the calculation of all quantities but angular relationships. As steady-state power-limit studies made by the authors have not involved angular relationships, the use of either theory is justified. In transient problems, however, angular relationships are of fundamental importance and, hence, the appropriate theory must be used.

A large amount of work has also been done on the power-angle characteristics of synchronous machines. Papers dealing with these studies, and synchronous-machine theory, will, it is hoped, be presented before the Institute in the near future.

Among the important conclusions reached as a result of the investigations made by the authors, and other interested engineers of the General Electric Company, may be mentioned:

1. Too great importance must not be attached to the transmission line as it is but one link in the circuit; the characteristics of terminal apparatus, such as synchronous machines, and methods of voltage regulation are of equal, if not greater, importance.

2. The only feature in which the stability of high-tension long-distance transmission and high-tension cable systems differs from that of any other type is in the limitation of the excitation of synchronous apparatus due to the charging kv-a. of the lines.

3. For slowly-applied loads, automatic voltage regulators and suitable exciters permit stable operation up to the same limit which can be obtained with manual control.

4. The problem of obtaining greater power limits offers two avenues of approach:

    (*a*) Modification of the characteristics of existing synchronous apparatus and transmission lines.

    (*b*) The development of new methods of voltage regulation.

5. Extensive miniature-system tests indicate that, no matter how fast load is applied, under similar conditions of excitation or voltage the power limit is always the same as the steady-state limit. In view of these results and experience, it appears that the

1. Both of General Electric Company, Schenectady, N. Y.

2. Groups of Papers presented at A. I. E. E. Conventions at Philadelphia, February, 1924, New York, February, 1925, and Seattle, Sept., 1925.

3. *Fundamental Considerations of Power Limits of Transmission Systems*, R. E. Doherty and H. H. Dewey, JOUR. A. I. E. E., Vol. XLIV, October, 1925, p. 1045.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926. Complete copies available upon request.

fundamental criterion of power-system stability is the final steady-state power limit.

6. Adequate speed of relaying is the vital factor in the maintenance of stability during system short circuits.

7. Reliable methods of calculation of system power limits, for steady-state conditions, are available. For the more complicated networks, a-c. miniature systems give excellent results.

8. At present there are no satisfactory methods of computing system power limits, under transient conditions, for any but the simplest cases. However, it is possible to study completely all transients ensuing from disturbances which do not result in instability, by means of the electromechanical analyzer.

Methods of Calculation

It has been indicated that reliable methods of determining system steady-state power limits are now available. In general, it has been found that the method of calculation adopted by the authors gives results of good engineering accuracy, as shown by the computed and test values given in this paper. Furthermore, these results agree very well with those secured by independent investigators using other schemes of analysis.

Calculations of system steady-state power limits are comparatively easy for simple systems comprising, say, one generating station, a line or two, and one receiving station. Where several branches are involved, analysis becomes more difficult; partial solutions by graphical methods are combined to give a complete solution. When the system under consideration comprises many branches, computation by these graphical methods becomes practically impossible and resort must be had to analysis by miniature a-c. systems.[4] Steady-state stability problems can be solved with the aid of miniature a-c. systems of the same order of size as the d-c. short-circuit calculating table, which has been of such invaluable aid.

For the study of system transients arising from dropping a line, suddenly adding a load, etc., there is no practical scheme of analysis available for any but the simplest cases. The unwieldiness of the step-by-step method[5] increases very rapidly with the number of elements in the system, and it soon becomes impossible of application. However, by using the equivalent-circuit idea,[6] it is possible to study the electromechanical transients in any system, no matter how complicated, for loads below the power limit; that is, where the differential equations for the system are linear.

4. *Artificial Representation of Power Systems*, H. H. Spencer and H. L. Hazen, Jour. A. I. E. E., Vol. XLIV, January 1925, p. 24.

5. *Power System Transients*, V. Bush and R. D. Booth, Jour. A. I. E. E., Vol. XLIV, March 1925, p. 229.

6. *Oscillographic Solution of Electromechanical Systems*, by C. A. Nickle, Jour. A. I. E. E., Vol. XLIV, December, 1925, p. 1277.

Description of Miniature System and Methods of Testing

When the investigation was commenced, it was realized that means should be available for verifying promising leads developed in analytical studies, and establishing the reliability of methods of calculation. Inasmuch as it was not feasible to use an actual system for this work, a miniature system of sufficient capacity to give reliable test information was set up in the factory. The equipment included several 225-kv-a. synchronous motors with direct-connected d-c. generators, units for setting up any type of line, exciters, standard vibrating-contact regulators, etc. By using the d-c. generator of a set as a motor supplied from the shop bus, and the corresponding unit of another set as a separately-excited generator supplying a water-rheostat load, it was possible to study systems comprising four synchronous units. The use of resistance loads prevented any possibility of hunting due to a feed back on the shop bus. For simulating an infinite generator, a 10,000-kv-a. alternator was available.

To correlate results obtained by miniature test with corresponding values for the actual system, it should be borne in mind that the miniature system was designed so that a voltage of 2300 corresponded to 220 kv. on an actual system; similarly, 180 kw. was equivalent to 150,000 kw.

Steady-State Studies

It is evident that any analysis of transmission-system power limits falls into two major divisions—one dealing with the limits obtaining for slowly-applied loads, as in steady-state operation, and the other with the limits for transient-state, suddenly-applied loads. Accordingly, the treatment of the subject in this paper follows more or less the above division.

Influence of Circuit Elements on Power Limits. The first system studied was a simple, two-machine system consisting of two 225-kv-a. units connected directly together, electrically. The machines were synchronized, the excitations adjusted to the desired values and maintained constant at those values, together with system frequency, as the load was slowly increased by increasing the d-c. generator excitation.

The next step consisted of the introduction of lines of various constants, proportional to different lengths of the actual 220-kv. transmission line. By computing the power-voltage curves for a system comprising an alternator, a line, and a synchronous motor, it was possible to determine the effect of the added impedance on the power limit. No effort was made to include the capacity susceptance of the actual line in the first analysis; this was done later. The constants of these lines, designated *L-R* lines, were as follows:

125-mi. *L-R* line $z_L = 1.27 + j\ 9.25$ ohms
250-mi. *L-R* line $z_L = 2.54 + j\ 18.5$ ohms
500-mi. *L-R* line $z_L = 5.09 + j\ 37.0$ ohms

A comprehensive idea of the relative effect of the various circuit elements on power limits can be gained by a study of Table I, which summarizes representative results for the different systems discussed.

The values given in Table I are self-explanatory. They indicate, among other things:

1. The importance of voltage regulators if the maximum possible operating capacity is desired.
2. That transmission-line impedance plays a large part in reducing the maximum power limit but that the synchronous-apparatus characteristics are equally important.
3. That transmission-line capacity susceptance reduces the power limit considerably.

TABLE I
COMPARATIVE POWER LIMITS

System	Excitation	Pull-out Power-Kw. Calculated	Pull-out Power-Kw. Test
1. Alternator and motor on same bus	Normal excitations	115	129
2. Alternator and motor on same bus	Normal regulators	280	—
3. Alternator, 125-mi. *L-R* line, motor	Normal excitations	99	107
4. Alternator, 125-mi. *L-R* line, motor	Normal regulators	—	260
5. Alternator, 250-mi. *L-R* line, motor	Normal excitations	85	89
6. Alternator, 250-mi. *L-R* line, motor	Normal regulators	168	155
7. Alternator, 500-mi. *L-R* line, motor	Normal excitations	65	68
8. Alternator, 500-mi. *L-R* line, motor	Normal regulators	110	104
9. Alternator, 250-mi. "nominal π" line, motor	Normal excitations	76	75
10. Alternator, 250-mi. "nominal π" line, motor	Normal regulators	144	134
11. Infinite generator, 250-mi. *L-R* line, infinite receiver	Normal regulators	283	—
12. Infinite generator, 250-mi. *L-R* line, normal motor	Normal excitations	—	125
13. Normal generator, 250-mi. *L-R* line, infinite receiver	Normal regulators	213	—

Sufficient has been said in the preceding discussion to indicate that a system with a number of machines operating in multiple should have a higher power limit than the simple straightaway transmission by virtue of the fact that the generating bus, or receiver bus, tends to become an infinite bus, a fact verified by investigation. Table II illustrates the effect of adding multiple generators and summarizes the power limits for a number of systems.

Use of Voltage Regulators. A brief survey of the comparative power limits given in Table I will indicate the advantage of operating a system at normal terminal voltage rather than normal excitations. It is not, of course, intended to infer that systems are so operated but merely to establish bench-marks to indicate the advantage, with respect to power limit or stability, of constant-voltage operation. As noted, the ratio of the normal-regulator power limit to the normal-excitation power limit varies from 2.5 to about 1.6, depending on the relative impedance of the circuits.

In view of the importance of maintaining those excitations which correspond to normal terminal voltage at the load being carried, it seems well to discuss at this point the mechanism of the operation by which the regulator maintains constant terminal voltage. Referring to Fig. 1, a number of power-voltage curves, with excitation as parameters, are shown. Suppose the system to be operating with excitation (i_4) and load (P_2). An increase in load of about 20 per cent will cause pull-out at that power at which $\frac{dP}{dE} = 0$. To carry a load greater than that causing pull-out at excitation (i_4), it is necessary to increase the excitation to, say, (i_6). In this case pull-out will occur at a load (P_3).

TABLE II
EFFECT OF MULTIPLE UNITS

System	Excitation	Pull-out Power in Kw. Calculated	Pull-out Power in Kw. Test
1. Alternator on same bus as motor	Normal excitations	115	129
2. Alternator and motor on same bus with addition of shunt synchronous condenser	" "	140	145
3. Alternator supplying two motors on same bus*	" "	157†	145†
4. Two alternators‡ supplying one motor on same bus	" "	155†	145†
5. Alternator, 250-mi. *L-R* line, and motor	Normal regulators	168	155
6. Two alternators‡ in multiple, 250-mi. *L-R* line, and motor	" "	—	192

*Approximately equal division of load.
†Total load.
‡Equal division of load.

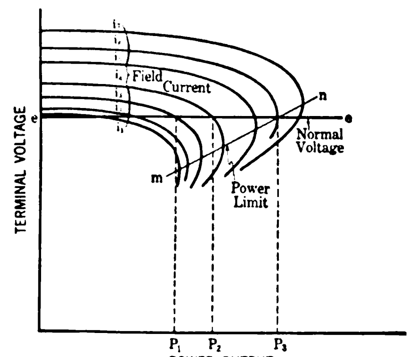

FIG. 1—TYPICAL CONSTANT-EXCITATION POWER-VOLTAGE CURVES

While it is possible to manually adjust the excitations for slowly-increasing loads, this is not feasible where rapid load additions may occur. Resort must accordingly be made to some automatic device which will rapidly adjust the excitation to the value corresponding to the actual load and the desired operating voltage. Such a device is the vibrating-contact type voltage regulator. It will be interesting to examine its operation.

As is well known, the voltage regulator is designed to maintain constant voltage at some point on a system—in this case, the supply and receiver busses. This is accomplished by increasing the excitation of the proper machine when the voltage at the regulated bus drops or vice versa. However, at any constant load, power factor and voltage, there is a definite excitation required, namely, that given by the intersection of the co-

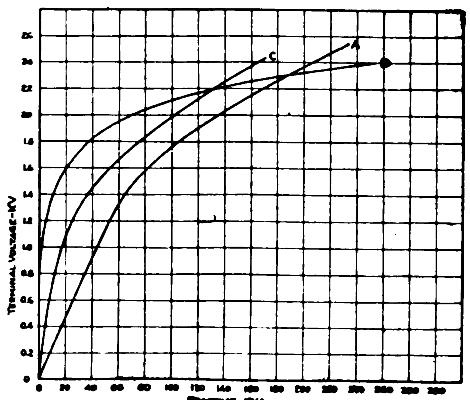

FIG. 2—VOLTAGE-REACTIVE KV-A. CHARACTERISTIC CURVES FOR VARIOUS REACTORS

Curve A—184 kv-a. unsaturated reactor
" B—184 " saturated reactor
" C—225 " synchronous condenser with 1.0 ampere field current

ordinates corresponding to power and voltage. In other words, the voltage regulator adjusts conditions by causing a transfer of operation from one constant-excitation (power-voltage) curve to another. It follows, then, that pull-out will take place at the intersection of the straight line representing the constant operating voltage with the locus of pull-out points, *i. e.*, power (P_3) and voltage (e), corresponding to excitation (i_6). This is the maximum power which can be delivered by the system at voltage (e). With imperfectly adjusted regulators, however, pull-out will take place at some power less than (P_3).

It must be borne in mind that system operation with voltage regulators consists of nothing more than a succession of steady-states, each with some particular constant value of excitation. If, for any reason, the regulators are unable to adjust conditions to those corresponding to stable operation, at any load, pull-out will take place along the power-voltage curve corresponding to the particular excitations then obtaining.

The preceding discussion will emphasize the vital necessity for voltage regulators on systems which it is desired to operate at loads close to the maximum power at the system voltage. This point has been demonstrated by actual experience on systems.

Influence of Machine Nominal Voltages on System Stability. Analysis of the preceding investigations led to the conclusion that system stability could be improved by increasing the machine nominal voltages for any particular terminal voltage. Two simple methods of accomplishing this were available, namely, the use of static shunt reactors and synchronous reactors (condensers). Accordingly, the use of such devices was investigated and a number of tests made.

The increase in power obtained by means of a shunt reactor is due to the greater excitation required to maintain a given terminal voltage for given power conditions. This increased excitation could be obtained more economically by lengthening the air-gap of the machine.

Similar results were obtained using an under-excited synchronous condenser in place of the shunt reactor. The current taken by a synchronous condenser is the difference between the terminal voltage and the nominal voltage divided by the synchronous reactance. When the nominal voltage is zero, the current is just the terminal voltage divided by the synchronous reactance, and the current-voltage curve is identical with that of a static reactor.

Having shown the effect of reactors, either static or synchronous, in increasing machine nominal voltage, studies of systems with lines were undertaken. The static reactors considered were of two types:

a. Unsaturated iron-core reactor
b. Saturated iron-core reactor

In Fig. 2, characteristic curves for the actual reactors used are compared with a corresponding curve for the synchronous condenser.

The advantage of using a saturated iron-core reactor[7] lies in the fact that the rate of change of reactive kv-a. consumed with respect to terminal voltage is much greater than for the ordinary non-saturated reactor. In other words, at normal voltage, the kv-a. consumed by the two types of reactor is the same, but at a lower terminal voltage, the kv-a. taken by the saturated reactor is much less. Therefore, any disturbance in the system producing a voltage decrease will cause a reduction in the armature reaction of the synchronous equipment, due to the reactive kv-a. taken by the reactor, thus making an increase in machine excitation available for maintaining stability.

With an appreciation of the effect of shunt reactors on system power limits, it is quite easy to see why the line capacity susceptance should reduce the power limit.

7. *Theory of D-C. Exciter Iron-Core Reacters and Regulators*, by A. Boyajian, TRANS. A. I. E. E., Vol. 43, 1924, p. 919.

The Application of the Saturated-Core Reactor Regulator, by D. K. Blake, A. I. E. E., Vol. 43, 1924, p. 937.

Losses in Iron Under the Action of Superposed A-C. and D-C. Excitations, by O. C. Charlton and J. E. Jackson, JOUR. A. I. E. E., Vol. 44, Nov. 1925, p. 1220.

Consider a system which simulates an actual 250-mi. straightaway system in which the actual line is replaced by the "nominal π" line. The capacity susceptance is, so far as its effect on the machine nominal voltages is concerned, simply a *negative* shunt reactance of about 70 ohms, reducing the required excitation for a given terminal voltage.

In this connection, it is interesting to consider the effect of adding multiple lines between generating and receiving equipment of a given kv-a. rating. Due to

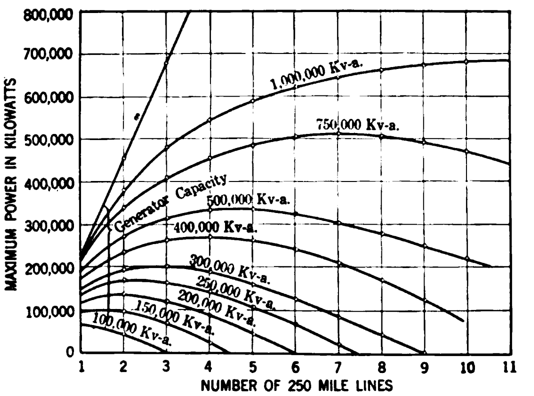

FIG. 3—MAXIMUM POWER WHICH CAN BE TRANSMITTED 250 MILES AT 220,000 VOLTS, SHOWN AS A FUNCTION OF THE CAPACITY OF SYNCHRONOUS APPARATUS, AND THE NUMBER OF TRANSMISSION CIRCUITS

the increase of charging kv-a. with numbers of lines, a point is soon reached where the decrease of machine excitations more than counterbalances the effective decrease in line reactance. When the number of parallel lines is increased beyond this point, a reduction in the power limit occurs. Fig. 3 illustrates this condition.

It is evident that shunt reactors may be used to compensate for the effect of the leading kv-a. taken by the line capacity susceptance, and thus improve the power limit. Actual studies of reactors and synchronous condensers on large projects indicate that the reactors may be the more advantageous, on the score of economy. As previously pointed out, the same result can be gained by lengthening the air-gap of the synchronous apparatus.

"Saturated" Machines. It should be evident from the preceding discussion that *any measure by which the field current can be increased with the same terminal voltage will improve the stability.* Several methods of accomplishing this have been mentioned under the head of "Influence of Machine Nominal Voltages on System Stability." In addition to methods previously discussed, there is another—that is, increasing the degree of saturation of the poles.

Consider the saturation curves of two synchronous machines as shown in Fig. 4, one for a "normal" machine with operatng range on the saturation curve somewhat below the knee, the other with normal voltage well above the knee. Furthermore, the machines will be of identical design except in so far as the cross-sectional area of the poles is concerned.

If the two machines be operated separately as generators with such field currents that normal terminal voltage occurs at no load, identical power increments on each will not cause the same lowering of the terminal voltage. In other words, *the saturated machine is stiffer.*

Such tests as were made indicate that the benefits obtained by the use of synchronous generators and motors with saturated poles are of the same order as could be obtained by lengthening the air-gap.

Use of Induction Generators on Transmission Systems. Induction generators have been suggested from time to time for use in connection with long transmission lines, but they have never come into practical use. During the course of the present investigation it was felt that there were certain merits in such use which should be carefully investigated. As known now, the power which can be transmitted over a line between two synchronous machines is limited by the phase relationships of the system. With the induction generator, however, the power delivered from the prime-mover shaft to the generator terminals depends upon the difference in speed of the prime mover and the terminal-voltage vector. With a prime mover and a rotor capable of transmitting any desired power from the prime-mover shaft to the stator circuit, the power limit will be dependent upon the angle between the rotor of the re-

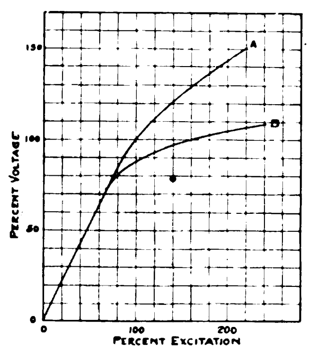

FIG. 4—OPEN-CIRCUIT CHARACTERISTIC CURVES
Curve A—Normal generator
Curve B—Saturated generator

ceiver-end motor and the air-gap flux of the generator. That is, the power limit of synchronous-to-synchronous transmission is a function of the angle between the machine rotors but with induction-synchronous transmission is dependent upon the angle between induction generator air-gap flux and synchronous motor rotor.

Although economic studies may indicate a possible margin in favor of the induction generators, there is practically no advantage to be gained by their use, so far as stability is concerned.

"Loaded" Transmission Systems. In recent years much attention has been given to the possibility of increasing the stability of power systems by the use of synchronous condensers at intermediate points.[8] Investigations made by the authors indicate that greater gains have been ascribed to such use of synchronous condensers[9] than is actually the case.

The addition of a synchronous condenser of the same rating as the terminal apparatus to the simple 500-mile *L-R* straightaway system increases the power limit at normal voltage from 110 kw. to 150 kw. or about 36 per cent. It must be remembered, however, that on actual systems, the synchronous condensers at loading points would ordinarily have a much smaller capacity than the terminal apparatus. Consequently, the percentage increase in power limit will be much less. Moreover, actual systems have lines with distributed capacitance which tends to accomplish the same object as the loading condenser. In other words, to secure any appreciable increase in maximum power of actual systems, the condenser used for loading must have a kv-a. capacity much higher than indicated by early investigations[10].

Like most problems of this type, the advantages of loading condensers, for any particular project, cannot be definitely stated without a careful economic study.

"Resistance" Loading of Transmission Systems. All the systems discussed so far have had synchronous motor loads—in other words, typical shaft loads, which have constant kilowatt and variable reactive kilovolt-ampere consumption; that is, the power is independent of the voltage. No reference has been made to high power-factor admittance loads, such as lighting, industrial heating, etc. It will, therefore, be interesting to turn attention for a few moments to the question of such loads—"resistance" loads—for long transmission systems.

Consider two synchronous machines tied together through an impedance. It is well known that the limit of stability occurs at the point at which $\frac{dP}{dE} = 0$, a fact verified many times by test. The criterion for maximum power, $\frac{dP}{dE} = 0$, holds only where power is the independent variable, as in shaft loads. Suppose, however, that one of the synchronous machines in this combination is replaced by a dead impedance load. Then, instability will *not* occur at the point where $\frac{dP}{dE} = 0$, nor at any other point, since for a dead load there is nothing with which the generator can fall out of step. There will, however, be a *maximum power* point for constant excitation on the generator. If voltage is maintained at the load by a synchronous condenser, it can be shown that instability will occur where $\frac{dR}{dE} = 0$, instead of $\frac{dP}{dE} = 0$, where the resistance (R) of the dead load is the independent variable.

The importance of choosing the proper criterion can be better appreciated if it is understood that a pure resistance load with a synchronous condenser for voltage regulation is equivalent to an infinite bus, as far as maximum power under steady-state conditions is concerned. This statement is true only when there is no other load on the system. To emphasize the importance of choosing the proper criterion, a system comprising both resistance and shaft loads may be cited.

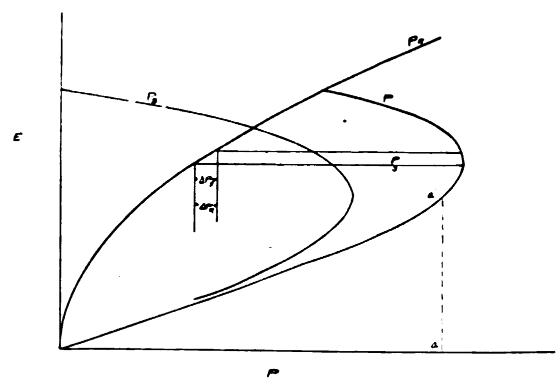

FIG. 5—TYPICAL POWER-VOLTAGE CHARACTERISTICS FOR SYSTEM WITH COMPOSITE SHAFT AND RESISTANCE LOAD

In such a case, consider what happens when the shaft load is increased. Any increment of shaft load results in a decrease of terminal voltage and, hence, a decrease in power consumed by the resistance load. A set of typical power-voltage characteristics of a system with both shaft and resistance load is shown in Fig. 5. Curve (P) represents the variation of total power with voltage, (P_R) the variation of resistance power with voltage, and (P_S) the variation of shaft power with voltage. It is evident from the figure that the slope of the curve of total power becomes infinite—that is, $\frac{dP}{dE} = 0$—at that point where an increase of shaft power is exactly equal to the resultant decrease in resistance power. However, *the system is still stable,* inasmuch as the slope of the curve of shaft power has not yet become infinite, and (P_S) *is*

8. *Voltage Regulation and Insulation for Large Power Long Distance Transmission Systems,* by F. G. Baum, TRANS. A. I. E. E., Vol. 40, 1921, p. 1017.

9. *Some Theoretical Considerations of Power Transmission Systems,* by C. L. Fortescue and C. F. Wagner, TRANS. A. I. E. E., Vol. 43, 1924, p. 16.

"*Power Limitations of Transmission Systems.*" by R. D. Evans and H. K. Sels, TRANS, A. I. E. E., Vol. 43, 1924, p. 26.

the independent variable. Breakdown occurs where

$$\frac{d\,P}{d\,E} = 0,$$

and the total power is as shown by the ordinate $(a\,a')$. In other words, a system with such a composite load may be stable even though operation is on the under side of the total power-voltage curve.

Compensation of Transmission-Line Inductive Reactance. Preceding discussion has shown the effect of the reactance of long transmission lines in limiting the amount of power which can be transmitted with stable operation. It is, then, apparent that any means by which this effect could be economically reduced would be advantageous. It is possible to reduce the line reactance by use of special line construction[10]. However, the decreased line reactance is gained at the expense of an increase in charging kv-a., which may partially offset or even more than offset the advantage gained.

However, by introducing series static condensers into the line[11], it is possible to effectively neutralize or compensate for the effect of line inductive reactance without any increase in charging kv-a. There are certain difficulties attendent upon such use of static condensers, as protection from excess voltages during short circuit. Careful investigations show the feasibility of series static condensers for this service hinges almost entirely on over-all economy.

Influence of Methods of Voltage Regulations on Stability. Careful analysis of the effect of various circuit elements, and special types of apparatus, on transmission-system stability, as discussed elsewhere in this paper, will indicate that the real criterion of stability is the inherent slope of the power-voltage characteristic. In other words, instability occurs when the slope of the power-voltage curve is such that

$\frac{d\,P}{d\,E} = 0$, for shaft loads. How can this occur in a

power system, the synchronous machines of which are provided with automatic voltage regulators?

As pointed out under "Use of Voltage Regulators," the regulator is merely a device for shifting the system from one constant-excitation condition to another, as dictated by the terminal voltage. Referring to Fig. 1, voltage is maintained by the regulator functioning in such a way that the system operates along the line (ee) by passing from one constant-excitation state to another. However, and this is the important point, the inherent stability of the system is not that indicated by the slope of the line (ee)—*i. e.*, $\frac{d\,E}{d\,P} = 0$ — but by the slope of some constant-excitation curve. It may be anyone of a number as shown, but it is always some one of the family of curves. It is in just this respect that regulated machines do not have the characteristic of an infinite bus with $\frac{d\,E}{d\,P} = 0$, the ideal type of voltage regulation.

In this connection, it will be of interest to examine the phenomena accompanying an increase of load on a piece of synchronous apparatus in a transmission system. Such an increase in load will result in a decrease in terminal voltage with a given excitation.

Now the voltage regulator is not responsive to the rate of change of voltage, but only to a value of voltage —the function itself; hence, it increases the excitation in the degree necessary to compensate for the increased armature reaction due to load only after the lapse of an appreciable time. That is, the field excitation is increased only after the voltage has dropped. Such investigations as made by the authors do no indicate that any appreciable gain in power limit can be secured by reducing the time constant of the excitation system below that of normal equipment. Compensation for increased load, and, hence, armature reaction, always lags behind the cause. This is important during transients and especially near the point of intersection of (ee) and (mn)—the point of pull-out. It is the reason why a system with regulated generating stations cannot be considered as having infinite supply busses and hence a power limit equal to that of the line itself.

Consider what happens when load is added to a d-c. generator provided with a compensating field winding. Simultaneously with the increase in armature reaction, a magnetomotive force is set up in opposition to it. Depending on the size of the compensating field, the effect of increased load may be entirely counterbalanced or compensated for—even over-compensated. A similar case is that of a circuit in which the inductive reactance is exactly balanced by an equal series capacitive reactance. What happens when the circuit load is increased? The voltage drops across both inductive and capacitive reactances increase simultaneously, but being of opposite phase, effectively neutralize each other. With respect to the terminals, there is no reactance drop.

Applying the principle enunciated above—*i. e.*, the effective neutralization of the cause by making the effect take place simultaneously—to synchronous equipment, the great importance of it can be seen. The machines in effect would have infinite capacity, limited only by heating and mechanical considerations. To realize the significance of this, refer to Table I and related discussion, where it is pointed out that the power limit of a 250-mi. miniature *L-R* line by itself is

10. *Output and Regulation of Long-Distance Lines*, Percy Thomas, TRANS. A. I. E. E., Vol. 28, 1909, p. 615.

11. Discussion by T. A. E. Belt on "*Present State of Transmission and Distribution Developments*," JOUR. A. I. E. E., Vol. 44 October, 1925, p. 1153.

283 kw., but with normal machines, only 168. kw. That is, the synchronous reactance of the machines reduces the power limit about 41 per cent. In actual systems, the effect of the generating and receiving equipment might even increase this value to 50 per cent.

It is evident that if some device can be applied to synchronous apparatus which will prevent a reduction of the net ampere turns tending to force flux through the magnetic circuit, such a device will effectively decrease the effect of armature reaction which is so detrimental to the stability and power limits of long transmission systems. That is, as load builds up, the armature reaction builds up, but simultaneously and due to exactly the same causes, the field ampere-turns must build up with the right magnitude and space phase to compensate for the armature reaction. *The perfect simultaneity of cause and effect effectively neutralizes armature reaction.*

Of course, to obtain the ideal in voltage regulation, the inherent reactance of synchronous machines must also be neutralized—as by the use of series static condensers of suitable capacity—in the same way that the effect of line reactance may be overcome.

It is apparent that it is somewhat difficult to completely accomplish what has been outlined above—for the effective compensation of armature reaction necessitates the application of field ampere-turns in the proper space phase and varying in magnitude and time with the armature reaction. It was realized, however, that any device which would increase the excitation in exact proportion to the armature reaction—or line current—and in perfect simultaneity with it, should be of considerable advantage.

Accordingly, a number of devices and methods for accomplishing this object were carefully investigated. Finally, it was decided that ordinary mercury-arc rectifiers used as adjuncts in the otherwise normal excitation circuits of synchronous apparatus appeared to offer the greatest promise.

The use of mercury-arc rectifiers has shown, in factory tests, that a very appreciable gain in stability and power limits can be secured. While practical application on power systems has not yet been made, it is confidently believed that at least a 50 per cent reduction in effective armature reaction can be secured. Moreover, a real scheme of voltage regulation, effective under steady and transient conditions, is for the first time made available.

Transient Studies

When the question of the stability of power-transmission systems recently came to the fore, it was thought that the worst condition of operation likely to be faced would be that obtaining during transient conditions. Such a transient state might arise from:

a. Sudden loss of a generating station

b. Sudden addition of load

c. Sudden loss of one or more multiple transmission lines

d. Major system short circuits

In fact, it was quite generally expected that the power limit for such transient conditions would be less than the steady-state pull-out power.

However, very complete analytical studies, verified by thorough tests on the miniature system used for the steady-state power-limit investigations previously discussed, have largely dispelled the doubts of successful operation of extensive power systems under heavy load transients. Briefly, the following important conclusions have been reached from the evidence furnished by analysis, miniature-system tests, and field experience.

1. The power limit of a system, when load is suddenly applied to some element in that system, is the same as the pull-out power for slowly-applied loads, provided conditions of excitation and voltage are the same for the two cases. Certain transitory phenomena, discussed later, so affect system stability that *the fundamental criterion of stability appears to be the steady-state power limit.*

2. Power oscillations during a transient-state induced by the sudden application of load will not be excessive with units of comparable rating at the various points on the system. With an infinite generating unit, or an extremely large system interconnected with a relatively small one, the power "overshoot" may approach 100 per cent of the load increment.

3. Maintenance of stability during short circuits is mainly a matter of adequate relaying as duration of the short circuit is probably the most important single factor entering the problem.

During the existence of a transient state caused by a sudden change of load or a short circuit, a number of factors come into play which do not appear in steady state operation. Among others, there are the kinetic energy of machines, the time element of electromagnetic circuits, as in excitation systems, and the load-time characteristic of prime-mover governors. For these reasons, the calculation of transient problems is much more involved than the computation of steady-state stability. However, rigorous mathematical methods and step-by-step analysis[5] can be applied to the simplest cases. The analysis of systems of any degree of complexity becomes almost hopelessly involved so that resort must be had to the equivalent-circuit idea[6], which is extremely useful for the study of transients involving loads below the steady-state power limit.

Effect of Suddenly Applied Loads. Inasmuch as the basic purpose of the transient studies undertaken by the authors and other interested engineers was the determination of the relation between steady-state and transient stability, and the factor affecting the latter, the miniature system previously described was utilized. It was possible to simulate the sudden loss of a generating station by opening the oil switch tying a generating unit to the system; the sudden addition of shaft load by

closing a switch throwing a water-rheostat load on the d-c. generator coupled to a synchronous motor at the receiver end of a system; the sudden addition of "resistance" load by switching a dead resistance load directly onto the system; and the sudden loss of one or more multiple transmission lines by opening the oil switch in one of two 250-mi. *L-R* lines connecting a 225-kv-a. generator to a synchronous motor of identical rating.

The steady-state power limit of any particular system studied was first obtained for various constant-voltage or constant-excitation conditions. Then, by means of repeated trials, it was possible to determine how much load could be suddenly added to the system without causing loss of synchronism,—instability. The results were tabulated for the various cases and, as mentioned, on analysis revealed the important fact that the power limit for transient state was essentially the same as that for steady state, under the same conditions of excitation or voltage.

It will readily be apparent from what has been said that any time delay in the various elements making up a system would play an important part in transient stability. There are two such elements:

1. The electromagnetic circuits
2. The prime-mover governors

As the first is quite fully discussed later, only the second will be considered here. Inasmuch as governors are relatively sluggish in action, it may be several seconds after a disturbance occurs before the governors of a system assume their new positions. Consequently, in analysis of what happens during the first moment or two, constant flow (of water, or steam) is commonly assumed.

Short Circuits. Load transients apparently do not decrease the power limit of a system but the transient conditions obtaining during a major system short circuit radically affect stability. Not only do the inertias of machines and the time elements of governors and excitation systems come into play, but also the isolating effect of the short circuit. That is, no power flow can take place past the point of short circuit in the phases affected. For this reason, if the fault is not quickly cleared, a three-phase short circuit is likely to result in instability. Single-phase short circuits, whether line-to-line or line-to-neutral, are not so serious, inasmuch as partial flow of power is possible.

Brief consideration of what takes place in a system during a short-circuit disturbance may be illuminating. Assume a straightaway transmission with a single-phase line-to-line short circuit at the midpoint.

Just prior to the occurrence of the short circuit, the machine rotors will have a definite space-phase relationship fixed by the constants of the system, the load and the voltage. The instant the disturbance occurs the transfer of power between the machines changes, ceasing entirely in the faulty phase, and the rotors commence to assume a new relative position in space, depending on load and voltage conditions prior to the short circuit, the power flow, and the governor characteristics. Consider the generator. If the torque exerted by the system remains at the same value as previously, the net effect on the generator during the first instant will be zero. However, as the net flux is reduced and, hence, the voltage, this torque is likewise reduced and the machine accelerates, assuming no action on the part of the governor. Should the governor act, this acceleration will be reduced. The rate of change of net flux will be rapid in the first few instants, gradually decreasing with increasing time. This, of course, assumes no action on the part of the regulator tending to change the field ampere-turn loading. Should the torque imposed by short-circuit conditions be initially less than the load torque, the acceleration of the generator will, necessarily, be greater. It is evident, then, that the speed, the space-phase relationship of the generator relative to the initial position, and the magnitude of the net flux, (hence, terminal voltage) are functions of the duration of the short circuit.

Inasmuch as similar conditions hold for the receiver-end synchronous apparatus, it is apparent that *the essential factor for maintenance of system stability during short-circuit disturbances is adequately fast relaying.* Experience with actual systems has amply justified this statement.

Experience on existing systems, tests and conservative calculations indicate that major system short circuits are the severest type of transient. Only by very fast relaying can stability be maintained for powers near the steady-state power limit.

Effect of the Excitation-System Time Element on Transient Stability. In the discussion of system stability under suddenly applied loads, it has been said that certain factors so strengthen or stiffen the system that it is inherently stable for any load up to the steady-state power limit. What are these factors?

Undoubtedly, the most important element in the *temporary stiffening* of a system during a disturbance is the *field transient.* Due to the inherent relationship between field and armature circuits, the magnetic flux linked with an alternator field cannot change in the first moment following the sudden addition of load.[12] The increased armature current induces a field m. m. f. tending to sustain a constant flux linkage. If there is no automatic device increasing the exciter voltage, the flux will gradually die down to a new steady-state condition. However, and this is the important point, *during the transient, the machine reactance is less than the synchronous reactance.* Initially, following the sudden application of load or short circuit, the transient reactance[13] is effective, and this gradually increases

12. "*A Simplified Method of Analyzing Short-Circuit Problems,*" by R. E. Doherty, TRANS. A. I. E. E., Vol. 42, 1923, p. 841.

13. The transient reactance includes both armature and field leakage reactance.

to the steady-state synchronous value. Furthermore, the inherent stiffening of the system enables the regulator to act, causing the exciter to build up. Briefly, it is a race between the rate at which the system assumes the new load and the rate at which the excitation can build up. Now, the period of oscillation of a system is of the order of one second, and, hence, the first power peak occurs in a half-second. The *field transient*, or the transient reactance, stiffens the system sufficiently to meet this condition. By the time the power peak occurs again, the excitation system has

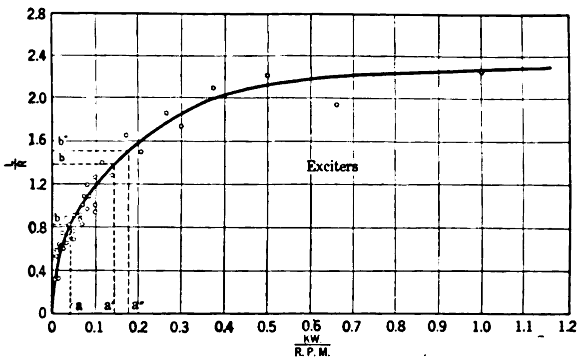

Fig. 6—Curve Indicating the Relation between the Time Constant and the Speed and Rating of Exciters

had considerable time in which to build up. In this respect, it will be interesting to note the relationship of the time constant $\left(\frac{L}{R}\right)$ to the volume of the exciter. Values for a large number of exciters, of different types and ratings, have been plotted in Fig. 6. In this case, the measure of volume used has been kilowatt per rev. per min., as this represents volume, for given current and magnetic densities. The actual exciters used in the experimental investigations are indicated by the points (ba), $(b'a')$, and $(b''a'')$.

It will be apparent that any scheme by which the resistance of the excitation circuit—that is, alternator field and exciter armature—can be reduced will tend to maintain constant flux linkages and so give the exciter a chance to build up. One method of accomplishing this would be the introduction of a *negative* resistance in the field circuit. A series exciter does function as a negative resistance. Its use in such a case has already been described.[3]

Neither the voltage regulator nor the series exciter, however, accomplish the primary object of the ideal regulation scheme—*i. e.*, the effective neutralization of armature reaction at the time it occurs. As previously pointed out, the mercury-arc rectifier, as an adjunct in excitation systems, does accomplish, to a large degree, this purpose, and in so doing, very materially stiffens any system so equipped, both in transient and steady states.

The inherent field transient so stiffens the average system that ordinary regulators and exciters are sufficiently responsive to maintain stability under heavy load transients. Mercury-arc rectifiers, or other devices accomplishing the same purpose, appear to be the most effective of all regulation schemes in reducing the effect of transients.

Conclusions

The preceding discussion has made it evident that the problem of stability is not confined to long-distance high-tension transmission lines, where economical considerations require operation close to the power limit. With the growth of the nation's power systems into widespread interconnected networks, and the consequent transmission of larger and larger blocks of power over short interstation tie lines, the problem of stability becomes vitally important, inasmuch as such short tie lines, on which depends reliability of service, may be operated too close to the power limit, with danger of instability.

In general, the investigations discussed have been most gratifying because they have indicated in what direction engineers interested in the design and operation of power systems should look for improvement. Furthermore, they have indicated that the real advances in obtaining additional stability lie in the application of certain types of apparatus—namely, devices for voltage regulation which fulfill the conditions of the ideal voltage-regulation scheme—*i. e.*, $\frac{dE}{dP} = 0$. Improvement may be effected by changes in design of present synchronous apparatus—such as lengthening the air-gap or operating the pole structures at high magnetic densities.

To summarize, then, the following important conclusions have been reached from the studies undertaken by the authors:

1. The characteristics of synchronous terminal apparatus are of great importance in their effect on power-system stability. In fact, they may be of greater importance than the transmission-line characteristics.

2. Automatic voltage regulators and suitable exciters are essential to obtain, under all conditions, the same power limit as could be obtained with manual control and slowly applied loads.

3. The charging kv-a. of long transmission lines and extensive cable networks exercises more of a detrimental effect on stability than has been hitherto appreciated.

4. Improvements in system stability can be readily made by modifications of present designs of apparatus. Investigations indicate that real advances in stability come from the adoption of methods of voltage regulation having inherent characteristics close to those of the

TABLE III
POWER LIMITS FOR SYSTEMS WITH SHUNT REACTORS

System	Supply-End Reactor		Receiver-End Reactor		Excitation —Amperes		Initial Conditions		Power Limits—Kw.	
	Type	Ohms	Type	Ohms	Generator	Motor	Volts	Kw. Motor Input	Calculated	Test
1. Alternator, 500-mi. L-R line, motor	Saturated	29.2*	——	——	9.9	4.8	2300	0	——	84
2. Alternator, 250-mi. L-R line, motor	Unsaturated	58.4	——	——	7.1	4.75	"	0	——	99
	"	"	——	——	7.15	5.2	"	50	——	111
	"	"	——	——	7.7	6.0	"	100	——	130
3. Alternator, 250-mi. L-R line, motor	"	"	Unsaturated	58.4	7.3	7.35	"	0	105	118
4. Alternator, 250-mi. L-R line, motor	"	29.2	——	——	4.7	4.7	—	0	——	62
	"	"	——	——	10.1	4.7	2300	0	108	108
	"	"	——	——	9.8	5.1	"	50	——	113
	"	"	——	——	10.3	5.9	"	100	——	132
5. Alternator, 250-mi. L-R line, motor	Saturated	29.2	——	——	2.15	2.	——	0	——	21
	"	"	——	——	9.55	4.8	2300	0	111	119
	"	"	——	——	10.2	5.1	"	50	——	135
	"	"	——	——	11.0	5.9	"	100	——	152
6. Alternator, 250-mi. L-R line, motor	"	29.2	Unsaturated	29.2	9.9	10.0	"	0	——	146
	Saturated	29.2	Unsaturated	29.2	9.95	10.3	2300	50	——	154
	"	"	"	"	10.8	10.8	"	100	——	165

* The saturated reactor has a reactance of 29.2 ohms at 2300 volts.

ideal—*i. e.*, $\frac{dE}{dP} = 0$. One method studied—the mercury-arc rectifier as an adjunct in the excitation circuits of synchronous equipment in shop tests—showed real advantages.

5. The criterion of stability under all methods of load application appears to be the steady-state power limit.

6. To ensure stability during short-circuit disturbances, a well-designed and adequately fast relaying system is essential.

7. Results of good engineering accuracy can be obtained in the computation of system steady-state power limits by the application of available methods of calculation, although in the more complicated cases resort must be had to solution by the a-c. miniature system.

Discussion at Midwinter Convention

PAPERS ON TRANSMISSION STABILITY

(Nickle and Lawton, Clarke[1], Wilkins[2], Evans and Wagner[3])

New York, N. Y., February 8, 1926

R. D. Evans: Miss Clarke's paper dealing with the use of equivalent circuits for analyzing static stability, is of very considerable interest. Probably the most important contribution in the paper is the method of using an equivalent circuit to obtain the angle between generator and motor for maximum power. I believe this general method will find extensive use.

In carrying out the calculations, Miss Clarke replaces a complicated network with shunt admittances, by an equivalent network of a single series impedance, but with equivalent supply and receiver voltages. Sometime ago we had occasion to solve a transmission network in which many of the branches involved a long transmission line, and this led to a somewhat similar method of calculation. It is not convenient to go into the mathematical analysis at this time, but in the written discussion, we will submit an alternative proof of the method of using equivalent networks and equivalent voltages, which method is based on the use of general circuit constants and is of very simple form. I might say that some of the formulas used by Miss Clarke have been independently derived by us and that, for example, the transformation of the general network to the equivalent pi and vice versa, will appear in the revision of the "Electrical Characteristics of Transmission Circuits" by William Nesbit, which is now in press.

On the middle of the first page, Miss Clarke states that she takes the characteristics of synchronous machines into account by assuming a definite value of synchronous impedance and a definite value of excitation voltage. These assumptions are used to determine the static stability limit. These assumptions apply when the excitation is fixed but do not apply when the excitation varies under the control of automatic voltage regulator.

The determination of the proper method of representing synchronous machines for the calculation of static limits is beyond the scope of Miss Clarke's paper, but since it affects the static limit, it seems pertinent to comment upon this phase of the problem. The methods described by Miss Clarke are not applicable to the determination of the effects of voltage regulators since they do not permit the analysis of the time variation in excitation and of rotor movement. In the paper by Evans and Wagner, it is pointed out that the use of automatic regulators will actually increase the static limit over the value obtainable under

1. A. I. E. E. Journal, April, 1926, p. 365.
2. A. I. E. E. Journal, February, 1926, p. 142.
3. A. I. E. E. Journal, April, 1926, p. 374.

hand control. These considerations do not destroy the usefulness of Miss Clarke's methods which apply for hand regulated system. The methods may also be of value for systems with automatic voltage regulator in case an assumption can be made as to a definite value of machine impedance and a definite value of machine voltage. For example, if the regulator were fast enough to maintain terminal voltage, then machine impedance could be neglected, or if the regulator were merely fast enough to maintain constant flux then leakage reactance should be used. The true static limit would be determined, however, by a transient analysis in the manner indicated in the Evans and Wagner paper.

(By letter): In the verbal discussion, it was not practical to go into a mathematical derivation of an alternative proof for the method of equivalent networks given in Miss Clarke's paper. This derivation follows:

Referring to Fig. 1, the general equations for this network maybe written as follows:

$$E_s = A\,E_r + B\,I_r \qquad (1)$$

$$I_s = C\,E_r + D\,I_r \qquad (2)$$

where the notation for voltages and currents are indicated in Fig. 1 and A, B, C, and D are the general circuit constants. Following the notation used in the paper, complex quantities will be understood without any designating mark but a conjugate will be indicated by a bar over the symbol.

Let us divide equation (1) and multiply Equation (2) by the circuit constant A which gives:

$$\frac{E_s}{A} = E_r + \frac{B}{A}\,I_r \qquad (3)$$

$$A\,I_s = A\,C\,E_r + A\,D\,I_r \qquad (4)$$

Consideration of the above equations will show that they

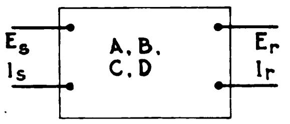

FIG. 1

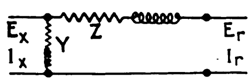

FIG. 2

FIG. 1—GENERAL NETWORK
FIG. 2—SIMPLIFIED NETWORK

correspond to the network shown in Fig. 2 below. The equations for the network of Fig. 2 are as follows:

$$E_x = E_r + Z\,I_r \qquad (5)$$

$$I_x = Y\,E_r + (1 + Y\,Z)\,I_r \qquad (6)$$

By comparing equations (5) and (6) with equations (3) and (4), it will be seen that:

$$E_x = \frac{E_s}{A} \text{ and } I_x = A\,I_s$$

Also

$$Z = \frac{B}{A} \text{ and } Y = A\,C$$

These considerations show that any network with constant impedance branches may be replaced by the network of the form shown in Fig. 2, using an equivalent supply voltage. It will be clear that the conditions at the receiver end for the equivalent network are identical with the conditions at the receiver end actual network. At the supply end, however, the voltage should be divided by A and the current multiplied by A. This simplification is obtained by the use of a transformation constant A, which constant is a complex number and necessitates a phase shift correction for power quantities as indicated below.

$$P_x + j\,Q_x = E_x\,\bar{I}_x = \frac{E_s}{A}\,\delta\,\bar{A}\,\bar{I}_s = \frac{\bar{A}}{A}\,E_s\,\bar{I}_s$$

By consideration of the simplified network of Fig. 2, it is possible to obtain the receiver power and the corresponding angle between supply and receiver voltages by consideration of only the series impedance Z and the phase shift in the equivalent supply voltage from the equivalent network.

Of course, the actual network might be divided in such a way as to permit the use of equivalent voltages at either end of the actual network.

We wish to emphasize the simple manner here employed to find an equivalent network which consists merely in rewriting the equations of the general network in the desired simplified form, and finding the equivalent network that corresponds thereto. The above method has been employed on a few occasions, but the phase shift introduced by the use of the equivalent voltage has been found to be somewhat confusing. The actual limiting angles between supply and receiver voltages may be computed directly from the general circuit constants for the over-all network, and the power corresponding to the limiting angle may be obtained graphically as is brought out in the accompanying discussion by Mr. Wagner.

H. W. Smith: A cursory review of Miss Clarke's and Mr. Nickle's papers indicates that methods are now available for the calculation of the steady-state power limit. These methods substantially agree for all practical purposes. Mr. Nickel's paper conveys the impression that the criterion of stability is the steady-state power limit although on the sixteenth page of his paper, tests are mentioned in which a dead single-phase, line-to-line short circuit, continued for half a second, reduces the power limit to 31 per cent of the steady-state power limit.

I think that all operating men will agree that if this is true, over-emphasis has been placed on the steady-state power limit. In any actual operating system, even though the best known relaying system is utilized, faults will occur, and on high-voltage systems they cannot be cleared in less than one-half second. It thus appears that the study of stability under fault conditions is extremely important.

Mr. Evans' and Mr. Wagner's paper is an extremely valuable contribution. They have developed a method of analysis of stability applied to an extensive transmission system, and this has been checked against actual tests which have been described in Mr. Wilkins' paper. The close agreement between the calculated results and test results seems to indicate that the method of analysis and assumptions made are correct enough for all practical cases. This paper indicates that for fault conditions, the transient stability is less than the steady-state limit. It would be very convenient if we could express this in terms of per cent of the steady-state power limit. This, however, can not be done, and for each system it will be necessary to determine the transient stability by a method of analysis indicated in Mr. Evans' paper.

In deciding on the limit to which systems can be worked the service standards must be considered. It may be permissible to have a system pull out of step under a fault condition that may occur at rare intervals, but if operation must be satisfactory for all fault conditions, the power limit must be considerably less than the steady-state limit.

H. H. Dewey: The general problem of power limits of transmission systems or stability has been before us only for the last year or two actively, and the papers that have been presented so far have left the subject in a somewhat confused state.

The problem as a whole is one that is assuming greater importance, as Mr. Wilkins points out, due to the interconnection of our power systems and the fact that we are endeavoring to make more use of our transmission lines. When we actively started the study of what limitations were important and what to do about it, we naturally started in a number of different directions and there was no very concerted effort made to direct our investigations along the lines that would produce immediate results.

The investigations that were made by the manufacturing companies with their artificial lines brought about certain basic results that were of immense importance. We found out things that we could have easily calculated if we had taken time enough and had got the idea but in our artificial transmission systems these suggestions came up as we noted the results of our tests.

When we had the first papers on this subject at Philadelphia two years ago, practically all of the authors, and I believe most of the men who discussed the papers, were willing to concede that stability depended very greatly on the excitation of our synchronous machines. They were also willing to concede that there was not very much hope of doing anything with our regulators or with artificial changes that could be made in the excitation during a transient. Starting out with that as a basis, we reached limitations of transmission that were surprisingly low. We found that it was difficult to get full rated output out of a generator when its excitation was limited by that necessary to produce normal terminal voltage under the conditions with which we started. That is one point that we come to a conclusion on on our artificial transmission tests that regulators were of extreme importance, and that due to certain facts such as the time element required to put on additional load or the rate at which transients come on, we could make use of artificial regulators and could thus increase the stability of a generator or a generator and its transmission line including transformers and all of the circuits in between.

So that, we feel, is an important point that we have fairly well settled on and I believe that the investigators fairly well agree that artificial regulation is possible and important.

There are a number of things that come before us in the study, some of which make us revamp some of our ideas on transmission. One point that I have voiced a few times and have been questioned on is the effect of charging current, the effect of capacity in our transmission line. It is in effect an absolute detriment. We have always in the past been in the habit of thinking that a long line introduced extra reactance and it was a bad thing to introduce such reactance and cause a voltage drop. We have felt it was compensated for by charging current of the line which had a tendency to hold up the voltage. That is true so far as regulation under specific conditions is concerned but when we are trying to get the last drop cut of the transmission system from the generator to the motor, if there is any charging current in between, that current reduces the excitation required on the generator and the excitation required for the synchronous load and it is an absolute detriment, therefore, because it reduces excitation and decreases the maximum power that can be transmitted. That is a point we dislike to give up but it is there just the same.

I was very much interested in Mr. Wilkins' paper on the test on a practical transmission system and fully agree with him in his statement that artificial transmission systems are of some use in studying the problem but the proof of the pudding is in the eating and we must apply our studies to a practical system and the points that have to be taken into consideration are so many and varied that we cannot reproduce them on an artificial system. We can get the basic principles, however, and those basic principles have been fairly well settled on by our studies on artificial lines and we hope there will be many cases of analyses made such as that on the Pacific Gas and Electric Company's system. The more complicated the system, the more difficulty we are going to encounter in making such a study because there are so many side issues coming in,—points Mr. Wilkins brought out, such as the speed of the relays, the action of the governors, the characteristics of the particular machines you have and the complicated number of machines of varied characteristics.

There are certain things that we know will increase stability. We know that a generator having low reactance helps to increase stability. The characteristics of transformers and characteristics of transmission lines themselves must be taken into consideration. The problem is one we are just starting on and one that is worthy of the combined efforts of all of our best people who have the opportunity to study these problems.

In general, we have not felt that the stability problem is one that was bothering us to any great extent, but usually when we have trouble there are so many things happening that we do know about that we concentrate on the analysis and cure of those particular troubles, and if we knock the system out of step we think it is another happening and one we have let go. Since we have started to study this problem, we have found case after case of pure power limitations that a few years ago we should have passed over as being an incident rather than the real cause of our difficulty.

The main problem before us is the question of the effect of short circuits. It has been pointed out by the authors of the papers that steady-state stability is something that is fairly definite, something we can increase to some extent by careful design of our system and regulating equipment and so forth, but the problem of short circuits is one that we know very little about. We know that we ride through certain types of short circuits. We know that other types break up our system. The analysis of the difference between these varied kinds of short circuits is one that requires more data before we can come to definite conclusions.

On high-voltage lines, we are much more likely to have grounds than we are to have line-to-line short circuits and I believe that has been the history of the 220,000-volt systems in California and the study made of their short circuits last fall brought me to the conclusion that with reasonably fast relaying, we can ride through a ground. It is a pretty difficult thing, however, to run through a phase-to-phase short circuit.

Mr. Wilkins pointed out some of their experiences and on the Southern California System, I found they have had many more grounds on the high-tension line than Mr. Wilkins has had due to the different conditions, but their record of relaying and holding in step has been excellent during those times. But with short circuits on the 66,000-volt system which is veritable network, the short circuits are of the order of 1,000,000 kv-a. when they are phase-to-phase. They have had great difficulty in keeping the system in step. They have dropped out of step fifteen times from the first of January to the first of October. That is an extremely serious condition when the drop is a matter of 300,000-kw. loads during those times.

That, you probably will say, is poor operating but operation hasn't much to do with it; it is the limitations we are getting into in the big system where we get short circuits right in the center of the system.

H. H. Spencer: I think the electrical engineering profession should be most grateful to Miss Clarke for having reduced so complicated a problem to a slide rule and arithmetical basis from the more complicated methods which we have been assumed to use during the past two or three years that the problem has been confronting us. Perhaps the most obvious difference between Miss Clarke's method of calculation, and some of the other methods which have been presented, is her choice of a constant generator reactance. Other investigations have presented methods of analysis which take into account the variation in synchronous reactance in accordance with the Blondel or similar diagram. I think it would be most interesting if Miss Clarke would point out what method is used in the selection of this constant synchronous reactance.

Another point which is perhaps not entirely obvious in the equivalent circuit method of calculation is that it is possible for the receiver network to which a transmission line is tied, to fall out of step *per se*. That is to say, that although a transmission line feeding a network may of itself be stable, the network which is fed may go into instability by virtue of its connection with the transmission line. Just how that works out can be seen by looking at Miss Clarke's example No. 3 on the 11th page of her paper.

Suppose the receiver system had consisted of 100,000 kv-a. of

synchronous generators at the receiver end and these generators had been loaded not to 45,000-kw. but to a load approximating their rating, say, 80,000-kw., allowing 20,000 kw. for spare capacity. Under such a set-up, it is quite possible that line would be able to transmit the calculated load of 132,600 kw., but that a reduction in the voltage at the receiver end while not producing instability between the receiver load and the sending end generators, would produce instability between the synchronous load and the receiver end synchronous generators.

In regard to the difference between steady-state and transient power limits, methods of analysis are certainly developed at the present date to the point where given the same assumptions, two engineers will come out with the same answer. The difference between the answers which are obtained from transient stability analysis lies, I believe, in the difference in the fundamental assumptions in regard to the flux relationships in the synchronous apparatus at the two ends of the line.

Now the problem of flux relationships in synchronous apparatus is not one of novelty, but on the contrary is one which has been dealt with for a long time and with consistent success by designing engineers. It is necessary for the engineer who would calculate stability, or power limits, simply to compute the flux relationships which exist under certain known conditions by means of perfectly definite methods which are in common use. Having disposed of the problem of flux relationship, the difficulty of the stability problem very largely disappears and the power limits are readily calculable.

If we concede that during a particular transient disturbance the flux in a generator or a synchronous motor remains essentially unchanged, then I think any engineer would have a tendency to feel that the power of limitations imposed during operation under the conditions which led to the development of the initial flux would obtain throughout the disturbance. Thus switching operations such as the dropping of a generator or one of two parallel transmission circuits will introduce no power limitations below those imposed by steady state operation since disturbances of this sort have no tendency to reduce materially the flux in the synchronous generators. Short circuits, on the other hand, which do reduce the flux in the synchronous apparatus may very possibly impose power limits appreciably below these encountered in steady state operations.

Several single-phase, short-circuit analyses which have been studied during the past few months have shown that in a system of ordinary design, the steady-state stability limit is very markedly reduced by single-phase short circuits to ground. However, by means of changing the circuit set-ups, introducing a zero sequence reactance in the transformer windings, or using neutral reactors, the steady-state stability limit of the transmission system can be very closely approached.

H. K. Sels: In order that I may present clearly and concisely a number of points in some chronological order, I am taking the liberty of reading a prepared discussion. I do not wish to deal in personalities but to present such criticisms as I have from the purely abstract viewpoint of an operating engineer for a large and extensive system—particularly since the papers have not been in my hands long enough to fully acquaint myself with their respective contents. After three years of theoretical and experimental investigations I am more interested in the questions,—what has been accomplished and whither are we bound? No single organization seems to be responsible for the headway that is being made and I offer that as a hint to some of our several transmission committees.

The question of stability is as old as the alternating current art itself. We have always been confronted with the problems of synchronizing power between large generating stations, "hunting" of synchronous motors and the stability of rotary converters. A large number of papers have been presented before the Institute relating to these problems. The impression one gets from the papers which have been presented on the subject of stability is that we have discovered something radically new, some vital thing in which our power systems are unduly weak. Such is not the case and our methods of electric distribution are no weaker than they have been, by virtue of this discovery. However, what we do have that is new is a broader vision of the problem and the relation of its elements, and new methods of attack, and we hope, after all the facts have been analyzed, that we will obtain a solution which will extend the power limits of transmission to the ultimate.

Fundamentally, what we are really interested in is the power limits of a transmission system. A large number of factors determine the power limits of a system. It may be the current carrying capacity of the wire; it may be the economical amount of power that can be transmitted over a given line before it pays to build additional lines and maintain the same continuity of service, or it may be the question of stability of operation, which are the subjects of today's papers.

Psychologically I think it would be better for us to speak more in terms of the power limit, remembering that stability is only one of the important factors involved.

I believe everyone is over-emphasizing the relation of stability to high-voltage transmission. Of course it is true that stability is more likely to fall within the economic power limits of transmission at the higher voltages, but this does not reduce the importance of stability at all voltages and on all systems. Every operator is familiar with the losing of load or the dropping out of synchronous apparatus during system disturbances and fundamentally this is nothing more than the effect of instability. Therefore any improvements for stability apply equally well throughout the system.

Just to refresh my memory on the general trend of opinion on the various factors entering into the stability question, I reviewed recently all the papers and discussions that have been presented before the Institute. From an operating viewpoint I was very much impressed with the technicalities and, to me, the impractical viewpoints which were expressed. I believe that the average engineer would be hopelessly lost in attempting to follow through calculations on anything more than a very simple transmission system rather than a large interconnected system where the attempt is made to keep short circuits as low as possible by using synchronizing buses with reactors between individual generators and other complications used in the layout of the modern system for dispatching load; in fact it is very much like the mathematical conundrum of trying to solve a problem having more unknown variables than equations.

In addition to the factors outlined by the various authors, let me indicate for a moment some of the multitudinous conditions which the operating engineer must consider in making any calculations on stability. First, today we have a certain distribution of power stations serving a given load in a given territory connected up with a certain arrangement of transmission. Tomorrow we have a more efficient generating station coming into operation, a new arrangement of transmission to new load centers, which entirely alters the fabrication of the system. In actual operation the load conditions obtained hour by hour, day by day and year by year, change on account of the relative efficiency of the generating units on the system, the variation in load and different set-ups of lines in and out of service due either to failure or ordinary maintenance. All of these features only serve to make an intricate problem more involved. In attempting to determine a method of calculation which can be used with some degree of accuracy, I believe we should use those assumptions which we find agree the closest to actual operating tests.

Today's papers indicate more than ever that the methods of calculation used by the different engineers do not differ greatly in theory, but there does seem to be some difference of opinion as yet on the assumptions to be made and whether the steady state or the transient state is more important. These differences

apparently account for the divergence in the results of calculations by different engineers. As I have already brought out, the problem is so intricate that at best the solution is a cut and try process in which your methods of calculation and assumptions must conform with the results obtained by experience. For this reason I believe that for the present at least we shall consider all calculations only qualitatively and not accept calculations by separate engineers as comparative unless made on the basis of the same assumptions. For example, I might agree with the general shape and relationship of the curves in Fig. 17 in the paper by Messrs. Nickle and Lawton, but not agree with the maximum power scale due to some difference in my calculations.

With regard to the relative importance of steady-state and transient conditions, I believe it is evident that in cases dealing with high voltage, long distance transmission where the stability limit falls within the economic power limit of the line the steady state performance of the line will be of primary importance, because with such a large amount of capital tied up in the transmission system every means possible will be used to make failures on the transmission practically unknown. While the transient state does not enter so much into economics of transmission, it should be expected that continuity of service to local loads as well as the extreme importance of keeping a large high voltage system operating continuously as a whole will make this a factor not to be overlooked. In the case of lower voltage and shorter distance transmission, we can point to case after case of both major and minor importance in which some disintegration of the system takes place during a system short circuit. In actual operating experience I have yet to hear of the case where a system designed to operate in parallel has fallen apart due to steady-state conditions except where the static limit was reached in the Southern California Edison system within what we might say is the economic emergency capacity of the line. However, I should like to ask what experience shows here that transient stability is not an important factor. Before too much discussion is entered into on steady-state and transient stability, it would be apropos to have the terms defined, and we may find more of us in agreement than is apparent at first. Personally I classify the steady-state stability limit as that load which breaks down a system when slowly applied and the transient stability limit as that load which breaks down a system when suddenly applied or during switching operations including short circuits. It is conceivable that under certain conditions of small load increments or minor switching operations, the two limits will be the same when so defined. Summing up the relative importance of steady-state and transient stability, here again I believe we must resort to actual operating experience to tell us where our weaknesses lie. It is commended that the various investigators review the interruption records of some of the operating companies.

If we must rely so much upon actual operating experience, you may then ask, "What are we gaining by all our calculations?" As an operating engineer, I turn to the manufacturers of electrical equipment for the answer to this question. There is relatively little that can be done in changing the characteristics of our transmission systems so as to get more power per circuit over them, but there is apparently much that can be done in the development of terminal equipment. As already indicated, calculations are of more use as a qualitative measure than as a quantitative measure, particularly in reducing the annual bickering as to the relative merits of designing equipment.

There is a point to which I have been leading in this connection and that is as to whether the design engineers of terminal equipment are making its characteristics to suit special cases or whether the improvements are to take the form of a general design which will be suitable to meet the ever-changing conditions in a developing system. For example, I believe these improvements in design should be of a general nature because if we picture the developments of a twenty- to thirty-year period in a large interconnected system, the various load centers in the network will pass through a number of stages in which machine characteristics of only a general nature will apply. Of course for periods of a longer time, we can, by the usual methods of accounting, charge off old equipment and buy new of suitable character. If we take a broad vision of the problem at this time, however, we have an opportunity for obtaining economies which otherwise might be lost.

I should like to call your attention to the related problem of short circuits. Broadly speaking, a short circuit on a system is merely a certain type of load, of which the characteristics are rather elusive, but we can assume conditions covering a wide range in the hope of representing the actual conditions and apply the same methods of calculation carried out in studying stability. Here, then, we have a new method of investigating short circuits which takes into account the various phase relations of the prime movers, giving us a better picture of the duty required of our oil circuit breakers. From one standpoint we may be pessimistic in making calculations on the assumption that the sources feeding the short circuits are all in phase, but on the other hand I believe we have been optimistic in the way our circuit breakers have been performing in interrupting large short circuits, the value of which has been obtained from short-circuit calculation on the d-c. tables. It may seem somewhat unfair to add to the criticisms of our circuit breaker performance but it is a question which is closely allied to the stability problem. The whole thing is like burning the candle at both ends. On one side, we are trying to make our systems more stable which, in a sense, means greater concentrations of power and greater short circuits, and on the other we are trying to keep our concentrations of power to a minimum and thereby relieve our short circuit requirements. How can we have our cake and eat it? The only possibility in view along this line is to lay out small individual systems interconnecting them for diversity and reserve purposes only, but this step is in direct opposition to present tendencies in operating economies.

It is easy to sit here, and I may as well add, in our offices, luxuriously basking in the sunshine of a successful convention or conference, and dispose of this and that theoretical possibility with some oratorical gesture, but we must remember that experience often reverses the best of our intentions. I might illustrate this by an actual happening. The continuity of service on a given substation bus having two independent power station sources and two independent feeders from each of these was questioned and the statement was made that a shutdown was well nigh impossible. Approximately six hours later the impossible happened and the substation had an interruption measured in hours and the trouble was not a bus fault. We must remember that there are a number of links in the chain between our design tables and the distribution of power to the ultimate consumer. We are dependent upon Tommy Riley, Buck Jones, Ted Flinn and the rest of the boys on the firing line, who, in weather like this, keep maintenance on switching to the point where we may expect fast relaying. The more we can incorporate improvements in the inherent characteristics of the apparatus itself the more we will remove the personal element and for that reason we should proceed slowly in getting greater stability with additional equipment that may not function at the critical moment. It is easy to set up operating conditions but often quite another matter to obtain them. Therefore, I believe it is more practical and economical to first improve the characteristics of equipment now in general use and then turn to the possibility of adding other auxiliary equipment.

C. A. Powel: There are two points mentioned by Mr. Wilkins, and also by Messrs. Evans and Wagner, upon which I wish to comment. The first is the character of system oscillations at times of a fault to ground. Ordinarily, one thinks of a short circuit as reducing the energy output of a generator. How-

ever, in the case of a fault to ground on a large transmission system, the effect may be to actually increase the generator power output. This is due to the resistance in the ground connections from the faulty conductor to the transformer neutral.

Three records have come to my notice, and in each of these cases the generator output was actually increased, and in two of them the prime mover input was also increased by the opening of the gates. While this evidence should not be construed as meaning that all faults to ground will increase the power output of generators, it certainly does substantiate the position which has been taken that the resistance of faults to ground must be carefully considered.

The second point is the fact brought out that there is no particular value for the transient limit of a transmission system. Loss of synchronism at times of fault is dependent not only upon the system layout, but also on the load being carried and on certain speculative elements as to location and character of the fault. The point seems to me important, because it involves the whole question of rating of transmission systems. If the operation is such that it is permissible to pull apart every time a fault occurs, then obviously it will be possible to carry a load not far from the static limit. If, however, the transmission system is expected to ride through the majority of troubles, the power transmitted must be kept considerably lower.

In view of these considerations, it is desirable to obtain data

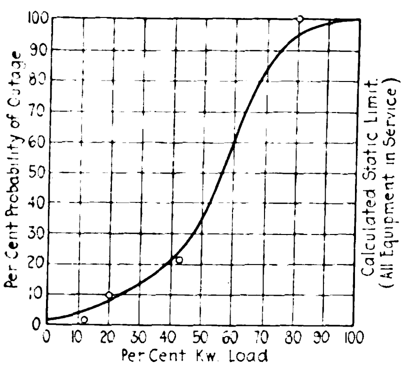

Fig. 3—Probability of Outage of Transmission System as a Function of Load in Case of Fault

as to outages and to plot the results in the form of a probable outage curve as a function of the load. Such a curve is shown in Fig. 3. All faults on the transmission line, and in addition, faults on secondary systems which produce outages, should be considered. It will be noted that the curve shows a definite but small probability of outage when the system is carrying zero load; such outage, for example, might be due to an operating error. The curve also approaches 100 per cent outage as an asymptote at the static limit. It becomes very steep in the middle portion.

The smooth curve which has been drawn is based on the limited amount of data which has been obtained for a particular system. While more complete data will probably change the exact points through which the curve would pass, it will not change its general shape.

The shape of the load curve on the transmission system must also affect its rating. If the power transmitted varies so that its peak value is only of short duration, the maximum rating can be kept higher with the same risk of outage, because the probability of faults is independent of the load.

Stability and not the losses in the lines determines the rating of a transmission system. Increasing the size of conductors will not appreciably increase the stability, and consequently the question of rating is of prime importance when deciding on the size of conductors to be used in a transmission system. The expenditure for extra heavy conductors may not always be justified.

R. E. Doherty: I think that the Institute is to be congratulated on having the papers which have been presented at this session, particularly the one of great importance, Mr. Wilkin's paper, which, for the first time, gives some actual operating data regarding these problems.

I should like to say a few words with respect to methods of calculations which have been referred to in various papers. A new subject, or a new phase of an old subject, came up recently, (within the last few years), and independent investigators attacked that problem. New nomenclature appeared, and each man has his own notion about those matters. Until they are standardized, we always shall have with us the well grounded objection of the next-to-the-last speaker, that he doesn't know what every one is talking about, and I gathered that he doubted whether the authors did. I have sympathy with his bewilderment.

Each one of us who studies this problem must make some simplifying assumptions. I think that there is one point on which we are all agreed; that a complicated power system network is not amenable to rigorous treatment by mathematical methods as we know them now, and I doubt that it ever will be. It is therefore necessary to make certain simplifying assumptions. Mr. A may make one assumption, Mr. B another assumption, and so on; but before he acts on it, you can rest assured that he is going to have some data or actual experience, some basis for his conclusion before he takes any step toward actually applying it. And if their conclusions on which action may be based are in substantial agreement, it seems of little avail, and certainly misleading, to publicly emphasize trifling disagreement of experts on certain details. While I may appear to be letting the cat out of the bag, so far as this apparent disagreement is concerned, I wish to state that when it comes down to brass tacks on a given proposition, to a study of some proposed system, the agreement among engineers seems to be pretty complete on what can be done and what cannot be done—which indicates to me that the more important factors are generally understood and agreed upon. I am sure all of you who are not daily living with this problem, would rather have those who are discuss and settle these disputed details over a table rather than here on the floor of the convention. I think one of the first things that could be settled in that way is nomenclature, and I propose that it should be done.

Just one word about this discussion of static stability and transient stability. I don't like to talk about stability. I share the view of a previous speaker, that "power limit" is a perfectly definite thing. It happens that the maximum power in some cases is also the limit of stability, but it is not in all cases. You can have a maximum power which is not the limit of stability, but I think all engineers are agreed on this: That there is a definite maximum power which can be transmitted over a given system under steady state at normal voltage. It is a perfectly definite thing, and everybody will agree on the value of that limit. And if so, let's talk about that limit.

We have found on investigation that if one throws on any load up to that limit, and the system is controlled by an ordinary vibrating commercial type regulator, the system will carry it. It will not lose synchronism. There may be such cases where synchronism would be lost, but we haven't found them. So long as the power to be carried is not greater than the static limit under the new condition—for instance, when a line section has been switched out—you can get away with it. In connection with this, I agree with the conditions mentioned at the top of page 2, second column, in the Evans and Wagner paper. The supposition is that if you have adequate relaying system and can promptly clear a line-to-ground fault, it is possible to carry through it.

In connection with this, Mr. Nickle states in his paper that

the static limit appears to be a criterion for the study or determination of power systems, and I submit that this is a reasonable position to take. It does not say that there are no other criteria, and that if it is satisfied, the system can not fall out of synchronism. It does say, however, that if it so happens, during a transition from condition *A* to condition *B*, the system is so regulated that it could carry condition *B* under steady state, then it can. by virtue of that regulation and the inherent electrical and mechanical characteristics of the synchronous machines, carry through the transition and remain in synchronism. Now if this were true in all cases, the steady-state limit for the worst condition *B* would be a comprehensive criterion. Our conclusion is that with proper regulation and, excluding short circuits, it would be generally true. It is probably true in the usual line-to-ground short circuit. However, whether or not we speak of the steady-state limit as a criterion, I earnestly submit that it is a definite figure which is characteristic of any given system, and is a quantity which any informed engineer with the same data will arrive at. It therefore constitutes a sort of a bench mark for reference.

I wish to add a word about high-speed excitation. Two elements are essential in an excitation system in order to increase the maximum power beyond the steady-state limit to which I have just referred. One is an exciter of sufficiently high magnetic speed. The other is an automatic regulator which would properly control the exciter. The high-speed exciter is easily obtained. However, no commercial regulator within our knowledge at the present time has the required characteristics to thus utilize such an exciter. The mercury-arc rectifier scheme[1] which was discussed at the Seattle Convention has the necessary inherent qualities. With proper regulator control there should be no discontinuity between the steady-state power limit obtained with the standard exciters as ordinarily regulated, and the limit obtained by the extremely high-speed excitation of the rectifier, so long as the increased exciter speed is properly applied. And while I reiterate that inherent characteristics of present day commercial vibrating regulators prevent their accomplishing this, it is nevertheless hoped that a regulator of proper characteristics may presently be available.

To sum up my discussion, it is certainly gratifying that all engineers who are studying these matters seem to be coming to the same general conception of this whole problem. There are certain trifling matters concerning which they are not yet in complete agreement because they have started out from slightly different bases, some thinking one assumption is more important than another. But these are not of general concern. The whole problem, I say, is sifting down to a narrower range in which we can all view it from the same angle and agree, provided we are careful about defining the terms we use.

C. L. Fortescue: I want to express my appreciation of the ingenious method Miss Clarke has developed to determine the static stability limit. I also wish to say, however, that the methods that have been used before are in reality no more complicated than Miss Clarke's method but the apparent simplicity of Miss Clarke's method is due largely to the able way in which it has been presented.

Regarding the paper by Messrs. Nickle and Lawton, I want to congratulate them upon this paper. It is an extremely readable paper. I want to emphasize in discussing this paper not the apparent differences in opinion between our group of papers and this one, but more the points on which we have come to an agreement. There is a tendency in discussions to pick out the points of disagreement and discuss them only. As a result of that, those who read the discussions say, as I heard Mr. Roper remark, "Well, we can't make head nor tail of this matter. Some say this is black and others say it is white." The static stability limit is a very definite limit. One might say it is an invariant of a given system. It is quite a definite value and can be determined without difficulty. I shall go Mr. Doherty one better and say the static stability limit as defined by constant excitation is one of the criteria of the stability of a system—not the criterion, but one of the criteria.

In connection with this static stability limit, in considering ways and means to raise this limit, we found with high speed automatic regulators we were able to get quite an appreciably larger amount of power over the circuit.

Now I am bringing out this point not to emphasize the point of difference, but because this artificial stability has an element of hope in it. If you can do it with a regulator today, you may be able to get a regulator that will do it still better tomorrow. You will surely be able to get more power over a given line tomorrow. Maybe the automatic regulator of special design will be the answer; maybe an inherent regulator scheme will be the answer. We don't know now, but one of these days we will know.

Now regarding the transient stability as one of the criteria of operation: I want to say that after reading over the conclusions in the paper I was rather struck by the fact that transient stability wasn't considered of great importance, but on reading over the paper itself, I found data presented there that led me to say that transient stability was just as much of a criterion as the static stability.

One statement in the paper, page 16, calls attention to single-phase faults and points out if the fault is removed instantaneously, the load can be carried right up to the stability limit. Now if you remove a fault instantaneously, you are doing exactly the same thing as if you cut out a section of line on a loaded transmission line instantaneously. And we know if you cut out sections of loaded lines, the effect on the load limit is very small, so I think that is the answer to that.

As a remedy, mention is made of quick operating relays; that is part of the remedy but we must go a step or two further than that. We must have quickly operating circuit breakers and we must have adequate voltage regulating systems, either high speed or inherent, and we may possibly have to help out with the governing system and also consider the effect of resistance of the fault. I wish to point this out because I myself reached somewhat different conclusions from those of the authors from the data they present in their paper. We can't say that one limit is more important than another limit. We have several limits. We have the static stability limit, and if you raise that, you also raise the transient stability limit as a general rule, so that we have several loopholes to follow in order to solve this problem.

As to methods of calculating transient stability, I may say that we have found it practical to calculate even relatively complicated systems by the point-by-point method. It is of course a long drawn out tedious method. There is no doubt a technique will be developed in the course of time to enable engineers to calculate power transients in more complicated types of systems. In other words, the present methods are cumbersome and long drawn out but they will be improved and perfected in the course of time.

We do not dissent from the opinion that a dynamic model may be evolved, but we insist that such a model must take into account the essential facts, the most outstanding of which is that the differential equation of the motion is not linear. The condition with which we are concerned in transient stability is that unless we get instantaneous removal of the fault, it does not permit of the use of approximately the linear form in analysis. In fact, the problem is similar to that of a pendulum and the difference between the two problems is the difference between the cycloidal pendulum and the simple pendulum, between the harmonic motion and the elliptical.

I bring this point up because I think Mr. Nickle in the course

1. *Fundamental Considerations of Power Limits of Transmission Systems*, by Doherty and Dewey, A. I. E. E. JOURNAL, October, 1925, p. 1045.

of time will undoubtedly get the right kind of dynamic model to find the answer to the problem in the proper terms.

As to the effect of machine characteristics, the importance of machine characteristics has been emphasized by the group of engineers to which I belong. Machines designed according to present practise must incorporate the necessary stiffness, to use the authors' term. This may be done by designing machines with lower synchronous impedance, that is, with long air-gaps or saturated poles. This applies to generators and synchronous condensers. In addition to this, we must have voltage regulators quickly responsive to changes in voltage.

An alternative method which may develop is the compensated machine which may be a generator or a condenser. Partial compensation in the case of a generator may be considered of advantage. Investigations on compensated machines are being carried out now and data is being obtained which will be available in due course.

In regard to the intermediate condenser, the authors have indicated a substantial gain with sufficient condenser capacity. While the capacity requirements as represented by them are large, it need not worry us as there is no doubt that in due time the right kind of machine which will give the desired results with smaller capacity will be developed.

W. P. Dobson: Mr. Wilkins evidently relied upon telephone signals to obtain simultaneous oscillograph records at widely separated stations. In 1912 and 1913 the writer, during an investigation of transients on 60- and 110-kv. systems, made use of an automatic attachment to an oscillograph to accomplish this result. The closing of a switch on the oscillograph table operated the high-tension breaker, the film-motor and shutter in proper sequence to obtain the desired record on the film. Circuit breakers in distant stations were connected to the oscillograph control by means of the system telephone circuits. It was possible to obtain records of transients of short duration on a standard 12-in. film and satisfactory records of transients of over one second's duration were obtained with a 42-in. film. The apparatus was designed by Professor H. W. Price of the University of Toronto and was used on the lines of the Toronto Power Co. and the Hydro-Electric Power Commission of Ontario over a period of 18 months. Several hundred records were taken with a negligible number of failures. It is believed that this was the first instance of the application of automatic control of an oscillograph for this purpose.

H. B. Dwight: On the 11th page of Miss Clarke's paper, there is a diagram in which leading reactive kv-a. are plotted downward. This is typical of the papers by several authors. There is also a group of writers who draw this type of diagram with leading reactive kv-a. plotted upward, the same way that leading reactive current would be plotted. It is an inconvenience to have these two opposite methods in use, and as diagrams of kw. and reactive kv-a. are of somewhat frequent occurrence for various purposes, it seems that the time has come when it is appropriate for the Institute to give a decision as to whether leading reactive kv-a. should be considered positive or negative, and should be plotted upward or downward in diagrams.

J. W. Legg: Mr. Wilkins deserves much credit for recognizing the value of reliable high-speed records, and for insisting on having apparatus capable of giving reliable graphs at these high speeds. The Esterline graphic instruments used in these tests were too sluggish of movement to warrant a high-speed chart until they were reconstructed with greatly increased restoring torque and more than 50 times normal power input. This necessitated a battery of special transformers and special switching schemes to throw the graphic instruments out of the circuit after operating less than half a minute, to prevent excessive heating.

In 1914, while still a student, the writer conceived a truly portable oscillograph to operate with a low-voltage incandescent lamp, and to have wattmeter elements, and other effective-value elements, as well as the standard elements for instantaneous values. The ease of obtaining truly high-speed graphs, freely crossing one another, appealed to the writer as being worth the inconvenience of photographic development. A daylight-loading film holder was conceived then but not developed and perfected until 1921. In spite of this improvement in film-holders, all effort was expended to develop high-speed graphic instruments requiring no photographic film. Progress has been made in this line, but the demand for higher and higher speed records (with correspondingly higher-speed movements) has surpassed all improvements in standard graphic instruments. This is shown very clearly in Mr. Wilkins' paper. The standard high-speed (so-called) graphic instruments were of practically no value for these important tests until remodelled and forced at fifty times normal input. C. F. Wagner saw the limitations of these instruments, after all the improvements he had made, and made up several oscillographic wattmeters to be placed inside our standard, portable oscillographs, and in separate cabinets using standard oscillograph lamps, lenses, film holders, etc. These confirmed the writer's predictions and proved very successful in these tests.

Several years ago the writer figured on an instantaneous, polyphase, reflecting, wattmeter-element, with a natural period of approximately 2000 cycles per second. A single-phase wattmeter element, with a natural period of 5000 cycles per second, would be very simple, but not particularly valuable on account of the high (double) frequency oscillation of the power wave on a-c. lines. The quick-acting (but not instantaneous) elements, pushed through for these tests, proved so successful that they will be commercialized, in an improved form, very soon.

A nine-element portable oscillograph, considerably smaller than its three-element predecessor described in the JOURNAL of February 1923, has been designed to give nine simultaneous records on one 7-in. width of film. Three of these oscillograph elements may be replaced by high-speed wattmeter elements, or by other effective-value elements when they are developed. Such an instrument will be ideal for stability tests, and for operation on chance disturbances. A daylight-loading long-film holder has been developed to take films 6½ in. wide and either 3, 6, 8, 16, or 24 ft. long. Twenty-four-foot films were used for the first time in these stability tests, passing through in less than six seconds. For lower speeds the film-holder can be made to operate quite reliably for daylight-loading and daylight-unloading.

During the discussion of the writer's paper, in 1923, on "Expansion of Oscillography," J. R. Craighead seemed to doubt if the oscillograph could be made to function, automatically, quickly enough to show what happened before the oil circuit-breakers functioned. All that the writer claimed then, and more too, has been done since then. Our portable oscillographs have been set up in substations and have operated, repeatedly, on chance disturbances, and have given valuable information as to the disturbance and breaker operation. Furthermore the new single-element oscillograph (the OSISO) can be set up to record chance disturbances within less than one-thousandth of a second after the closing of a quick-acting relay. The 4-volt lamp is initially excited by a condenser charged to 110 volts, d-c. The lighting of the lamp is quick enough to obtain a perfect oscillogram of the chance rupture of the arc in a quick-acting circuit breaker on d-c. lines. With the proper quick-acting relay, operating on the steepness-of-wave-front principle, the oscillograph will function perfectly within two-thousandths of a second after the very start of a short circuit, before the quick-acting breaker can reduce the short-circuit current. The photographic film must be kept rotating all the time, for such extremely quick operation.

The advantages of such apparatus are being better and more universally recognized, and oscillography will continue to expand and be a greater and greater help to others besides the electrical manufacturer.

Svend Barfoed: In designing transmission systems to safely carry a specified load, I have in the past used methods that are very direct. They involve the use of diagrams in which the various factors affecting the power limit of a transmission system appear together and may thus be studied more easily. As yet I have not found any necessity for transmutation of the diagram and method into others which, as far as can be seen, are the exact equivalent. The accompanying diagrams illustrate such a study.

Fig. 4 has been described several times. The load lines are shown advancing by eights up to full load; to scale they are meas-

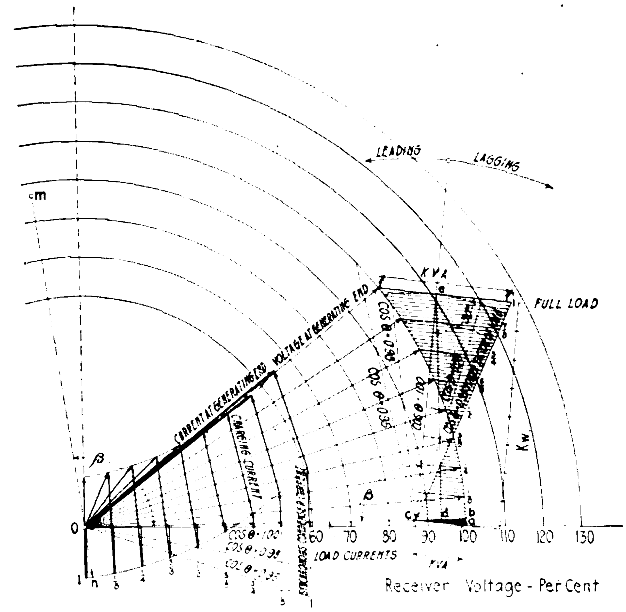

Fig. 4—Typical Regulation Diagram for High-Capacity Transmission Line

ured in position in kw. The magnetizing power is measured parallel to the load lines to the same scale in kv-a., being for example $c\,F$ at unity power factor of load at full load or $F'\,F$ at a power factor of 0.95. The magnetizing effect of the charging current is given by $a\,c$. Thus all factors affecting the trans-

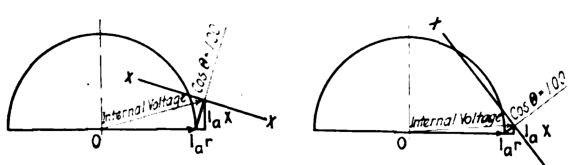

Fig 5 Fig. 6

Figs. 5-6—Generator Diagrams for Different Ratios $\dfrac{I\,r}{I\,X}$

mission limit of power of the line and transformers is had at a glance. It is at once apparent that all factors are very definite and do not admit of discussions of a qualitative nature. For any given relation the line and the transformers have characteristics which are fixed and quantitatively known. It can easily be seen that the smaller the resistance compared to a given reactance the higher the power limit, and highest for zero resistance. In other words, the more nearly vertical line $c\,e$ is, the higher the power limit. On the other hand, with nearly zero reactance the power limit would be very low indeed. The criterion is the tangency of a load line to any one of the circles shown on which it may be desired to operate. Tangency represents the static load transmission limit. Swinging the unity power-factor line $c\,e$ around c as center to the right, representing a designed decrease in reactance for the same resistance, makes

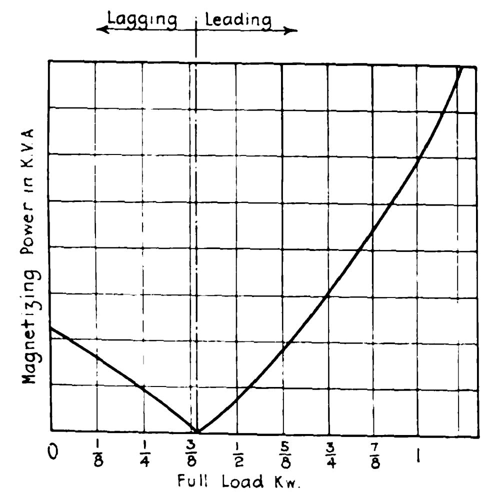

Fig. 7—Magnetizing Power Required from Synchronous Machines on System (From Diagram Similar to Fig. 4)

the maximum load lines become tangent to the circles at smaller and smaller loads and when finally the load lines become nearly vertical the ability of the system to transmit power almost vanishes. It is thus seen that in order to transmit power with alternating current the proper relation between resistance and reactance must prevail and it is evident that low resistance lines are highly desirable since the reactance of the line can be changed but little due to clearance limitations. Similar reasoning holds for the transformers, but with them it is also desirable that the reactances are no greater than required for the strength of the

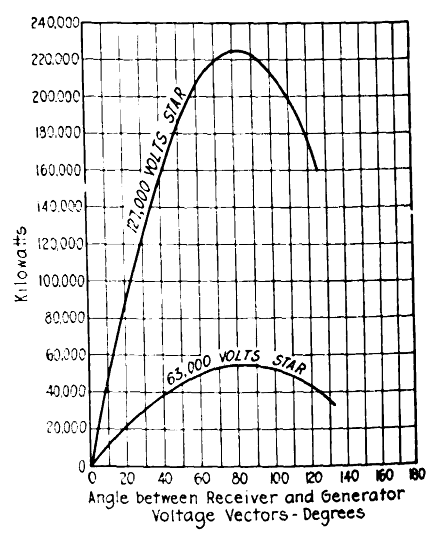

Fig. 8—Static Stability Curves—200 Miles of Line (Plotted from Diagrams Similar to Fig. 4)

mechanical structure during short circuit. At previous meetings when power transmission limits have been discussed, the characteristics of the synchronous machinery have been included, but in no very definite manner. It is with respect to the synchronous machines that it is ventured to hoist a warning signal. It is seldom that a large power plant contains but one machine. If there are several it is imperative that they have such character-

istics that they will operate properly in parallel under all conditions of load and can readily be synchronized. There must be no hunting between them. If for the sake of increased power transmission limit the synchronous reactance is very much reduced, hunting will surely occur between generators running in parallel in the same station, and stability, possibly, may only be secured again by adding reactors external to the machines. This is an old story and is visually shown in Figs. 5 and 6. In Fig. 7 the ratio $\frac{I_a r}{I_a x}$ permits the proper synchronizing force to develop between machines due to a large amount of power possible of transmission between them. In Fig. 6 the ratio $\frac{I_a r}{I_a x}$ is such that the limit to the synchronizing force is very quickly reached with the machines liable to fall out of step.

The effect of the load power factor is given at once by these diagrams, and there is nothing vague about the amount of magnetizing power required to compensate for power factor, either for voltage regulation or for a given power transmission limit. The synchronous condenser is a very admirable machine to give or consume magnetizing power in the required amount. It will perform exactly as desired if the V curve of zero power load coincides with the magnetizing power curve of Fig. 7.

From the above it is seen that the line and transformer characteristics and the charging current do not lend themselves to a discussion of power transmission limits. They are to be considered known and fixed within narrow limits. As long as we transmit power with alternating current, the charging current cannot be removed and to say that it is detrimental to a higher power limit is like saying that the current flowing in a coil of wire is undesirable because it heats the coil.

The power limit of a given transmission system is therefore influenced chiefly by the characteristics of synchronous apparatus. I accept the statement that the machine designers know how to design machines for maximum transmission of power. That being so, the transmission line designer would like to know in what manner this is done. He would like to know how the synchronous reactance is apportioned between self induction and armature reaction, how compensated for, whether means to affect a quick response to excitation power is counteracted by means to affect damping of power swings, and whether a machine designed for maximum power limit is a suitable machine for installation in a plant where there are several which must safely operate in parallel on the same bus bars.

It has been said that power factor has much to do with the power transmission limit. To be sure it has, but in a perfectly definite manner. Power factor lagging means that magnetizing power must be furnished by synchronous machines either at one end of the line or both; power factor leading means that magnetizing power must be absorbed by synchronous machines or by some other variable tractor. If the rate of change in magnetizing power is such that the excitation power of the field structures cannot follow at the same rate, oscillations will be started. Tests on actual systems cannot reveal much in this connection since the magnetic structures cannot be changed. Such tests belong on the test floors of the manufacturer. With machines of conventional design it appears that transmitting power at 220 kv. up to 250 mi. is safe when the lines are loaded to one ampere per 2200 cir. mils and condensers located only at the receiving end. This can be improved by suitable engineering of the line itself. A discussion of this would, however, lead too far at this time. Only this,—there must not be added further apparatus in power houses, substations or elsewhere until circuit breakers for 220-kv. operation have been improved to the point where they no longer constitute the present limit to transmission of power. The circuit breaker must perform its function without destroying itself too soon and it must open the circuit at such a rate that a power arc on the line will not have time to seriously injure the conductor. The circuit breaker must be relied upon to transfer without distress the energy from a line section in trouble to a parallel line. The normal energy to be transferred is of the order of 130,000 kw. It is comparatively easy to compute power swings and to provide a sufficient margin of safety. It is far more difficult to design economically a system where disturbances causing power oscillations will inherently be reduced to a minimum. The first problems to solve are 220-kv. circuit breakers and line insulation.

F. L. Lawton: It is certainly in order to compliment Mr. Wilkins and his associates on the courage and initiative displayed by them in attempting investigations of system stability on a power system of the magnitude described. Further, the addition of field tests of this type to the theoretical studies undertaken in the past few years affords an opportunity of passing judgment on the assumptions made in those studies.

It is indeed encouraging to note the real agreement between the conclusions reached by Mr. Wilkins and those presented by Mr. Nickle and myself, today, and also those in a recent paper[4].

The writer disagrees with Mr. Wilkin's observations anent the place filled by the use of artificial lines and miniature equipment. It is, of course, true that test data, whether obtained on an actual network or on miniature systems as used by Mr. Nickle and myself, apply only to specific conditions on given systems. However, and this is important, *it is virtually impossible to assign the right values to the factors affecting the stability of a real network*, of anything like the complexity of the Pacific Gas and Electric Co.'s transmission and distribution system. With the miniature system, methods of analysis can be studied, actual cases[5] checked, and *the methods of analysis may then be applied with real confidence in the soundness thereof to the solution of stability problems.* In this respect, the miniature systems with synchronous apparatus up to a few hundred kv-a. capacity have been of great assistance but it is not suggested that a 225-kv-a. system be used for the solution of stability—or rather, power limit—problems. For these there are available:

(a) The miniature system of Spencer and Hazen[6].
(b) The equivalent-circuit method of Nickle[7].
(c) Proven methods of computation.
(d) Experience.

When anyone conversant with the difficulties involved in analyzing system power limits by theoretical methods visualizes the physical data applying to the system in Fig.1, he will have a better appreciation of what a miniature-system method of stability analysis means.

When results of good engineering accuracy, directly applicable to proposed or existing power networks, can be obtained relatively easily and expeditiously by use of a miniature-system method and proved principles, it is presumed that they will be used and "actual quantitative values for this fundamental data" will *not* need to be "measured." Such miniature systems and principles, it would appear, are already available.

Regarding the contention that system stability, as a problem, is inextricably entangled with operating economics, this is largely true but, nevertheless, good progress can be made in determining the power limits of transmission systems under the majority of circumstances likely to arise.

The results obtained by Mr. Wilkins when the 220-kv. line at Pit No. 1 was switched out under a load of 24,000-kw. agree quite closely with those obtained by Mr. Nickle and the writer. I think that a little closer consideration will convince Mr. Wilkins that the cause of the greater disturbance on closing

4. *Fundamental Considerations of Power Limits.* R. E. Doherty and H. H. Dewey. A. I. E. E. JOURNAL, October, 1925, p. 1045.

5. Such as the case described by H. A. Barre in the *Electric Journal* for June, 1925, and discussed by R. D. Evans, A. I. E. E. JOURNAL, January, 1926, p. 70-71 and by R. E. Doherty, p. 75-76.

6. *The Artificial Representation of Power Systems.* H. H. Spencer and H. L. Hazen, A. I. E. E. JOURNAL, Jan., 1925, p. 24.

7. *Oscillograph Solution of Electro-Mechanical Systems.* C. A. Nickle, A. I. E. E. JOURNAL, Dec., 1925, p. 1277.

the line was entirely due to the effect of the line charging current in changing the phase and magnitude of the "open line" voltage relative to that on the generator side of the closing circuit breaker.

In connection with the above, it might be added that an oscillographic wattmeter with characteristics similar to that described was used throughout the major part of the miniature-system tests previously referred to.

To conclude, it appears that the first extensive investigation of power limits on an actual system of a fairly high degree of complexity leads to conclusions in substantial agreement with those presented by Mr. Nickle and myself, as well as others, entirely from the results of miniature-system studies, coupled with field experience and office analysis.

A. P. Mackerras: A pleasing feature of this paper is the use of graphical methods. Graphical solutions are usually sufficiently accurate for practical purposes; and, in addition to their rapidity, they give a better physical conception of the problem than algebraic formulas, and indicate more readily the effect of changes in the quantities involved.

In the construction of Fig. 3B, it has been pointed out that the locus of points at which $P\,Q$ subtends a constant angle is a circle with centre R. But it may also be of interest to note that the locus of points the distances of which from A and B are in a fixed ratio is also a circle. If the line $A\,B$ is divided internally at N and externally at N' in the given ratio E_A/E_B, this circle has $N\,N'$ for its diameter.

In Appendix C the equation

$$\text{Power} = \frac{1}{2}\,(E\,I + E\,\bar{I})$$

is given. The truth of this equation may readily be seen from the accompanying diagram. Let $O\,A$ be standard phase, and

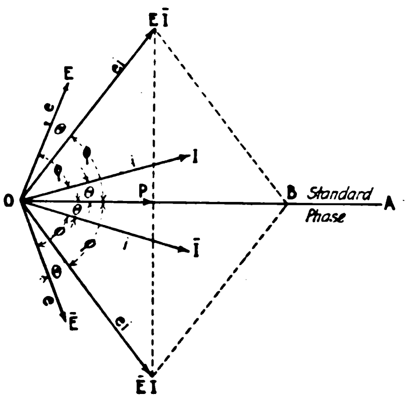

Fig. 9

let E and I be the voltage and current vectors the magnitudes of which are e and i. Then the conjugate vectors E and $\bar{I}$ will also have magnitudes of e and i, and their angles with $O\,A$ will be equal and opposite to those of E and I. To multiply the vector E by the vector I, we multiply their magnitudes and add (with due regard to sign) the angles they make with $O\,A$. The vector $E\,\bar{I}$ will therefore have a magnitude of $e\,i$ and will make an angle ϕ above $O\,A$, where ϕ is the angle between E and I. Similarly the vector $\bar{E}\,I$ will have a magnitude of $e\,i$ and make an angle ϕ below $O\,A$. Then clearly, the vector sum $\bar{E}\,I + E\,\bar{I}$ will be equal to $O\,B$, or $2\,e\,i\cos\phi$, which is twice the power in the circuit.

Sidney Withington (communicated after adjournment): Since the limit of power transmission is a function of the system frequency, it is entirely conceivable that in the transmission of large amounts of power over long distances it may be found desirable to adopt relatively lower frequencies than the standard 60 cycles; for instance 25 cycles or even lower. In this case there would be large frequency-changing substations at the centers of distribution. The frequency-changer sets might perform also the function of synchronous condensers, and the increment of cost would be relatively small compared to the total transmission line cost.

If this occurs and a low frequency is adopted for long distance transmission, it is entirely within the range of possibility that it would be economical for the electrified railroads of the country to obtain their power direct from these major transmission lines without the medium of rotary apparatus, perhaps balancing the load among the phases in sections. This is significant, considering the possibilities of railroad electrification, and may be a controlling factor in developing a standard system.

C. F. Wagner (communicated after adjournment): Miss Clarke has presented methods for the calculation of static stability for constant field current in a clear and concise manner. It should be noted in passing, however, that these limits do not represent the ultimate when automatic voltage regulators are used to maintain voltage. Miss Clarke uses the logical device of

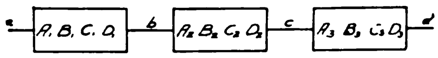

Fig. 10

representing loads where possible by static networks. This results in considerable simplification.

Using the various devices pointed out by Miss Clarke, the most general case in which the problem can still be reduced to a single synchronous machine at each end is that shown in Fig. 9, herewith, in which the three rectangles represent general networks, E_a and E_d the internal voltages and b and c the points at which the voltages are known.

Messrs. Evans and Sels in the July 1921 number of the *Electric Journal* have indicated how three general networks in series can be combined into one equivalent, so that the following expression is obtained.

$$\check{e}_a = \check{A}_0\,\check{e}_d + \check{B}_0\,\check{I}_d \qquad (1)$$

where $\check{A}_0$ and $\check{B}_0$ are the general circuit constants for the three combined networks, $\check{e}_a$ and $\check{e}_d$ the star voltages at a and d respectively and $\check{I}_d$ the current at d.

Transposing equation (1)

$$\check{I}_d = \frac{1}{\check{B}_0}\,\check{e}_a - \frac{\check{A}_0}{\check{B}_0}\,\check{e}_d \qquad (2)$$

The power at d

$$P_d + j\,Q_d = 3\,\check{e}_d\,\hat{I}_d = \frac{1}{\hat{B}_0}\,\hat{E}_a\,\check{E}_d - \frac{\hat{A}_0}{\hat{B}_0}\,E_d^2 \qquad (3)$$

when E_a and E_d are phase volts at a and d respectively. Now let

$$\check{E}_d = E_d\,\epsilon^{j0} \text{ and } \check{E}_a = E_a\,\epsilon^{j\phi} \qquad (4)$$

$$P_d + j\,Q_d = \frac{1}{\hat{B}_0}\,E_d\,E_a\,^{-j\phi} - \frac{\hat{A}_0}{\hat{B}_0}\,E_d^2 \qquad (5)$$

The real component of the above expression P_d becomes a maximum when

$$\phi = \tan^{-1}\frac{b_0}{a_0}$$

where a_0 and b_0 are the components of $\check{B}_0 = a_0 + j\,b_0$. This determines the angle ϕ between a and d for which maximum power is delivered at d. It is necessary to calculate only the $\check{B}_0$ constant for the combined network.

$$\check{B}_0 = \check{A}_1\,(\check{B}_3\,\check{A}_2 + \check{D}_3\,\check{B}_2) + \check{B}_1\,(\check{B}_3\,\check{C}_2 + \check{D}_3\,\check{D}_2)$$

Having obtained the maximum over-all angle corresponding to maximum power delivered, the actual value of power delivered

can be determined by the following graphical means. From a knowledge of A_2, B_2, C_2, D_2 and the voltages at b and c, the sending and receiving-end power circle diagrams for the middle section can be drawn as shown by the heavy lines in Fig. 10. For any angle ϕ_2 between the voltages at b and c the power flow at these points is indicated by the points m and n. Every point such as m on the supply circle must also represent a point on a receiving circle for the first section. This latter circle is represented by the expression

$$P_b + j\,Q_b = \frac{1}{\hat{B}_1} E_a\,E_b\,\epsilon^{-j\phi_1} - \frac{\hat{A}_1}{\hat{B}_1} E_b^2$$

The center of this circle is located at $-\dfrac{\hat{A}_1}{\hat{B}_1} E_b^2$. It will be noted that all of these quantities are known and can be plotted at the point p. Now while the value of the voltage E_a is unknown (and incidentally will not be necessary to determine) the reference vector from which the angle ϕ_1 is measured can be drawn making an angle with the horizontal equal to that of $\dfrac{1}{\hat{B}_1}$ which angle is the same as the angle of $\check{B}_1$, *i. e.*, $\tan^{-1}\dfrac{b_1}{a_1}$ where $\check{B}_1 = a_1 + j\,b_1$. As stated previously, the point m must lie on the circle, therefore, and angle ϕ_1 between

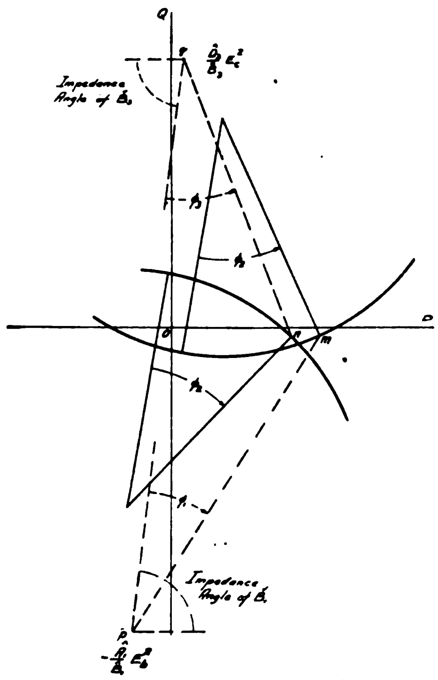

FIG. 11

$p\,m$ and the reference line indicates the angle between the voltages at a and b for the power transmitted at c corresponding to point n.

A similar construction applies to the receiving-end network. The power at c into this network is expressed

$$P_c + j\,Q_c = \frac{\hat{D}_3}{\hat{B}_3} E_c^2 - \frac{1}{\hat{B}_3} E_c\,E_d\,\epsilon^{+j\phi_3}$$

The center of the circle q is determined by $\dfrac{\hat{D}_3}{\hat{B}_3} E_c^2$ and the reference line makes an angle with the horizontal equal to that of $-\dfrac{1}{\hat{B}_3}$, *i. e.*, $\tan^{-1}\dfrac{b_3}{a_3}$ where $\check{B}_3 = a_3 + j\,b_3$.

The angle ϕ_3 between $n\,q$ and the reference line indicates the angle between the voltages at c and d. Therefore $\phi_1 + \phi_2 + \phi_3$ gives the total angle between the voltages at a and d for the power conditions at c corresponding to the point n. After a few

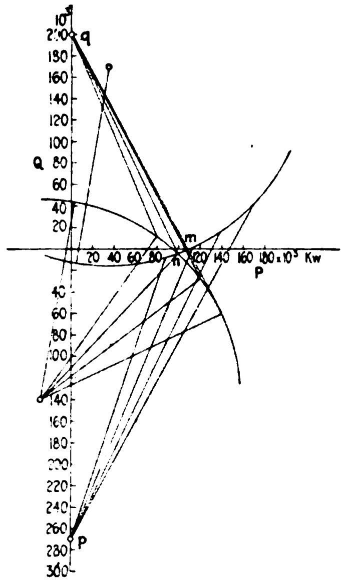

FIG. 12

trials the point n can be determined for which $\phi_1 + \phi_2 + \phi_3 = \phi$. This value of power indicates the maximum that can be transmitted at c.

The general method can best be illustrated by means of a solution of a particular case. The example chosen is that indicated on the eighth page of Miss Clarke's paper which involves the determination of the steady-state limit for a 270,000-kv-a. generator, transformers, a 250-mi. line and a 170,000- kv-a. synchronous motor. Complete details of line and machine characteristics are given on the sixth page of the paper. The voltage at the generator terminals will be maintained at an equivalent of 220 kv. and that at the receiving end at 200 kv. by hand regulation.

The combined constants for transformers and line are:

$$A_2 = 0.8431 + j\,0.0279$$
$$B_2 = 39.6 + j\,232.1$$
$$C_2 = (0.0104 + j\,1.248)\,10^{-3}$$
$$D_2 = 0.8428 + j\,0.0280$$

These constants enable one to construct the sending and receiving power circle diagrams in the ordinary way. These are indicated by the full lines in Fig. 11.

The center of the receiving circles for network 1 is located at $-\dfrac{\hat{A}_1}{\hat{B}_1} E_b^2$. Since this network contains only the generator reactance

$$\check{A}_1 = 1.0$$
$$\check{B}_1 = 0 + j\,X_1$$

and

$$\frac{\hat{A}_1}{\hat{B}_1} = \frac{1}{-j\,X_1}$$

$$-\frac{\hat{A}_1}{\hat{B}_1} E_b^2 = -j\,\frac{E_b^2}{X_1}$$

$$= -j\,\frac{220 \times 220{,}000}{179.2} = -j\,270{,}000 \text{ kv-a.}$$

Incidentally, this is equal to the sustained short circuit kv-a. at 220 kv. This point is indicated by the letter p on Fig. 3. The reference line coincides with the axis of reactive power.

The center of sending circles for network 3 is obtained in a similar manner.

$$\check{D}_3 = 1.0$$

$$\check{B}_3 = 0 + j\,X_3$$

$$\frac{\check{D}_3}{\check{B}_3} = \frac{1}{j\,X_3}$$

The center is located at

$$\frac{\check{D}_3}{\check{B}_3} E_c^2 = \frac{E_c^2}{-j\,X_3}$$

$$= j\,\frac{200 \times 200{,}000}{200} = j\,200{,}000$$

This point is plotted at q, the reference line being the axis of reactive power.

Now give ϕ_2 an arbitrary value, say 34 deg., and determine

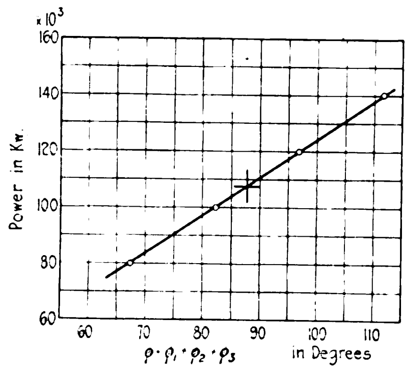

FIG. 13

m and n for this value. Draw $m\,p$ and $n\,q$ and measure ϕ_1 and ϕ_2.

$$\phi_1 = 22.3 \text{ deg.}$$

$$\phi_2 = 26.0 \text{ deg.}$$

$$\phi_1 + \phi_2 + \phi_3 = 82.3 \text{ deg.}$$

The total angle between internal voltages is then equal to 82.3 deg. for 100,000 kw. transmitted at receiving end. Choose a different value of ϕ_2 and repeat. By this means the curve shown in Fig. 4 can be obtained.

Substituting in the equation for B_0, this constant is found equal to

$$B_0 = 28.6 + j\,506.7$$

$$\phi = \tan^{-1}\frac{506.7}{28.6}$$

$$= 518.7$$

$$= 86.7$$

From Fig. 4 the maximum power, which occurs for $\phi = 86.7$ deg., is equal to 106,500 kw. which value checks the result obtained by Miss Clarke.

C. A. Nickle: There seems to be a misunderstanding of what the authors intended to convey by their use of the terms "steady-state power limit" and "transient-load power limit." To make this matter clearer, let us consider three cases of load change which may be classified as transient changes.

First, let us consider the change involved in throwing on a load. Before the load is thrown on, the line will have a certain voltage and the synchronous machines will have their magnetic circuits excited to give this voltage. Under this adjustment, the line will carry a definite maximum load of the type to be thrown on. What the authors intended to convey was that it makes very little difference in the ability of the system to carry the load whether this load is thrown on gradually or rapidly or even instantaneously.

Second, consider dropping a section of the line. We do not intend to say that the steady-state power limit to be used is that of the line before the section is dropped. The steady-state power limit to be used is the limit of the line with the section out and our tests again indicate that we can drop a section of a line which is carrying power so as to leave the remaining section with a load equal to its steady-state value and that this may be done gradually or quickly.

Third, consider the case of short circuits. In the case of three-phase short circuits, of course, no power can be transmitted beyond *the short circuit; that is, the final steady-state power has been reduced to zero*, and the load at that point will be dropped unless the relays relieve the condition very quickly. In the case of single-phase short circuits, the line has been weakened in its ability to carry steady-state power but the amount will be a definite value. If we take this same line with the short circuit permanently on and calculate its steady-state power limit,—that is, for loads slowly applied,—this will give the same value as when the short circuit is suddenly applied, the magnetic adjustment of the synchronous machines remaining unchanged.

It is very important that we choose the proper steady-state power limit. The reason single-phase short circuits are severe is because they reduce the value of the steady-state power which the system can carry. When we were able to carry 31 per cent of the steady-state power of the line before short circuit it meant that the steady-state value to be used was the value with short circuit on the line. If we increase the steady-state power limit by means of special excitation systems, such as mercury arc and other schemes, we also increase the transient power limit to the same value. In every case where we have tried this on the miniature system, we have been able to create any condition suddenly that we could produce slowly and still maintain synchronous operation.

Edith Clarke: Mr. Evans and Mr. Wagner have stated in their discussions that the methods used in my paper to obtain the maximum power which can be transmitted over a given transmission system under steady state are applicable for constant field currents and when the voltage is regulated by hand, but do not apply when there is an automatic voltage regulator on the system. Mr. Spencer has asked how the constant generator reactance, which is to be used in the calculations for maximum power, is selected.

In order to answer satisfactorily, it will be necessary to define constant field or fixed excitation and hand regulation and to explain what is meant by *equivalent* synchronous impedance.

For simplicity, assume a synchronous generator and motor on the same bus with constant and equal fields on both machines; then increase the load until the machines fall out of step, plotting power delivered *vs.* terminal voltage. If this is done for a number of different field currents, it will be noted that there is one curve in which maximum or breakdown power occurs at normal terminal voltage. On the curves corresponding to lower field currents, maximum power occurs at voltages below normal, while on curves corresponding to higher field currents, maximum power occurs at voltages above normal. With given fixed excitations maximum power will not in general occur at normal voltage. When hand regulation is used and load is slowly added so that normal voltage is maintained, the maximum power limit is usually understood to mean the power corresponding to that fixed excitation for which breakdown power occurs at normal terminal voltage.

It has been found by tests that with regulators such as are used commercially today, it is not possible to transmit more than the maximum power limit as defined above by hand regulation. I agree with Mr. Evans that if regulators were fast enough to maintain terminal voltage, the machine impedance could be

neglected; or if fast enough to maintain constant flux, then leakage reactance could be used; but until something is done to increase their speed of operation, the maximum power limit with voltage regulators will be the limit obtained by hand regulation.

Equivalent synchronous impedance is a fictitious value used for convenience to obtain maximum power. The field current corresponding to it is a fictitious current and does not represent actual field current. The justification for using *equivalent* synchronous impedance is that by its use the calculations have been greatly simplified and the calculated maximum power has been found to give a satisfactory check upon test values.

For a given machine, the sustained impedance which replaces leakage reactance and armature reaction is not constant, except for a machine of zero saturation, but varies with terminal voltage, power factor and load. The *equivalent* synchronous impedance likewise is not constant for a given machine but depends upon terminal voltage, power factor and load. In steady-state stability problems a voltage regulator is assumed; therefore maximum power is obtained at normal terminal voltage. The power factor on the generator for long lines heavily loaded is not far from unity. The load on the generator may be estimated after one approximation. Therefore, terminal voltage is known and power factor and load can be estimated.

When the leakage reactance, the armature reaction, and the saturation curve of a generator are given, the following *equivalent* synchronous impedance has been found to give a good approximation for maximum power.

$$\text{Equivalent synchronous impedance} = (\text{leakage reactance}) \text{ plus } \left(\text{armature reaction} \times \frac{\text{slope of saturation curve}}{\text{slope of air gap line}}\right).$$

The leakage reactance will be given in per cent values. The armature reaction should be expressed in per cent of the air-gap ampere-turns corresponding to no-load normal voltage. The slope of the saturation curve should be obtained at a point corresponding to virtual voltage. Virtual voltage depends upon terminal voltage, power factor and load, and may be estimated, but in general the slope of the saturation curve at normal terminal voltage may be used.

With voltage regulators or with hand regulation, the maximum or breakdown power will occur at normal terminal voltage so that the same value of *equivalent* synchronous impedance will be used and the same value for maximum power will be obtained in either case. With fixed excitations, however, the conditions are different since the voltage at which maximum power occurs is not given. The procedure is not so direct as where normal voltage is maintained but *equivalent* synchronous impedance may be estimated and maximum power obtained after one or two approximations.

R. D. Evans and C. F. Wagner: Mr. Sels makes a plea for a definition of stability limits, so that we may all know what the other fellow is talking about. We might refer to the definition as given in our paper in which we say that the stability may be defined as the capacity of a power system to remain in equilibrium under steady-load conditions and its ability to regain a state of equilibrium after a disturbance has taken place. The first part of the definition is referred to as static stability and the second part as transient stability.

Mr. Sels believes that the static limit is of the utmost importance. He believes that in the future it will be possible so to improve insulation that insulator failures will be very rare. We hope that such will be the case, but we are living in the present, not the future. For that reason, we believe that transient stability is of more importance at the present time than static stability.

Mr. Sels also stated that we have the stability problem present in all metropolitan systems. In general, however, the stability calculations for metropolitan systems are much more difficult and complicated than for long-distance transmission systems. In the latter the line constitutes the greater part of the impedance between the two points considered, the impedance of the terminal equipment acting more in the nature of a correction factor. In addition, generators at each end of the transmission line can be grouped together and considered as units. In metropolitan districts the connecting impedances are much more complicated and in most cases it is not permissible to simplify the problem by grouping the generators into two groups. The effect of faults and changes in voltages is more problematic.

The curve presented by Mr. Powel showing the relation between transmitted load and the probability of outage is both interesting and important. It would seem desirable to obtain similar data on the operation of other existing systems. Such data might be analyzed in a number of ways, one of which would be the plotting of the number of outages for different loads. Such a curve would take into account the load cycle under which the system is operated, and also the variation in the probability of failure during different parts of the day. Ater a considerable amount of data were available, it would be possible to plot curves for each of the various types of disturbances, such as low-tension faults, three-phase faults, and flashovers to ground; and from a study of these curves to determine the amount of consideration which should be given to each type of disturbance in making additions to existing systems, or in laying out new projects. In order to compare data on different systems, it would be desirable to plot the outage curve in terms of the angle between supply and receiver ends. This function would form the basis of comparison of operation of different systems. The collection of such system-operating data can best be obtained by the use of such recording instruments as described in the paper by Mr. Wilkins and in the discussion by Mr. Legg.

In connection with Mr. Doherty's discussion, we agree with him that the static limit is a more definite quantity than the transient limit. The point which we wish to emphasize is that system stability under disturbances is the more important problem and that the transient stability limit is the more important limit. We agree that with fixed excitation in machines, the maximum limit is quite a definite quantity. However, this limit is not the same as the limit of a system operating with voltage regulators for the case of slowly increasing loads. Under this condition of operation, the true static limit will be in excess of the limit determined by fixed excitation. This arises because of the phenomenon which, in our paper, is termed "artificial stability." It is stated in the paper by Nickle and Lawton, and is endorsed by Mr. Doherty, that the only function of the regulator is to increase automatically the excitation as the load is applied, the actual limit being the same as that for hand control. Our paper presents results of analytical work on this problem which indicate that a condition of artificial stability in which the system is held together merely by the action of regulators, is possible. Since this paper was written, these results have been verified by experiments. The set-up consisted of a d-c. motor, a-c. generator, artificial line, an a-c. synchronous motor, and a d-c. generator loaded on resistors. With hand regulation, increasing the excitation to maintain constant terminal voltage as the load was slowly applied produced a limit of 65.1 kw., and with voltage regulators 79.6 kw., an increase of some 20 per cent. Mr. Doherty states that tests which he has carried out have not shown the existence of stable operation for loads beyond the static limit determined by hand control. He does not deny the possibility of such operation, but merely states that he has not found such a condition. It is possible that this disagreement may be ascribed to differences in the mechanical inertia and in the time constants of machines, particularly of exciters.

While we point out that this additional limit is available, we do not wish to imply that we advise working to this limit in ordinary operation. It should be recognized that this limit is available, and that advantage could be taken of it for emer-

gency operation. This matter of artificial stability, however, is largely one of academic interest. We do not wish to emphasize it too strongly. The real limit of practical importance which we have pointed out, and have tried to emphasize, is the transient limit. It is gratifying to find that the tests of Messrs. Nickle and Lawton on miniature systems bear out this contention.

Prof. Dwight has called attention to the difference in the method of plotting reactive kv-a. in power-circle diagrams. In the absence of an A. I. E. E. standard governing this practise, the various investigators have used the convention that seemed to them most logical and convenient. We heartily endorse Prof. Dwight's plea for A. I. E. E. standardization ruling on this point.

Mr. Barfoed brings up the matter of line insulation and circuit-breaker performance for 220-kv. systems, as affecting the general stability problem. In addition, Mr. Wilkins has called attention to the fact that 220-kv. circuit breakers may have a small time lag between the opening of the three poles. This difference in time in the test described by Mr. Wilkins was due to the failure to secure simultaneous mechanical opening of the three poles of the circuit-breaker. This is evidenced by the fact that the time required for opening the breaker was closely the same and independent of the load carried in the various tests. The oscillograph records also showed the time of arcing was approximately the same on the three poles, and could not be responsible for the period of about 0.2 seconds from the beginning of arcing on the first pole to the final interruption of the circuit. The 220-kv. circuit breakers can be adjusted to open the contacts on the several poles in about a cycle, as measured by the cycle counter. Furthermore, it may be pointed out that in the new breakers for 220-kv. service, further improvements have been made which secure more positive action, and facilitate adjustment in the field. Tests of a type similar to that described in the paper have been made subsequently, and in these it was found that the difference in time of operation at the three poles was less than two cycles.

Mr. Withington has called attention to the fact that the power limits at 25 cycles are considerably higher than at 60 cycles. This is a pertinent point in connection with the selection of the frequency to be used for railway electrification and general power purposes.

Mr. Roy Wilkins: It might be worthwhile to give the actual operating experience to reassure those who contemplate building such lines that they can be operated. One line has been in operation for twenty-two months and the other about nine months. There have been twenty-six total cases of trouble, of which two were mechanical, four were caused by birds (which was definitely known since the birds were killed), two by lightning, and five were located but the cause not known. The remainder have never been located. Four of these interruptions, of which two were mechanical and two caused by lightning, caused interruptions of one line of longer than three minutes. The balance were momentary line interruptions and the line went back without any change whatever. These lines are normally charged from the generating plant at reduced frequency, usually thirty-five cycles, in which they build up with the field circuit open, to the normal voltage and little above normal current. The condenser is then put on at the receiving end and they are brought up to full frequency and paralleled at the receiving end. Thereafter the load is pulled up and they are paralleled at the sending end. Customarily, this is carried out without any dispatching whatever, and the whole procedure has been carried out in approximately one minute. In times of great stress, for instance, if one line goes out over the peak when the load is high, we charge the full 202 miles back to the system and parallel at the power house. This gives a voltage rise at the substation end of 10 per cent and is not customarily carried out.

The two lines, by the ordinary method of analysis, will carry about 198,000 kw. each. We plan never to run over 120,000 kw. on them. At such time that the load increases above this point, segregating points will be added in the line. When development requires, there will be four complete lines.

The question has been brought up about the oscillographic wattmeter and meters. This oscillographic wattmeter is more or less of a novelty. It is felt that it is reasonably accurate. It requires so little power that the ordinary bushing-type transformer will supply it without serious error in ratio and it will record disturbances lasting as short a time as about $^1/_{20}$ sec.

DIELECTRIC ABSORPTION AND THEORIES OF DIELECTRIC BEHAVIOR[1]

(WHITEHEAD)

AND

THEORY OF ABSORPTION IN SOLID DIELECTRICS[2]

(KARAPETOFF)

NEW YORK, N. Y., FEBRUARY 8, 1926

A. E. Kennelly: In Faraday's time, the properties of substances under magnetic stress or magnetization, and the properties of dielectric materials under dielectric stress or electric induction, were studied and were regarded as of great interest by him and by his followers.

It seems remarkable that, using the relatively feeble magnetic stresses and magnetic fluxes of ordinary dynamoelectric machinery according to Ewing's theory, it is not necessary to go deeper perhaps than the molecules of the iron or steel in order to account for the main features of magnetic induction. No doubt when we come to consider much more powerful magnetic stresses such as in the Zeeman effect it may be necessary to go deeper than merely into the molecule, or into groups of molecules. On the other hand, however, in order to account for the behavior of dielectric material under electric stresses, it seems that even with the relatively feeble stresses of electric signalling, a consideration of groups of molecules or even of molecules themselves is inadequate, and it seems necessary to descend to the subatomic state to explain the phenomena.

Strange to say, in the early history of electrical engineering, going back to the time when the only electrical engineers were the telegraph engineers, the study of dielectric absorption was found necessary for practical purposes, in order to specify the insulation resistance of a given length of any kind of solid insulated conductor. It was necessary as our textbooks show, as far back as the 1850s, to take some account of dielectric absorption, and it was known that the apparent insulation resistance at the beginning of the first quarter-minute was different from what would be obtained at the first half-minute or at the first minute. It became necessary, I think, in the 1860's, to define the measured insulation as that obtainable at a certain definite interval of time, let us say one minute or three minutes after the application of the continuous dielectric stress.

W. A. Del Mar: I have run into the same difficulty that Professor Whitehead mentioned; namely, that the physicists who are working on the theory of electrons and the ultimate nature of matter have not reached a stage of progress in their work where they can help us very materially in our theories of absorption in electric strength, and I don't believe that very great progress will be made until the physicists who are dealing in those ultimate matters make some further steps forward.

A few years ago I would have thought that the experimental physicists and those who are dealing with such matters as electric strength and absorption were the ones who would have to take the principal steps in order to reach a rational theory of the behavior of dielectric, but I have now come to the view that the pure scientists are the ones upon whom we are waiting.

We must be careful, in studying such a subject as dielectric

1. A. I. E. E. JOURNAL, June 1926, p. 515.
2. A. I. E. E. JOURNAL, March, 1926, p. 236.

loss and power factor, not to put a word in place of a phenomenon and take refuge behind the word. There is a little danger that we may do that with the word "absorption". It is taken to cover a multitude of sins, and when one reads through Professor Whitehead's admirable summary, one has to stop occasionally and think: What is the meaning of this "absorption?" Is it not just a word which is being used in a general way to cover a great variety of phenomena?

One might perhaps get the impression, by reading Professor Whitehead's summary, that there are several theories which might be chosen from, to explain the phenomenon, whereas more likely all of these theories will be required in some measure to explain it in full.

R. E. Marbury: Dr. Whitehead has given us a very complete review and valuable bibliography of what has been done on dielectric absorption and related phenomena.

Our experience has indicated that Maxwell's theory can explain dielectric absorption and a-c. losses of the low frequency type. Maxwell's theory assumes that the s. i. c. and resistivity of the dielectric remain fixed. This is generally the case in solids, but with semi-liquid dielectrics, such as oil-impregnated paper, there is evidence of changes in either s. i. c., resistivity, or both, with voltage, or temperature. This may be illustrated by plotting the residual voltage under a fixed set of conditions, against various applied voltages. If the law of superposition holds and if the resistivity and s. i. c. remained fixed throughout, a straight line relation would be found. This is not the case, as we find that the residual does not increase proportional to voltage. In some specimens the applied voltage may be doubled with little effect on the residual. The conditions may be changed so as to modify this relation. For example, if the duration of charge is made very small, such as 0.0015 sec., the resulting curve may be a straight line and appear to follow the law of superposition. This, among other things, leads us to believe that this departure from the law of superposition is caused by a movement of moisture, and when the duration of charge is made too quick for the moisture, the dielectric acts like a solid, as is to be expected.

A dielectric which shows this non-proportional residual possesses other interesting characteristics. For example, the losses will decrease with increased voltage. Such a dielectric will show a marked decrease in losses with time after the application of voltage. The latter effect may be seen by measuring the losses at five-sec. intervals, starting five sec. after the voltage is applied.

It is now possible to predict quite definitely certain characteristics of a condenser from absorption tests of the proper type. These characteristics are:

1. Whether the losses will decrease or remain constant with voltage.
2. How the capacity will vary with frequency.
3. Completeness of drying process.
4. Magnitude of loss variation with temperature.
5. Whether the condenser will give good performance on alternating current.
6. Whether the condenser has characteristics desirable for d-c. operation.

We can predict less accurately the actual losses, and can calculate a curve which will have a shape closely following the real curve which will be found if losses are plotted against voltage.

It appears that a complete interpretation of absorption curves will make possible a closer control of dielectric characteristics than has heretofore been possible.

R. W. Atkinson: I wish to remark that great increase in our knowledge of dielectric phenomena is certain to be made in the next few years on account of the interest and attention given these problems by the leading physicists in the faculties of the colleges and universities of this country. The present and other recent contributions are an important part of the recent advance, especially as leading toward a clearer understanding of dielectric phenomena.

When Mr. Fisher, for our company, first began measuring dielectric losses, before I was associated with him and also during the early part of my work, we found it useful to measure both quantities, dielectric absorption and dielectric loss, and a very close relation between them was observed, and for a long time both measurements were faithfully made on all materials.

Later, the large increase in the number of dielectric loss measurements necessitated that attention should be concentrated on the loss end of the problem. But I believe it is important to have further investigation of the absorption side, and have no doubt it will lead to valuable knowledge of the subject.

I believe that the greater part of the losses in paper cable dielectrics at high temperature can be quite largely accounted for by specific numerical application of Maxwell's method.

E. S. Lee: If you will look into the bibliography which Dr. Whitehead has prepared, you will find some three hundred and fifty items, and yet we have the work of Tank—one man—given to us as "apparently the only effort so far made for a direct check between measured loss and loss computed from measured absorption."

I think that is a condition about which we ought to think and I think that it is largely because of that condition that Professor Karapetoff worked out a formula which we could use in this regard. In other words, if, for any insulation we shall determine the curve of current against time and determine it well,—that is, allow the insulation to retain its initial condition between each measurement and obtain the curve with which we are familiar and then obtain the constants M and N, which you will find in Professor Karapetoff's paper, from that curve,—then the dielectric power loss of the insulation may be calculated from the equations given. This value may then be compared with measured values, and we shall be able to determine whether or not the equations which Professor Karapetoff has derived are applicable to the work which we have at hand.

We have tried to do this, somewhat, and have found, thus far, that out of 13 articles in the literature, only one had data which we could substitute in these equations.

So I make a plea to those of us who are interested enough to obtain data, that we shall obtain it in such a manner that we may make proper substitutions into the formula which Professor Karapetoff has derived in order to determine whether or not it applies. When you consider all of the work that Dr. Whitehead and his Committee have done, and when you find the meager amount of data that is available for substitution directly into such formulas as we have, it seems as though we had overlooked something in connection with the work, which should be rectified in the future.

D. W. Roper: Dr. Kennelly, I believe, stated that our knowledge of this subject was far from complete.

And Mr. Lee apparently has somewhat the same idea, because, after a careful study of the paper, he picks out one sentence which sums up the knowledge that he was able to use on the subject.

Now, if there is all that difficulty in getting some real knowledge about the very simplest forms of insulation, how much more difficult and how much more remote is the chance of our getting some fundamental knowledge regarding such a very complex insulation as impregnated paper, such as is used in our lead-covered cables. Dr. Whitehead touches upon that point a little in his final paragraph.

I have been endeavoring, with a very great effort, to find some method of measuring the quality of the insulation without destroying the insulation, and apparently there is no such method. We don't know enough about insulation to measure the quality, without destroying it, and so what we do in practise is to measure the quality of some samples of insulation and then include in our cable or our machinery some insulation which is similar

to the samples we have tested; and we hope that the insulation which we use will be just as good as the samples. Until we can get more fundamental knowledge of the properties of the insulation, we shall not be able to replace that hope with knowledge.

J. Slepian: Equation No. (**10**) in Dr. Whitehead's paper and No. (**21**) in Professor Karapetoff's, written with a little different notation

$$D = K_o E + \int_0^t E(u)\,\phi(t-u)\,d\,u \qquad (1)$$

is a very interesting one and gives a complete account of the electrical behavior of a dielectric in those cases in which it applies. Professor Karapetoff has called the function ϕ a relaxation function. Another viewpoint is to call the function a memory function, as this function indicates how much the dielectric remembers of the voltage which has been impressed upon it in the past. As will be seen in Fig. 1, if $E\,(u)$ represents the voltage gradient which has been applied to the dielectric from the time $u = 0$, then at the time $u = t$ the displacement of the dielectric according to the above equation depends not only upon the value of E at the time $u = t$ but on all the preceding values. However, the preceding values are not taken with equal weight but are multiplied by a factor which diminishes as the time recedes further into the past. The function $\phi\,(t - u)$ represents this weighing factor. In other words, it shows how the dielectric has a diminishing recollection of past voltages.

The equation (**1**) follows directly from the principle of superposition, as both Professor Karapetoff and Professor Whitehead

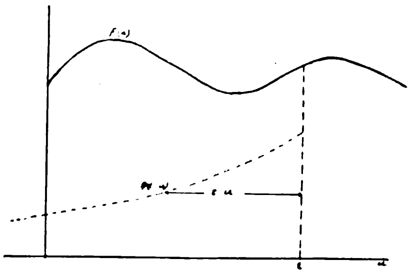

Fig. 1

bring out. It is also true that solutions of linear differential equations with constant coefficients can always be expressed in the form of equation (**1**). The simplest memory function is probably that which corresponds to a first order linear differential equation and that is a simple exponential. The memory functions of higher order differential equations are made up of sums of exponential functions. If a number of electrical systems, each satisfying a first order linear differential equation and therefore having a simple exponential memory function, are coupled together in any way, the resulting system is characterized by a linear differential equation of high order, with a more complicated memory function. Likewise a given system with a complex memory function is equivalent in its action to a large number of simple systems coupled together.

The resolution of the complicated system into simple systems is quite indeterminate and can be effected in a variety of ways. Referring specifically to the problem of the dielectric, it has been attempted to resolve the dielectric with complex memory function into an aggregate of dielectrics with simple memory functions, but such resolutions are indeterminate and usually of little value unless properties other than checking ordinary electrical measurements are considered. Maxwell, Wagner, and others suppose the dielectric made up of an assemblage of materials, each having a simple dielectric constant and ohmic resistivity. Karapetoff makes the dielectric consist of an aggregate of small pieces of dielectric, each piece having a simple memory function, without explaining how it comes to have that property. Von Schweidler assumes various kinds of molecules each with its own memory function combining to give a more complex memory function to the dielectric.

All of these theories lead to the same result,—namely, the equation (**1**)—and say no more than that the principle of superposition applies to the dielectric. Maxwell & Wagner's theories will have value only in those cases in which portions of the dielectric can actually be found which have simple dielectric constant and ohmic conductivity. Karapetoff's theory likewise will have value only if he can actually determine by means independent of the ordinary electrical measurements, the existence of portions of dielectric having simple memory functions. Von Schweidler too must show independent evidence of the existence of his various kinds of molecules. All these theories are sufficient to account for the principle of superposition. None of them is necessary. It seems to be a choice of being satisfied with the idea of the homogeneous substance having complex dielectric properties or a complex assemblage of materials having simple dielectric properties. Unless, however, there is physical evidence of some kind for the existence of the complex assemblage of simple substances, I do not believe that anything is gained over the assumption of the homogeneous substance with complex characteristics. As far as agreeing with electrical measurements, all these theories are on a par, provided they accurately represent the memory function of the dielectric.

That these theories without other physical evidence do not add to our knowledge of the dielectric seems to be intimated by Professor Whitehead when on page 11 he says of Von Schweidler's theory "The analysis has the character of a mathematical fiction," and again further along on the same page, in speaking of the check which Grover made upon the Pellat theory, "It appears certain that an equally good agreement would have been obtained from Wagner's equations; in fact it is safe to say the same of any theory providing for the medium a sufficient number of terms, all obeying a continually decreasing function $\phi\,(t)$ of relatively simple form but with different values of the constant terms."

While it is true that a heterogeneous assemblage of simple dielectrics will show absorption and satisfy the principal superposition, it does not follow that a material showing absorption is necessarily heterogeneous, and to my mind the physical evidence on that point is far from conclusive. Very pure substances show little absorption, but, at the same time, they usually show a tremendously high resistance. When two pure substances are mixed they frequently show absorption, but such mixtures are hardly to be described as heterogeneous and the absorption which arises frequently is not consistent with the numerical values of the dielectric constant and resistivity of the pure materials themselves. For example, a mixture of pure water and pure sulphuric acid shows a great conductivity which cannot be accounted for on the theory that it is a heterogeneous assemblage of the pure substances, each of which has a tremendously high resistance.

How universal is the principle of superposition for dielectrics? The existence of the irreversible current which Dr. Whitehead points out shows at once that it does not always apply. Last year Mr. Marbury, in his paper on oil condensers, showed phenomena which contradicted the principle of superposition. The departure from the law of superposition may take place in various ways. First the memory function may change with time of application of voltage as, for example, when water in the pores of a material is displaced gradually by the electric field. The memory function may change with amplitude of voltage as it undoubtedly does near the dielectric breakdown point of the material, or finally the properties of the material may not be characterizable by a memory or relaxation function at all.

The paragraphs of Professor Whitehead on electric hysteresis, I think, are exceedingly good and to the point. The phenomena of dielectric absorption and magnetic hysteresis are too unlike in character to be confused by a similar name. In the language

of my preceding discussion, whereas a dielectric has memory of past electric fields which diminishes with lapse of time, a piece of iron has an unchanging memory of the fields which have acted upon it. You may put a piece of iron through magnetic cycles today and tomorrow the iron will be ready to go on from where it left off, no effect of the magnetic fields of the previous day being lost.

The work of Debye and Schrodinger, I believe, deserves more than the casual mention which Professor Whitehead gives. Their polarized molecules have an actual physical reality, since, in their work on dielectric constants of gases, they are able to explain the dielectric properties by assuming that all the molecules of the gas are polarized with moments of the order of magnitude consistent with other phenomena and are able to predict correctly the effect of temperature by calculations from the kinetic theory of gases; thus Debye and Schrodinger give a complete theory of the dielectric properties of an un-ionized gas, the only case in which such complete theory has been given.

I wish to take issue with Professor Whitehead with respect to what he calls the fundamental equations of electromagnetism. In his classification on page 7 he implies that some of the theories given involve deviations from the fundamental laws. I believe the common usage is to regard the following equations as given by Maxwell fundamental:

$$\text{Curl } E = -\frac{d^B}{d\,t} \tag{1}$$

$$\text{Curl } H = 4\,\pi \frac{d\,D}{d\,t} + 4\;C\,\pi \tag{2}$$

$$\text{Div. } B = 0 \tag{3}$$

$$\text{Div. } D = -\,4\,\pi\,\zeta \tag{4}$$

These equations correspond respectively, the first to Faraday's law of induction, the second to the manner in which conduction and displacement currents give rise to magnetic fields. The third equation states the fact that free magnetic charge does not exist, and the fourth, that lines of electric flux terminate in electric charge. These four equations are not sufficient to determine the quantities E, H, B and D, but further relations must be found connecting B and H and D and E, depending upon the properties of the material considered. In the simplest theories, it is customary to take $B = \omega\,H$ and $D = \epsilon\,E$. These last equations are the ones which are not adopted by some of the theories which Professor Whitehead mentions. However, they are not fundamental in electromagnetism; they are only a very special case in electromagnetism.

C. A. Adams: As I was originally responsible for the organization of the Insulation Committee, of which Dr. Whitehead's excellent paper is a one-man report, I am naturally interested in its progress.

But the attack which I had in mind was a very much more vigorous one that is now being conducted largely by voluntary services.

A more thorough understanding of dielectric phenomena in solid and semi-solid dielectrics constitutes the most important problem in the whole field of electrical engineering at this time. But unfortunately it is a terrifically complicated and difficult problem from the standpoint of modern theory. It has been almost completely ignored or shirked by our American physicists, and the very suggestive and interesting first steps taken by two or three foreign physicists are buried in the proceedings of the more highly scientific organizations.

This most important problem is not going to be solved by engineers. We need a comprehensive fundamental research involving the cooperation of the best physicists and chemists that the world affords, and backed financially by the great corporations who either manufacture or use insulating material.

The cost to any individual corporation would be small, if they all took part, particularly if the cooperation were extended to other countries, as it should be in a problem of such fundamental scientific and commercial importance.

Much research work in this field is now being conducted in this country, but mostly by engineers, who, owing to lack of thorough knowledge of modern theory, are only skimming the surface. Moreover, there is no thorough cooperation, and much duplication of effort.

If the A. I. E. E. wishes to stand for cooperation and progress, here is certainly a supreme opportunity.

S. L. Gokhale: I have nothing to contribute directly to the topic under discussion; my purpose is merely to supplement the very suggestive remarks of Dr. Kennelly by an interesting experiment of ours in the General Engineering Laboratory.

Dr. Kennelly has suggested that the dielectric phenomena are perhaps sub-atomic in their nature; he also referred to the magnetic phenomena as being analogous to the dielectric phenomena, so that any insight into the one phenomenon might help to give us a better understanding of the other. The experiment I am going to describe refers to magnetics, and I am describing it in the hope that it may prove of use to those who are trying to study corresponding phenomena in dielectrics.

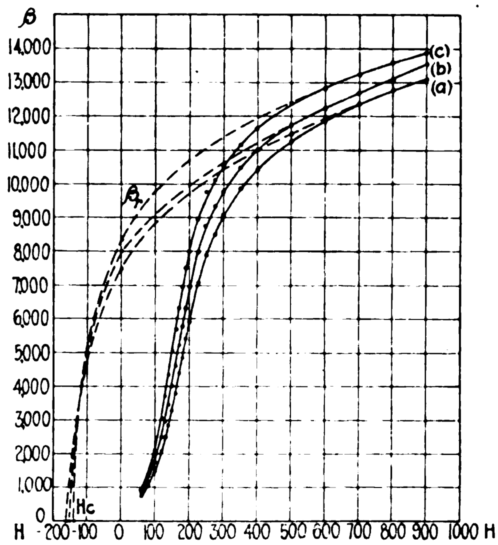

FIG. 2—COBALT MAGNET STEEL (SAMPLE NO. 16-1) CHANGE OF MAGNETIC CHARACTERISTICS APPARENTLY DUE TO STRONG MAGNETIZING FORCE

The sample under test was a toroid ring sample of cobalt magnet steel, wound for a magnetizing force of about $H = 1000\,g$. The resulting curves are shown in Table I. The curve (a) is the result of the first test; the point for $H = 900$ gave at first $\beta = 13{,}000$, but the reading could not be repeated on second and subsequent tests, and on going back it was found that other points could not be duplicated also. The whole test was therefore repeated, and gave the curve (b). At $H = 900$, the curve developed the same anomaly as before. The whole test was therefore repeated once more, which gave the curve (c). A fourth test gave a further shift of about 50 gausses with a corresponding increase of deflection of half a millimeter. The sample seems to have reached a steady state now. The hysteresis curve (dotted) is conjectural, but the cardinal points $\beta\,r$ and H_c are observation points. It seems that during the test the sample was softening, probably under the influence of the strong magnetizing force. It was probably not a heat effect, as the precaution against heating had been tried out in some previous tests, and was found to be quite satisfactory; no thermic measurements were made in this particular case.

In trying to interpret the phenomenon, my first guess was that there was some change in the structure of the molecular

COBALT MAGNET STEEL

Ring-Form Sample No. P-16-1

Test (a)

H	B	Br	H c
60	750		
80	1050		
100	1500		
120	2080		
130	2450		
140	2850		
150	3300		
160	3800		
170	4400		
180	4850		
190	5350		
200	5950		
225	7100		
250	7900		
275	8520		
300	9100		
350	9880		
400	10450		
500	11250	7250	
600	11850	7350	
700	12400	7400	162
800	12800	7500	162
900	13100	7500	(Reading not duplicated
1000		No Test	on repeating)

Test (b)

60	800		
80	1200		
100	1750		
120	2500		
130	2960		
140	3480		
150	4020		
160	4600		
170	5250		
180	5800		
190	6350		
200	6950		
225	8020		
250	8780		
275	9350		
300	9780		
350	10480		
400	11000		
500	11750	7750	
600	12250	7750	
700	12700	8000	149
800	13100	8000	149
900	13550	8150	(Reading changed after
1000	No test		first reading)

Test (c)

60	920		
80	1400		
100	2100		
120	3050		
130	3700		
140	4350		
150	5050		
160	5700		
170	6350		
180	6950		
190	7500		
200	8000		
225	8950		
250	9750		
275	10100		
300	10550		
350	11150		
400	11650		
500	12400	8240	140.0
600	12850	8350	141.0
700	13250	8350	141.4
800	13600	8350	141.8
900	13900	8350	142.0
1000	14100	8350	142.0

systems which are supposed to be oriented during magnetization. This explanation implies a modification of Weber's theory, which refers to orientation of the molecules. On trying to discuss the question with my colleagues in the Research Laboratory, I was informed that in view of the recent researches about the structure of the crystals, as revealed by the X-Ray spectroscope, there is no intermediate step between an atom of iron and a complete crystal. The phenomenon of magnetism should therefore be regarded as an atomic or sub-atomic phenomenon, which leaves no room for Weber's theory of molecular orientation, and even less room for my theory of molecule-system orientation.

I do not claim to have understood the phenomenon; I am not even convinced that it is sub-atomic. I am mentioning it here in the hope that it might help in some way towards a better understanding of the process of magnetic polarization in the first place, and of dielectric polarization by analogy.

J. B. Whitehead: All writers on the theory of dielectric absorption have discussed the form of the curves of current of residual charge and discharge. A number of these are set forth in my present paper. All such workers have recognized that a single term of any of the forms mentioned will rarely represent the experimental curve. Hopkinson found for his samples that two terms were not enough, and Maxwell gave general expressions for n terms as required in a mixture of $n + 1$ materials. A number of observers have found that for some simple substances one term is closely sufficient.

Professor Karapetoff's paper is based on the assumption that a great many, perhaps an infinite number, of such terms are necessary. The Germans, Wagner and Von Schweidler, have also made this assumption and have attempted analytical developments which should in effect permit us to assign definite constants to particular materials which would fit the relative importance of this large number of terms and so define the behavior of the material. Professor Karapetoff has gone somewhat further, first in selecting a function fixing the distribution of the series of terms which is somewhat easier to handle, second in allowing us to follow more intimately his ingenious mathematical manipulation, and particularly in evaluating the changes which may be looked for under alternating voltage, in the values of conductivity and permittivity as affected by his "generalized absorption."

But while we may admire the persistence and skill manifested in these developments, I question seriously whether they constitute the necessary path by which we will ultimately reach a position in which we can control and predict the performance of dielectrics for the following reasons:

It has never been shown that $\phi\ (t)$ is uniform or the same for any given material. Why discuss $F\ (\alpha)$ if it may have widely different forms for the same material prepared in different places? The absorption of any material may be continually reduced by greater and greater care in purification. Hopkinson showed that while two terms were not sufficient to account for his curves, not many more would be required. Steinmetz showed that even in so highly absorbent a dielectric as cable insulation, three terms were sufficient to very closely account for the observed curve. There are many instances where one term appears sufficient. F. Tank has studied $\phi\ (t)$ for very small values of t, has found it of simple form, *i. e.*, one term, and that the use of a single term in developing the expression for loss under alternating voltage gives values in accord with experiment.

Professor Karapetoff states that the time for a rational theory of dielectric absorption has not arrived. One must ascribe this statement to momentary forgetfulness, induced by deep interest in the theory of Pellat, and his elaborate development thereof. I am sure that he will agree with me that Maxwell's theory of dielectric absorption, relying as it does only on fundamental electromagnetic theory, and in no wise invoking the structure of the atom, is in every respect a rational theory. Maxwell, as everyone knows, explains dielectric absorption entirely in terms of the specific conductivities and specific inductive capacities of

different substances when mixed together. It accounts qualitatively at least for most of the important phenomena to be observed in the dielectrics of practise, and does this quite as satisfactorily as any other theory. If it is not subject to exact experimental corroboration, it has certainly never been shown that this is not due to the impossibility of obtaining strictly pure and simple materials or mixtures. Maxwell himself recognized the probability of this difficulty and extended his expressions so as to embrace any number of different materials. Followers of his theory have always assumed that the several terms often needed to account for the shape of the curves of charge and discharge, are due to the presence of other substances or impurities throughout the mass of the principal dielectric. Wagner is a follower of Maxwell, and in his development of the distribution function he has attempted to picture the type and method of mixture of the conducting impurities in the mass of the dielectric. If this view is correct, and there seems to be no satisfactory contradiction of it, it would appear that the evaluation of distribution functions such as assumed by Von Schweidler and Wagner, and now by Professor Karapetoff, resolves itself into an effort to define the particular ways in which impurities may occur in a fundamental material. Obviously there is no reason to suppose that on this basis the distribution function can ever be the same in any two cases, even for the same fundamental material.

These questions have long excited the discussion of those interested in the theory of dielectric theory and behavior. The following are a few experimental problems the solution of which would go far toward solution of some of the open questions:

To fix the definite curves of particular substances, and the accuracy with which they can be reproduced.

To determine the importance of their departures from simple curves.

To study the control of these curves.

To study their behavior in combination in different substances.

To study the relation between absorption and loss for some of the simpler cases.

In my opinion careful work in these directions will be found to greatly simplify the present confusion as to the nature and behavior of dielectric absorption, and further will result in enormous simplification of the problem of engineering design and insulating mediums.

H. L. Curtis (by letter): Dr. Whitehead has reviewed a large amount of literature and has made an excellent summary of our present knowledge of the anomalous behavior of dielectrics. It is a fair and impartial discussion of all the theories that have been proposed to explain this most baffling phenomenon. It should serve as a starting point in the extension of our knowledge of dielectrics.

I agree with the author that, from a theoretical standpoint, the most satisfactory theory of dielectric absorption is that of Maxwell's stratified dielectric. However, I do not agree that there is any chance that it can explain all the observed facts. One illustration will suffice. The application to alternating current phenomena of Maxwell's theory or any of the modifications proposed by Rowland, Wagner, and others, invariably leads to an equation for the phase difference which is equivalent to equation (**31**). For high frequencies, this equation takes the approximate form

$$\tan \delta = \frac{k}{\omega T}$$

so that for such frequencies the phase difference is inversely proportional to the frequency. Now there are abundant data to show that this is not the case in many dielectrics. Hence in such dielectrics it appears impossible to explain the phenomena on the basis of this theory.

However, there are other dielectrics where the observed phenomena are largely explainable by Maxwell's theory. Moreover from the fundamental assumptions of this theory it must play some part, however small, in most absorption phenomena, since homogeneous dielectrics are extremely rare. The conclusion must therefore be drawn that the final explanation of dielectric absorption will include at least two theories of which Maxwell's stratified dielectric will be one.

Professor Karapetoff has given a very clear derivation of the integral equation (Eq. No. **21**) which results when the principle of superposition is applied to an absorbing dielectric in an alternating electric field. Wagner's relaxation function (Eq. **25**) is then inserted in this integral equation and the solution carried to a point where both the change of capacitance with frequency and the power factor are expressed in terms of integrals which involve both the relaxation function and the frequency. An empirical expression (Eq. **56**) for the relaxation function is then assumed and the integrals evaluated. The results (Eqs. **103** and **104**) are given in terms of ascending powers of the frequency. There is, however, no discussion of the convergence of these series. It is evident that, for high frequencies, they either diverge or become impracticable as methods of representing the function.

The value of the paper would have been greatly increased had it contained some numerical examples. At best the results as given are applicable only to low frequencies. Whether this includes frequencies that are of any practical or theoretical value can not be judged from the equations as given. Until the paper is completed by the application of the equations to typical sets of data, one should withhold judgment as to the value of the results obtained.

J. Katzman: Professor Whitehead's paper reviewing and bringing together the many theories of dielectric absorption and indicating the behavior of dielectrics under various conditions as found by former experimenters is certainly of inestimable value to all those engaged in this work. However, the divergence of views, theories, and results obtained makes it impossible, as yet, to predict effects from given causes. Qualitatively predictions can more readily be made, provided the knowledge of accumulated facts is had. Effect of temperature may be prophesied if it is known and remembered that according to Hopkinson and others, absorption current increases with temperature, and that according to Wagner, rate of absorption and decay is increased with temperature and the total absorbed charge remains unaltered. From Lahousse's equations it may be surmised that a loss in a dielectric will vary as the square of the voltage. Similarly, effects of frequency on loss per cycle, on loss per minute, and on capacity, and the effect of voltage

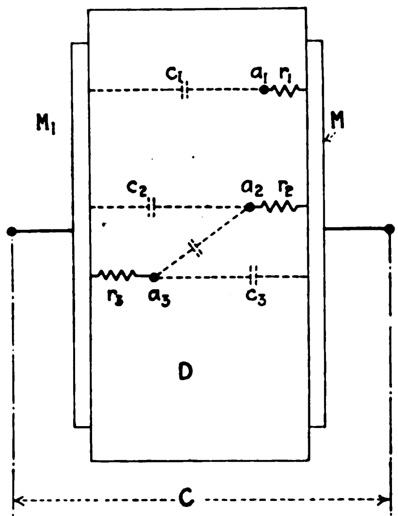

FIG. 3

on absorbed charge, etc., may be foretold if results of former experiments are remembered, or resorted to.

To be able to say, even approximately, what may be expected when a dielectric is made to undergo a change, is often of great value, and this may be deduced from a consideration of the properties of conductors and specific inductive capacity only. Assume the dielectric to have conducting particles embedded in it and the dielectric itself to have conductivity. Fig. 3 is a diagram of a condenser having a dielectric D, the metallic plates M_1, M_2 on the opposite faces of the dielectric, and some of the conducting particles a_1, a_2, a_3; r_1, r_2, r_3 are the resistance of the dielectric between respective plates and particles as shown. Each of the particles will form a sub-condenser with one of the plates or with each other as indicated. By forming a mental picture of such a condenser, all of the facts mentioned before concerning dielectrics can be reasoned out. Thus when the applied e. m. f. is altered, the charging current of each of these sub-condensers is proportionally altered and therefore $I_3^2\, r_1$, $I_1^2\, r_1$, etc., varies as the square of the voltage. The summation of these losses being assumed to produce the absorption loss, it is seen that absorption loss will vary as the square of the applied e. m. f.

With but very few exceptions when temperature is increased

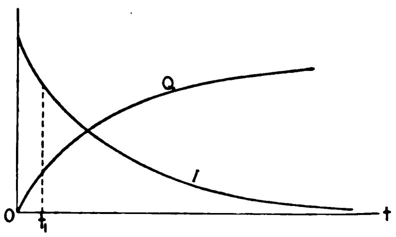

FIG. 4—CURVES OF VARIATION OF CHARGE AND CHARGING CURRENT WITH TIME

the resistivity of solid insulators reduces.[1] Hence resistances r_1, r_2, etc. reduce. The effect is therefore to reduce the time constants $c_1\, r_1$, $c_2\, r_2$, etc. of the sub-condensers, thus increasing the rate of absorption and decay, but does not alter the total absorbed charge, in accordance with Wagner's conclusions. The absorption current having increased, $I_1^2\, r_1$, etc. increases even though r_1 does decrease. The result to be expected then is an increase in power loss due to absorption.

When the frequency is increased the time available for charging the sub-condenser is decreased, and as can be seen from Fig. 4, if this time is t_1, the condensers will be only partially charged, with the result that absorption loss per cycle is decreased since the loss per cycle is $\int_0^{t_1} I^2\, r\, d\, t$. From the shape of curve I, it is obvious that the greatest loss occurs only at the beginning and therefore the reduction in loss is less in proportion as the frequency is increased. It follows then that the loss per second is increased by an increase of frequency. It is readily conceivable that the sub-condensers increase the capacity C by increasing the ratio Q/E, where Q is the total charge and E the applied e. m. f. At very high frequencies, however, the charge on the sub-condensers becomes practically zero, as can be seen from the curve Fig. 2, and hence the capacity of the condenser becomes equal to the geometric capacity. In other words the capacity of the condenser approaches the geometric capacity as the frequency is increased.

By similar reasoning, and these involving only elementary principles, other predictions may be deduced.

A further development of this idea is under preparation.

1. Dietric in Phys. Zs. 11, p. 187, 1910 shows that $R_t = R_0\, e^{\frac{-qt}{273(273+t)}}$ q being a constant depending on the material and t the temperature.

E. R. Le Ghait: Professor Karapetoff's mathematical analysis will certainly be of great interest to all those occupied with the behavior of dielectrics. He does not make any assumption on the physical nature of the phenomena. The work we have done with fibrous insulating materials has led us to the opinion that Maxwell's ideas are, in that case, quite capable of explaining the observed phenomena, provided however, one takes into consideration the complicated structure of the dielectric. We believe that the absorption as well as the dielectric losses at commercial frequencies are due for the greater part to the presence of very small quantities of moisture imprisoned in the capillary tubes of the fibers. If we then consider the dielectric as composed of a very great number of very thin paths crossing from one electrode to the other, and apply Professor Karapetoff's analysis, his function $F(\alpha)$ will be the law of distribution of the moisture among those paths. If the curve $F(\alpha)$ has a very pronounced peak it will indicate that all the paths have pretty much the same amount of moisture. If on the contrary $F(\alpha)$ is a comparatively flat curve it will indicate that some paths contain much more moisture than others.

If then the moisture is the cause of the dielectric loss the knowledge of the function $F(\alpha)$ will give us an indication of whether the loss is uniformly distributed all over the dielectric or whether it is for the greater part concentrated in some of the paths, these paths constituting possibly weak spots on account of the deterioration of the insulation due to an exaggerated loss in a given point.

Dr. Whitehead, in his comments of Maxwell's theory, calls attention to the fact that pronounced absorption is observed in substances that can have in them only small amounts of impurities. This is probably due to the peculiar shape of the lines of force in a dielectric containing materials of different specific inductive capacities.

Our own experience agrees with Dr. Whitehead's opinion that dielectric losses are closely related to absorption. In fact, in the case of unimpregnated paper, starting from residual voltage curves obtained with a dielectric previously left charged at 100 volts d-c. for a certain time and then left short circuited for a very short time, we are able to compute 60-cycle losses with less than five per cent error.

In the case of oil-impregnated paper, greater difficulties are encountered, as in that case the law of superposition does not hold true (this being probably due to movements in the oil under the influence of the electric field, of moisture and other components of high specific inductive capacity). In correlation with this, the power factor at a given frequency varies widely with the value of the applied voltage. It may, however, prove to be possible in the future to make a low voltage d-c. absorption test enabling one to predict with sufficient accuracy the a-c. losses at a voltage many times higher, and perhaps even to predict the curve of variation of power factor with applied voltage.

Discussion at Cleveland

PAPERS ON PAPER-MACHINE DRIVE

(STAEGE[1], ROGERS[2] AND NORRIS[3])

CLEVELAND, OHIO, MARCH 18, 1926

T. D. Montgomery: Mr. Staege says that a speed adjustment of from 0.1 to one per cent is required. Does this mean that some classes of paper require 0.1 per cent while others require one per cent, or that regulation anywhere between 0.1 per cent and one per cent meets all conditions of paper making?

Reference is made to differentials, either electrical or mechanical, and Mr. Staege refers to the accumulative lag in drive and master shaft and field clutch. Would there not be the

1. A. I. E. E. JOURNAL, March, 1926, p. 272.
2. A. I. E. E. JOURNAL, April, 1926, p. 323.
3. A. I. E. E. JOURNAL, May, 1926, p. 432.

equivalent lag with either the mechanical or electrical differential, in so far as affecting the regulation?

L. W. W. Morrow: The object of all of these drives as outlined in the papers seems to be to answer the speed-regulation requirements in the production of paper. I should like to see something that would show the response of these drives to the actual requirements; in other words, if there is a change in load in any one section, what is the time interval until adjustment to that situation by the drive? Each drive has been described, but we haven't definite time data as to the results accomplished by the drive.

F. C. Bowler: We have heard a great deal about the exact regulation which will be produced by these various types of drives and emphasis has been put on the need of exact regulation. I presume that the authors have made some experiments tending to show what the actual regulation has been with the various types of mechanical drive which we have had in the past. I wish that might be brought out. In other words, it is a question in my mind whether we aren't putting emphasis on something that is more refined than we need. We have made paper a good many years with belts and gears, and personally I doubt if we have ever had such regulation with mechanical drives as any of these new sectional drives will give us.

N. D. Paine: I would like to agree with Mr. Bowler and say that we are inclined, perhaps, in the sectional drive, to attain too exact speed requirements. As he said, we have made paper for years with belts and pulleys, and now, with the electrical drive, it is more a question, especially on the large 234-in. machines, of starting the dryers than of the actual speed control.

We do get exceptionally good speed control with the mechanical interlock, of which our company has four on the 234-in. machines.

The papers lay quite a bit of stress on the fact that there is a large amount of stored energy in some types of motors. With regard to the mechanical interlock drive, that stored energy is used to very good purpose. The master shaft being driven from the dryer section of 34 6-ft. dryers, weighing 12 tons each, naturally maintains an extremely steady speed, as the energy stored in this section smooths out any slight speed variation which might occur due to small voltage fluctuations.

Coming down to the various section motors, I can say, especially on the couch—which we have watched more particularly—that speed control, where the paper is the weakest, with our Harland or mechanical interlock, is maintained with a small field variation, from 0.05 to 0.10 ampere, in the shunt field, which is with the machine running at 750 to 800 ft. per minute.

H. L. Sanborn: There seems to be a question as to exactly what basic principles the electrical manufacturers are endeavoring to correct with their electric drive.

Mr. Staege refers to a steel mill as having a very heavy load, which would not exactly apply to the electric drive. There is little comparison between the steel-mill and the paper-machine variable loads, yet a plugged calender will subject its motor to two and one-half times its starting torque, probably as great a variation as the steel mill when the ratio of power in use is considered. This and other inherent conditions peculiar to paper-machine operation produce a system of variables making load changes one of the big factors the electric drive is called upon to correct.

These load variables may be caused by mechanical conditions, vacuum changes on the wire, poor bearings, sections out of alignment, stock changes, clothing, etc.

We have in the Abitibi Mill at Iroquois Falls the Westinghouse electric sectional drive. We find it more reliable than our mechanical types after four years of operation. The whole machine has greater flexibility. The operating efficiency has increased and as a whole the close regulation tends to produce greater tonnage over the corresponding machines of the same size having mechanical drive. The breaks on this particular machine have decreased and there has been a reduction in repair labor and material.

In the main, however, I think, we have perhaps forced upon the manufacturer of electrical material a very severe problem, but you must endeavor to bear this in mind:—The paper mill has been running for years and years, as Mr. Bowler states, and the electric drive is endeavoring to take up these old-time conditions and produce results superior to the mechanical type of drive, without redesigning the paper machine to fit the electric drive.

Our sectional drive has accomplished this feat at the Abitibi mill and the average operating efficiency on our paper machine equipped with this drive, conditions being equal, has not been exceeded, and on the average has not been approached by either the mechanical or non-sectional electric-driven machines in our plant.

J. F. Rhodes: I think my two friends who have just spoken have brought up very important arguments. I believe the Mead Pulp & Paper Company put in two of the first drives.

I think the main object in the machine drive is to keep the sections together, that is, synchronized. With the old machines we had an engine that required steam pressure to be constant all the time. Then we depended upon the governor to maintain the speed. After the paper maker got his paper over the machine, he had nothing more to worry about unless his thickness changed or something caused a break.

As we get into the electrical drives the main thing seems to be to get away from the engine and the only problem left is to supply the steam for drying. However, paper makers feel that if anything breaks down it will do so at the weakest point. If these things become so complicated that a brush gives away or a contact goes, we have to hunt the trouble, and in the meantime we may have lost three or four hours of production. The old type of machine was so simple that almost any paper maker could very quickly find out what the trouble was and get started quickly.

In building a new paper mill I do not think there would be any doubt that he would adopt the extraction type turbine and put in the late type of electric drive, getting the one that was the simplest, and required the least amount of space, and of course the financial end would come in.

I think we should aim towards simplicity in choosing drives. I do not believe there is any change in the load of the machine after it is started and the paper is going over the machine perfectly. If there should be a break at the calenders there probably would be a change in load there for a while which would react back to the motor-generator set and that would in turn slow down, if it was not properly regulated, reacting back into the machine again, causing another break.

R. T. Kintzing: These papers are so broad in scope that they necessarily have devoted but a limited space to electric control used on sectional drives. Control designers should be credited with solution of the very difficult electrical problem of precise motor-speed regulation. I should like to point out a few of the other control features involved in this application, and also to supplement the statements made in some of the papers concerning the various types of speed regulators.

Starting, stopping and inching are the usual operations required in controlling the individual section motors. Certain sections are occasionally reversed, others are temporarily slowed down, and other motors start and stop simultaneously. Running-load conditions are usually constant. Starting-load conditions may be those of a friction load or those of a load having high inertia. The latter are the most difficult to regulate. Starting-load conditions on the dryer and calender section are unusually severe.

Individual resistor-type automatic starters having positive time-limit acceleration are best on account of starting from a bus, the voltage of which may vary over a broad range to provide for different machine speeds. Push-button-operated starters with motor-driven cam-operated accelerating contactors have proved

very satisfactory. Time-limit overload and low-voltage protection is necessary. Starting motors at full field strength is desirable to obtain high starting torque with minimum starting currents.

The armatures of the section motors are connected to an adjustable-voltage generator while their fields and the control circuits obtain power from a constant-voltage exciter generator. All circuit breakers, disconnect switches, etc., should be connected to interlock the two sources of d-c. power and prevent damage from incorrect sequence of operation. It should be impossible to energize the control circuit of any section motor unless all of the switches furnishing power to the motor circuits are closed. Opening any switch should immediately de-energize the control circuits of all sections depending upon power supply from that switch.

Auxiliary motors driving exciters or blowers for forced motor ventilation should have their control apparatus interlocked and connected to insure their operation when the power-supplying generator is started and to cut off the power supply in case of overload on these auxiliary motors.

The many panels necessary for controlling and regulating the required apparatus should be assembled into one switchboard which can be located remote from the heat, water and dust of the machine room and under the charge of authorized workmen.

In addition to the usual push-button stations for starting, stopping and inching the section motors and for changing the speed of the entire machine, there is furnished with the equipment described in Mr. Staege's paper a "Safe-Run" station for each section which permits the section control to be made safe when it is necessary to work around dangerous parts of the machine and which cannot be restored to the running position until unlocked.

Heavy dryer sections and calenders require starting torques many times in excess of the running torque, while presses and other sections usually are started at reduced load and do not need much more than normal torque to start. If the range of operating speed and voltage is broad, special provision must be made to change the value of starting resistors as the voltage changes.

When starting currents become large enough to overload the generator, and cause undesirable voltage variations, means must be provided to obtain the necessary torque without these objectionable features. Separate low-voltage generators for starting purposes, separate starting motors, and series-parallel controls are methods in common use. In the case of dryer sections geared together, satisfactory stable division of the load on the driving motors can be obtained by a proper design of the motor. Motors having good speed regulation are necessary, but these unfortunately will not ordinarily parallel with equal division of load. It has been possible by means of special windings to design motors which have excellent speed-regulation characteristics and at the same time divide their loads equally when geared together.

A successful speed-regulating system must have ability to hold constant motor speed in spite of the various causes tending to change it, must respond quickly enough to avoid damage to the partly finished sheet of paper, and must operate with a minimum of attention. If the regulator can make a change in field strength of sufficient magnitude, can make it fast enough, and can stop when exactly the right amount of change has been made, successful operation is assured. Ruggedness and serviceability must be obtained in the design to make it a commercial success after these fundamental requirements have been secured. The most important features of the regulator described by Mr. Staege is its ability to produce a perfectly graduated change in effective value of the field resistor by the simple method of intermittently short-circuiting resistor steps by means of a conductor having a variable width. Enough resistor steps can be used to give all of the regulating capacity ever needed. Unlike former systems, the amount of resistance is not limited by the master speed. Those sections having high inertia and requiring more gradual changes in resistance can be equipped with smaller-pitch screws. As a result it is not necessary to sacrifice regulating capacity on the high-inertia sections and the lighter sections can be made to respond more quickly. An infinite number of resistance values between maximum and minimum may be secured. The regulator is truly differential in action and must produce 100 per cent speed correction before its action stops. Mechanically the apparatus employed is simple and substantial. It is evident that this system possesses to a very marked degree all three of the fundamental requirements: capacity, quick response and smooth regulation.

E. F. Bearce: The sectional electric drive for paper machines has accomplished some very definite results for the industry.

In the manufacture of news print, this drive is especially advantageous since it permits of the high paper speeds with positive regulation. For the higher-grade paper manufacturer the drive has provided regulation of speed which is one of the important features required to get a sheet of uniform weight and caliber. These points of advantage are in comparison with the older methods of drives using a variable-speed back line in which the speed may be limited by belt or pulley design and the use of a variable-speed steam-engine drive having a regulation not less than three per cent.

It is also interesting to compare the cost of the sectional drive with the variable-speed drive using a back line, both as to first cost and maintenance. It has been determined that the first cost of the sectional electric drive is a little greater than the back-line drive, but is considerably more economical as regards maintenance.

The papers have brought out some very interesting points as to the details of construction and arrangement of the three different drives, each one having distinct points of advantage, and all three in successful operation in different parts of the country.

The manufacturers of this equipment are to be congratulated on the development of this drive as one of their greatest contributions to the advancement of the paper industry, and I am sure every paper maker is ready to cooperate with them in the continuance of their good work.

E. B. Wright: We operate seven machines; three of them are driven electrically by d-c. variable-speed motors through a line shaft with cone pulleys and friction clutches.

This type of drive works out very nicely, the regulation being good if the exciter voltage remains constant. The least variation in exciter voltage causes a change in speed of the d-c. motors.

A motor-generator set, with exciter direct-connected, is used to drive the variable-speed lines. This set takes its power from an extraction turbine, which when operating at maximum rating and extracting the maximum amount of steam, at times falls below normal speed, which affects the exciter voltage causing a variation at the paper machine.

I should like to ask the speakers how the cost of installing the individual drive compares with line-shaft drive in new installations, also how maintenance costs compare.

R. S. White: Mr. Wright mentioned a variation in speed of the prime mover causing a speed change on the paper machine. My experience has been the same.

We have a synchronous motor-generator set with exciter direct-connected. This exciter supplies the excitation to the d-c. generator as well as the synchronous motor. Therefore any slight change in speed causes a voltage variation in the d-c. generator due to the exciter voltage varying.

When first starting, we had considerable trouble with the governor of our turbine and consequently had all sorts of speed variations. Now if the paper-machine head box were set

for, say, 25-lb. paper at 300 ft. per min. and then the machine suddenly changed to 325 ft., it would cause the paper to drop in weight and change the dryness at the same time.

All paper-machine drives, in my estimation, should have voltage regulators to take care of just such trouble as we experienced. I understand that all Harland drives are now furnished with voltage regulators.

The Harland drive for our No. 2 machine has been in operation four months and the No. 1 machine two months. Outside of the trouble mentioned we have not any fault to find with the performance of the drives.

When we started the No. 2 machine we had a suction press roll 22 in. in diameter. Soon this was removed and a 26-in. rubber press roll installed. Since this roll was 4 in. larger, it had to run slower. Now the field rheostat or regulator did not have a range wide enough to cover this, so we had to change the gears and get a larger ratio.

It seems to me that these regulators should be designed to cover a much larger range than they do in our machines, as paper mills change managers and each one wants different equipment. And in order to drive this equipment extra gears must be kept in stock.

Mr. Norris mentioned something that seems to me is more important than close regulation between sections, and that is the control of the supply to the machines. Why not have the pumps interlocked so as to give uniform supply? If the supply to the machine is not fed on the wire at a uniform rate, the paper cannot be of good quality. There should be an automatic arrangement so that in case the machine changed speed, the opening from the head box (if a Fourdrinier machine) would change in direct proportion to the speed.

C. A. Farrell: We have all three drives, single-motor, sectional and mechanical. I guess the proof of the pudding is in the eating, and all of our machine men are unanimous for the electric drive. We find that they like the sectional drive the best, although I can't see but that we get almost as good regulation with the single motor. Of course, we have belt trouble. I notice that one of the manufacturers has a provision also, I think, in the face of the motor for cutting in some series windings. I would like to ask whether that is necessary on all of the sections or just a few, and whether it is for starting purposes only.

Mr. Norris says that he uses compound-wound motors, and the other manufacturers use shunt motors. I wonder if there is a reason for that.

I think our sectional drive was one of the first. Our motors are larger than necessary and we don't have any trouble from temperature, but I wonder if the motor is enclosed only to keep the water out of the machine or if they depend upon the forced air to keep down the temperature and therefore use a smaller motor.

I would like to know what sizes of motors are used in the drives today compared with ours. We have 35- to 50-h. p. motors, I believe.

We are particularly interested from the maintenance standpoint in the temperature of the motors. As large as our motors are, in the heat of summer they frequently run temperatures that are pretty high.

Tom Harvey: I look at this from an owner's standpoint. I am wondering if these people who put in these very expensive electric drives are getting a return on the money invested.

We have four machines making box board. I was very much disappointed that none of the speakers said a word on box board. Our tonnage amounts to the total tonnage of all of the news paper, all of the book paper and all of the writing paper made in the United States, and I think it should be recognized.

One of the authors shows a drawing of a cylinder machine and does not say a word about it.

We have one old mill that has been running about 25 years, and because of the crowding of the mill we decided some few years ago to electrify it. We have spent considerable money in that mill and I suppose it is electrified as well as any other boxboard mill with the exception perhaps of the mill at Ritman, Ohio.

We find that we don't get the return on the mill with the large investment that we do from the mill with the smaller investment. We also get much larger tonnage from the mill that is what I call directly driven from the steam engine with the rope drive. We have very little electricity in that mill.

I can readily see that the electric drive is a great advantage to the people who are making news paper and are running their machines up to a 1000 ft. a minute, but I have yet to be shown where a manufacturer is justified in spending the amount of money that he has to spend to put in the electric driven machine. I doubt very much if the stockholders would be satisfied if they could see the results from the machines that are not electrified.

J. H. Crossley: We have only just started up our first two sectional-drive machines, which are the General Electric Company's drive.

I should like to ask Mr. Norris what he means when he says that when their interlock is out of action, the wet end of the machine does not run wild? I am curious to know what would happen to our drive if our regulator should go out of action.

A. O. Spierling: I was glad to hear Mr. Harvey refer to the financial studies which must be made when considering the addition of electric drives to paper machines.

At the present time we, at Hammermill, are using the mechanical type of drive on each of our five paper machines. About four years ago we investigated the electric drive and have been giving considerable attention to it since. We credit the electrical manufacturers with doing a splendid piece of engineering work in perfecting the electric drive. Any of the three types of electric drive described, we believe, will work very well but their installation involves considerable expense which is sometimes very hard to justify.

We have thus far been unable to find how we could produce paper any cheaper by replacing our present drive with the electric type of drive.

There is one point, however, which has been brought out here at this meeting which if shown to be true would immediately touch any paper maker's heart and that is the statement that with the electric drive a better quality of paper might be produced. If this is true, the paper maker would be immediately much in favor of this type of drive because if he can produce a better quality of paper he can get more money for it and therefore justify the expenditure.

Of course, the thermodynamics of the matter enter very much into it, and it is a heat problem from start to finish. We charge against our paper machines the heat units that are used not only for the engine drive but also for the air that must be supplied to carry away the evaporated moisture.

Everything of that nature has to be taken into consideration before a person can say whether or not he is justified in putting in such a drive. It may, however, work out better with a new installation or with larger machines than it does with an existing installation of moderate-sized machines. Our machines are comparatively small compared to 300-in. machines. We manufacture a high-grade bond paper and run at speeds anywhere from about 100 ft. a minute up to 500 ft. a minute.

W. W. Spratt: One of the items touched upon is the heat balance of the paper mill. I believe it is an important subject to which we should give serious thought.

Mr. Norris, in his paper, mentioned that the 125-ton machine requires, roughly, 39,000 lb. of steam an hr. This, he estimates, is equivalent to 1000 e. h. p.

Let us assume that for the class of mills considered, power is worth from ½ to one cent a kw-hr. Mills having adequate hydroelectric development, principally in Canada, may,

of course, get power for less than a ½ cent. Depending on the cost of competing power and cost of coal in the district analyzed, it is estimated that it may be worth from $5000 to $25,000 a year as an incentive for the mill to obtain by-product power from this quantity of steam. Taking an average condition of $15,000, the average mill would hardly, under these conditions, utilize live steam through reducing valves to do the work in the dryers, which points out the importance of consideration of some sort of non-condensing or by-product prime mover as a source of power for the paper machine.

This is the question which I know Mr. Harvey, in his discussion, was referring to, especially in relation to board mills. I have seen many cases in board mills which did not have the best type of heat balance. Unfortunately, in the case of mills that do not have the heat balance worked out well, and are electrified, the story gets around that it is uneconomical to drive the mill electrically, while, with a much better heat balance, taking full advantage of the possibilities of generating by-product power, such a situation would not be so marked and the advantages of electric drive could well gap the difference of some of the losses on the pure question of steam utilization, as referred to the engine drive which unfortunately still predominates in board mills.

I believe the greatest advantage of a sectional drive is in a new mill where advantage can be taken of the smaller space and the basement can be utilized for other purposes. I know of one mill which installed sectional drive merely on the basis of lower building cost and other items which have not been discussed. They operate a board machine from 50 to 200 ft. per minute. Fortunately, they happen to be located where they can buy power from Niagara and they have a cheap power rate which assists them. Even in their case, however, there would be some advantage in using a non-condensing unit to drive the d-c. generator.

We have heard a very interesting discussion touching on the relative merits of moderate-speed motors versus direct-connected, slower-speed motors. The discussion took us into the question of stored energy of the different motors. We are chiefly interested, however, in maintaining the speed of the motors, whether we do it by means of an interlock system, synchronous-motor tie-in system, or regulator system. In this connection, I believe we all agree that the system with the maximum stored energy is less susceptible to speed changes. The stored energy tends to maintain the speed at the proper value. Our problem is one of maintaining the desired speed and a large stored energy assists us. It is only when we are away from the desired speed that a large stored energy would be a disadvantage.

I should like to ask two questions; one is with relation to the system utilizing the dryer sections as a master. I should like to ask why that is done,rather than having a regulator which is entirely independent of any one section of the machine.

I should like to ask Mr. Rogers how long it takes the vernier brush arm of the synchronous-dynamometer regulator to travel from one extreme to the other.

N. D. Paine: May I answer one of the last questions,—as to why the dryer section is used as a master section? I mentioned before that the immense amount of inertia in the dryers naturally tends to keep them at a very steady speed. As a matter of fact, using a Bristol tachometer which is extremely sensitive, we have found that when we had that tachometer on the master shaft, it would draw a straighter line than you could with a ruler for possibly four or five hours on end. It also obviates the necessity of using section regulators. You cut down your initial cost in that way.

It has been mentioned that when the dryer section is shut down the master shaft is stopped and the section motors are running wild. This is not correct. When the dryers are shut down, the section motors automatically go to the non-interlock point of the field regulator, which is only one or two commutator or face-plate segments away from the operating position of the regulator brush arm, and this position is less than 0.25 ampere in field-strength value. I happen to know that our own paper makers hardly realize that there is any difference in speed once we have our regulators set when the dryers are shut down. In fact, once the dryers are shut down, you are not making paper; you can't handle it the full width of the sheet; you can only take your lead strip up to the third press at most, so why worry?

L. E. Markle: It is common practise in paper mills to have the machine operating for 24 hours a day, over a period of six days in the week. In view of this continuous service, the mechanical duty required of the rheostat mechanism described by Mr. Norris as a breathing process must be rather severe. We should like to ask whether special precaution is taken in the selection of materials and the construction of the face plate and brush mechanism?

Several of the paper-mill representatives as well as the authors of all of the papers have emphasized the necessity for close speed regulation at all times. Since the permissible changes in speed are so small, it is certainly true that any system which will correct to a finer degree than other systems is desirable. All systems require some speed reference as a master. This unit may be a section of the paper machine such as the dryers, or it may be a unit driven by a separate motor. Since any change in the speed of the master unit affects the speed of the entire paper machine, causing it to speed up or slow down as the master speed changes, it would seem that an installation as described by Mr. Staege, where the speed of the master set is regulated just the same as the speed of any of the main driving motors, would naturally give a closer speed regulation.

I feel this point vital because as mentioned before the limits of permissible variation are small, and any system which can regulate better than another, no matter how small the amount, is preferable.

S. A. Staege: Mr. Rogers calls attention to the controversy on the relative merits of high-speed, medium-width machines as compared with medium-speed, very wide machines, and indicates that there is now a tendency to favor the former. A more complete statement would be to say that the high-speed, medium-width machine first reached its supremacy, but is now being followed by the high-speed, very wide machine, as there does not appear to be any fundamental reason why the very wide machines should not operate at equally as high a speed as the medium-width machine. Present practise indicates wider machines than ever built before combined with a maximum contemplated speed so far unapproached in actual commercial practise by several hundred feet per minute. The real limitations of the paper machine both as to speed and to width are determined by such factors as the maximum speed at which the sheet can be formed properly and by economic factors pertaining to the machine clothing, initial cost, etc., and not at all by the drive.

All available data confirm the indication that the power required by the several sections of the paper machine varies directly as the width of the machine and directly as the speed of the machine so long as the other relevant factors remain substantially constant.

I do not agree with Mr. Rogers' statement that the synchronous-motor tie-in system is a preventive and that the regulator type of control is a corrective system, nor am I able to agree that in the regulator type of control there is no restraining power to hold the motors in place. In fact, in the case of sectional drive, the d-c. motor has available a restraining torque equivalent to far more than the full-load torque of the motor, whereas, in the case of the synchronous, tie-in system, the full-load torque of the synchronous motor is far less than the normal torque of the d-c. driving motor. It is quite true, however, as Mr. Rogers has said, that the success of the regulator type of control depends upon the amount of angular dis-

placement which causes the regulator to function and by the time element of the motor field. This means that there should be absolutely no lost motion and that resistance be cut in or out of the motor field circuit with the smallest possible change in angular displacement of the motor. It also means that the time element of the motor field circuit should be as short as possible, which is inevitably associated with relatively high-speed motors.

I should like to ask Mr. Rogers if he does not feel that a speed change of a section of the machine of 0.15 per cent which he has indicated may result from a load change, in the case of the synchronous-motor, tie-in system, is not too much for satisfactory operation, particularly at the dry end of the machine. Personally, I feel that such an amount of speed change between sections is far in excess of safe or desirable limits.

In the case of the synchronous-motor, tie-in system, I should like to ask Mr. Rogers at what speed the frame of the synchronous motor is made to rotate by the small variable-speed, d-c. motor. It would appear that if the speed at which the frame rotates is a very small percentage of the rotor speed, then the change in speed of the small, d-c. motor might have to be several hundred per cent to accomplish a change in speed of the d-c., section-driving motor of, say, 10 per cent to compensate for possible changes in diameter of the roll, change in draw, etc.

I would also like to ask whether the paragraph in his paper immediately preceding the description of the synchronous-dynamometer type applies to the paragraph immediately preceding it.

From Mr. Rogers' conclusions, it appears that the three authors are now unanimously in agreement that regulator control best meets the requirements of sectional paper-machine drive.

It is stated by Mr. Rogers that the synchronous dynamometer regulator operates on an angular displacement corresponding to approximately 0.05 per cent change in speed of the controlled motor. Obviously, if there is a change in speed, the angular displacement will continue to increase until the speed is corrected and it would be desirable to know how long this 0.05 per cent change in speed must continue to obtain a sufficient angular displacement to operate the regulator.

It would be interesting to know through how many mechanical degrees the stator of the synchronous dynamometer would have to rotate to move the commutator rheostat brushes through 450 operating points. I should also like to ask what means are employed to actuate the brush on the large-step portion of the commutator rheostat. I should like to ask Mr. Rogers of what the anti-hunting features consist in the regulator equipment described by him.

Mr. Norris in describing the interlock regulating system states that in practise the brush arm quietly breathes between two contacts. I should like to ask the order of the frequency of oscillation for the various sections of the paper machine and the actual amount of angular displacement through which the d-c., section-driving motor oscillates in response to the resistance changes.

A statement is made by Mr. Norris that should the master section shut down, whether it is the dryer section or a small master motor, all the other sections automatically still continue to run at the speed at which they were first operating. I should like to ask through what means this is accomplished.

H. W. Rogers: In connection with Mr. Staege's paper, I would like to say that the General Electric Company installed and put into successful operation in 1909 a sectional paper machine drive with a definite tie-in between the sections.

Mr. Staege describes the synchronous tie-in type of drive and states that any change in load on the part of one section will affect the speed of the entire paper machine. In this connection, I wish to state that the use of synchronous motors on each section of the paper machine is analogous to a positive mechanical tie-in between the sections, and the machine operates as though driven by a single motor. Therefore, the effect on the total load of a change in load on one section is a matter of two or three per cent and the effect on the speed of the machine as a whole for such a change in load is less than 0.1 per cent.

After describing the improvements which have been made in the synchronous tie-in type of drive, Mr. Staege states that the effect of speed variation in the small d-c. motors which rotate the synchronous-motor stator frame on the main driving motor is approximately inversely proportional to the ratio of the worm gear used in driving the stator. This statement is incorrect inasmuch as the gear ratio has nothing whatever to do with the speed regulation of the d-c. motor. A small d-c. motor drives the synchronous-motor stator at a speed which permits of proper draw adjustment, this speed being only a small percentage of the speed at which the main motor is operated. Therefore, any variation in speed of the small motor directly affects the speed of the stator, but the stator speed being a small percentage of the rotor speed, its effect on the main driving unit is inappreciable.

In my experience I have found that the control of the high-speed machine is the simplest problem with which we have to contend and that the low-speed and wide machines present the greatest difficulty.

I am interested to know just where the third type of regulator mentioned by Mr. Staege is in operation and on how many machines. I should also like to ask what provision is made to eliminate a so-called wild machine when the master set is shut down.

The European drive to which Mr. Staege refers on the ninth page consists of a-c. commutator motors and has been in successful operation at the Empire Mills, Ltd., for practically two years and is now being followed up by a second installation in another mill.

S. A. Staege: I think there is some misapprehension as to the effect of inertia in the moving system with respect to the regulation of the paper machine. As Mr. Spratt indicated, where there is considerable flywheel effect, regulation is frequently easier than where there is very little. I might say that in respect to the dryer sections where there is a very great amount of flywheel effect, the rotary-contactor regulator which has been described is able to take care of the regulation just as completely as on a press section where the inertia is almost negligible. In fact, I am unable to see that the amount of flywheel effect should seriously affect the regulation of the paper machine. The amount of stored energy in the motor is so small compared with the inertia in the dryers that I look upon it as a very small factor. It is perfectly true that if there is lost motion then a large amount of flywheel effect is undesirable; in fact, it is difficult if not impossible to regulate if you have lost motion in the regulating system. It is of course true that the high-speed motor does have more flywheel effect than a low-speed motor.

The speed of the motor field is the next controlling factor, providing the regulator works instantaneously. The rotary-contactor regulator's movement is absolutely synchronous with the change in angular displacement. The only possible chance for any delay in the corrective effect is in the time element of the motor field, and with the high-speed motor the field is very quick as compared with the field of the large slow-speed motor where there is much more iron and turns and the inductance is a great deal more. The response of the armature current will follow with practically no lag as soon as the field is changed.

I am not able to follow Mr. Rogers in his conclusions that the field is not a controlling factor in the time element of the motor.

The magnetic contactor is a very reliable piece of apparatus. When the contacts are made they rub and roll together, presenting changing surfaces, and the contacts never blister nor accumulate dirt.

Mr. Montgomery inquired as to the degree of regulation required, mentioning 0.1 per cent, and asking whether that was necessary. On the wet end of the machine, between the couch and the first press, the machine can stand considerably more than 0.1

per cent variation without breaking the sheet or causing any very serious consequences. I feel that any change in speed, however, tends to weaken the sheet although it may not be very serious. Farther on toward the dry end of the machine, a variation of 0.1 per cent would cause very serious straining of the sheet and between the dryer and the calender an elongation of the sheet of 0.1 per cent would almost certainly break the sheet. There are some grades of paper, of course, that have more elasticity than others.

The differential accumulative effect referred to which applies to both mechanical and electrical differential devices is accumulative in characteristics. If there is a change in speed, no matter how small, as long as it is allowed to continue the angular displacement keeps accumulating. And the accumulated value of departure, if it is attached to something which is supposed to regulate, will become greater and greater until the required action has taken place. The rapidity with which the corrective effect will be brought about is dependent upon the relations between the various parts, gear ratios if it is gears, or some other similar factors in determining the speed at which the secondary movement takes place.

Mr. Bowler called attention to the degree of regulation as compared with that of the mechanical drive. As brought out in these papers, mechanical drives are subject to belt slippage, and it is very well known that belts are liable to slip anywhere from a small fraction of a per cent to two or three per cent, depending upon the loading or condition of the belt, the arc of contact with the pulleys, the tension and numerous other factors. Of course, the amount of belt slippage, other things being equal, is nearly a straight-line function of the load transmitted, and if the total slippage, for instance, is two per cent under full load, a change in load of 10 per cent could be expected to produce a variation in that slippage of 0.2 per cent. However, a little moisture on the belt is likely to cause variations in the slippage of considerably larger values. It is the variation in slippage which affects the draw rather than the total or base slippage. If the drives all slipped exactly the same amount and never changed, you would have just as good a draw as though they did not slip at all.

Mr. Paine speaks of starting the dryers and comments on the stored energy. It is true, as I have indicated, that there is a great deal of stored energy in the dryers and they have to be started more slowly than the other sections of the machine. But if the proper time element is given they should be brought to full speed and synchronized with the control system without any difficulty. And where the regulator is designed in such a way that it starts up with full field on the motors and then after the motor gets up to nearly the operating speed the regulator gradually cuts in the field resistance, bringing it up to regulating values, there is no shock brought about and nothing to start oscillations. Of course, if you cut in the regulating resistance suddenly in the full amount, it is possible, if it is too much, to start oscillations of the dryers which might not easily be damped out, but when the resistance values are of the correct amount and the speed at which it is cut in properly controlled, there is no difficulty.

However, it is true that on the dryer sections with large inertia, the steepness of the regulation curve should be less than on sections with less inertia, because they cannot respond so quickly. You have there not only the lag of the motor field, but you have the inertia lag of the rotating mass, and the speed of cutting in the resistance must be adapted to the torque the motor is able to develop and to the inertia of the system.

Mr. Sanborn speaks of sudden variations and overloading conditions. The rotary-contactor regulator, which has been discussed by me, is designed to take care of any changes in load from no load to 50 or 100 per cent overload and still maintain the draw, and it does it. It has enough resistance and cuts it in at a sufficient rate to prevent more than a transient change in speed. That differs from the earlier types of regulators in which there was not a sufficient amount of regulating resistance to take care of such wide changes and in which it couldn't be cut in fast enough to overcome the initial tendency to drop off in speed faster than it could correct it.

Mr. Rodes mentioned the possibility of the brushes breaking on the regulator. If a brush should break or a wire should break in the rotary-contactor control, which is nothing more than a rheostat in which every step is divided into an infinite number of small increments of resistance, all that would happen would be that the drum would move longitudinally on the shaft a small fraction of an inch. In fact, if you were to lift out one brush while running the drum would move up about 1/16 in. and present the next step, and you could take out a number of steps of resistance or cut the wires, and it would simply move up far enough to compensate for it. You would hardly see any change in the draw at all; probably you wouldn't see any.

The simplicity of the sectional drive is not fully appreciated by most paper-mill people. Electrical apparatus has been so standardized and used so long that there is no uncertainty about its performance. It will probably stand up and give good service as long as any kind of mechanical device with similar treatment. And the records show that the maintenance is extremely low, something that cannot be met or even approached by most mechanical drives. As an illustration, one drive, of which a record was sent to me recently, has been in operation just one year, and had a total maintenance expense of $21.

Mr. Bearch questions whether there is too much refinement. I believe as long as we can get refinement without complication we ought to have it.

Mr. Harvey has raised a very interesting point in regard to cylinder machines. We have sectional drives on two-cylinder machines and they are giving a very good account of themselves. The maintenance is negligibly small and the power used is about 50 per cent less than where mechanical drive is used.

The draw can be controlled with greater precision with sectional drives than with any possible mechanical drive. And it can be held where wanted.

H. W. Rogers: In answer to Mr. Staege's reference to my statement that "the speed regulator which will best satisfy the exacting conditions of operation and appearance is the synchronous dynamometer regulator," I might say that this refers only to the regulator type of drive and its latest development. The statement has no reference to the synchronous tie-in type of drive which is being furnished and will continue to be furnished for some applications.

These two types of drive are fundamentally different; they each possess certain advantages and are both successful drives and yet they cannot be considered in the same class.

The question of torque available in the motors for maintaining constant speed under varying load conditions has been brought up. It is evident that the main driving motors have an abundance of it, whether slow-speed or moderate-speed motors are used. With the synchronous tie-in type of drive the restraining power is in the synchronous motors which have 20 per cent of the main motor capacity and have a pull-out torque of 200 per cent; consequently, they will hold the speed constant within a 40 per cent change in load either as a motor or as a generator, which is well within the load changes encountered on a paper machine. With the regulator type of drive the restraining power must come from the main driving motor and it is simply a question of whether it is instantaneously available for maintaining constant speed.

Both slow-speed direct-connected motors and moderate-speed geared motors have been successfully used on paper machines, but in my experience the purchaser has shown a marked preference for the slow-speed direct-connected motor. No difficulty has been experienced in designing either type to meet the requirements and it has been largely a matter of balancing the lower maintenance of one against the lower first cost of the other.

The moderate-speed motor will not respond more readily to changes in field strength than the slow-speed motor nor will it give a greater amount of torque for starting heavy loads. Slow-speed motors with good regulation can be made.

The slow-speed motor has a heavy armature with comparatively large WR^2, while the moderate-speed motor is of small diameter with a low WR^2, and while this might appear as an advantage to the moderate-speed motor, the truth is that we are not particularly concerned with the WR^2.

The stored energy in the armature is, however, of vital importance and is a direct indication of the ease and rapidity with which the motor will respond to the regulator and to changes in field. Since the stored energy in the armature is proportional to the square of the speed, it increases very rapidly in the higher speed motor, in spite of the smaller WR^2, and is many times larger in the moderate-speed motor than in the slow-speed motor.

As a further comparison the torque required to bring the motors to full speed in a given time may be of interest. Here again is a direct comparison of the responsiveness of the slow-speed motor and the moderate-speed motor, and while such wide changes in speed are not to be encountered, the comparison holds true for any percentage change in speed.

The moderate-speed motor has fewer armature conductors and a lower armature reaction; it also has a much lower inductance in the field than the slow-speed motor. The field, therefore, should and does respond more quickly to changes in current but that question is beside the point. What we are primarily interested in is the rapidity with which the armature responds to field changes and that is an entirely different question. The advantages are all with the slow-speed motor, and in the nature of things the field of the moderate-speed motor must of necessity respond about six times as rapidly as the slow-speed motor field to be on the same basis. This is not the case, but if it were possible the moderate-speed motor would still require many times greater change in armature current to produce the same responsiveness in speed, as the slow-speed motor.

It is well known that where rapid cycles and quick reversals are required, as in rolling mills and some machine-tool applications, the moderate-speed motor is always abandoned in favor of the slow-speed motor. The most important example of this application is the high-speed elevator which is driven by the slowest speed motor (65 rev. per min.) to secure sensitive control and quick response.

As regards regulation, it should be sufficient to state that hundreds of motors have been built at speeds from 38 to 100 rev. per min. with practically flat speed curves.

The slow-speed motor not only has as much torque as it is possible to obtain from any moderate-speed motor, but it has more active material and a much greater heat-storage capacity. It will stand greater overloads and more punishment without ill effect than the moderate-speed motor.

In first cost the advantage is with the moderate-speed motor, but in all other respects the advantages are with the slow-speed motor which may be summed up as follows:

1. The slow-speed motor has a much lower stored energy.
2. It requires less torque to produce a given change in speed.
3. The armature will respond more quickly to field changes.
4. It has a greater heat-storage capacity.
5. It will stand heavier overloads and more punishment with no ill effects.

In his remarks justifying the use of moderate-speed motors, Mr. Spratt has stated that heavy inertia or large stored energy is an advantage in maintaining speed, whereas Mr. Staege has admitted that the dryers, which have a large inertia, are more difficult to control since they do not respond quickly to changes.

The stored energy of a couch or press section may approximate 29 or 30 kilowatt-seconds, whereas the stored energy of a slow-speed motor armature is probably not more than one-quarter of it. The stored energy of the modertate-speed motor armature is probably two and one-half times that of the couch or press section and constitutes the bulk of the stored energy involved.

Mr. Paine has suggested the use of the dryers as a master. This is a practise that has been followed extensively on news machines and other machines with a narrow speed range and I can see no objection to it. It simplifies the control somewhat and does not affect the speed of the other sections when shut down as the regulators retain their operating position.

On wide-range machines, however, making book kraft or heavy papers, there is a tendency for the calenders to pull the dryers ahead and change the speed of the whole machine. Consequently a master set is a decided advantage in this case.

Several discussors have intimated that perhaps the electrical manufacturers are striving for unnecessary perfection and Mr. Montgomery has asked what regulation is actually required. In actual tests on mechanical drives I have found the regulation between sections to be as high as 1.2 per cent without affecting the operation of the machine or causing any complaint, and while I do not think that this should be taken as any criterion, it does indicate that exact speeds are not absolutely essential. Any of the sectional drives thus far developed will maintain speeds far beyond the possibilities of any mechanical drive.

All of the regulators described are synchronous in type and operate on the principle of an angular displacement between the two elements, the successful operation depending upon the magnitude of the displacement which causes the regulator to function. With the synchronous dynamometer I have described, a displacement of one-quarter of a mechanical degree or less between the stator and rotor will cause the stator to move and the movement ceases when the angular displacement disappears. Under these conditions there is no cumulative effect as is common with a mechanical drive. We have made no oscillograms of the synchronous dynamometer regulator, but from close observations I have made it seems to respond instantly to changes in load such as are normally encountered on the calender. Under normal conditions of operation the vernier brush on the upper half of the commutator rheostat will have sufficient range to meet all requirements but for extreme load changes the lower brush, which operates on coarser resistance steps, comes into play. This lower brush is carried on a yoked arm between the yokes of which the vernier brush moves and until the vernier brush has made its complete travel, the lower brush does not move.

All of the regulators described operate on the same fundamental principle of shunt-field control; they all operate on the basis of an angular displacement between the two elements and it is simply a question of which one operates on the smallest displacement, and which one is the simplest mechanically and electrically and has the lowest maintenance.

Mr. Harvey has requested information regarding the cost of sectional drives and I might answer him by stating that, where a new machine is involved, it is always possible to justify the sectional electric drive over a mechanical drive with either single motor or steam engine.

The use of auxiliary series fields on the dryer and calender motors was practised to a certain extent on some of the earlier drives, but at present we use shunt characteristics on both motors and generators with saturated fields on the dryer and calender motors for starting.

The use of enclosed motors is dependent upon the wish of the purchaser, but in no case do the enclosing features affect the temperature rating nor are such features ever used to justify smaller frames.

R. N. Norris: Mr. Montgomery asked a question on the degree of control—was 0.1 per cent sufficient? I think that a little better than that is necessary. So far as I can see from measurements taken personally, the average we have got can be taken at 0.03 per cent. That is from very careful measurements taken over a period of years.

I don't think there is anything in the accumulative effect. I agree with Mr. Rogers in that.

Mr. Bowler referred to the exactness of regulation on mechanical drives. I think Mr. Staege replied to that in what he said about belt slip. I don't think I need to say anything more about it, except to say that Mr. Bowler is quite right when he says that for years paper makers have made paper on mechanically driven machines satisfactorily. That is perfectly true, but then, of course, we reached a stage in paper machines where they became bigger and they have to be operated at much higher speeds, and the increased speed necessarily led to the development of these sectional drives which, once developed, proved to be far superior to mechanical drives in several respects.

Mr. Paine referred to the question of using the dryer section as the master section, and Mr. Staege also made a comment on this point. It is of course perfectly easy for dryer sections to be controlled. It is not at all a question of not being able to control them. It is purely a question of convenient arrangement of the plant.

It is often of considerable advantage to use the dryer sections, which are heavy and have considerable momentum, as a means of giving steady speed to the master shaft. If it is desired to control the dryer section it can be easily done. But why do it if it is not necessary? Why not simplify the equipment? That is one of the things at which we have aimed, namely, simplification in construction and installation.

If, however, it is required to control the dryer sections, as is advisable on book machines, kraft machines, tissue machines, etc., etc., then all that is necessary is to drive the master shaft with a small master motor and interlock the dryer sections to that. As a matter of fact there are in operation in Canada three interlock drives so driven and two in England, the two in England being big newsprint machines and the three in Canada being smaller book machines.

I agree with Mr. Rogers that for the high-speed news machine the drive of the master section by the dryers is all right, but for book machines, kraft machines, and tissue machines, it is questionable, and my inclination is to have the master motor for driving the master shaft, and not to drive from the dryer section.

Mr. Sanborn asked what the basic principle is that we are endeavoring to correct. We are of course endeavoring to correct the degree of variation in angular movement of paper-machine rolls, and the amount of load variation we are endeavoring to take account of is the normal load variations which occur on a paper machine.

I agree with Mr. Staege that he average conditions of load on a paper machine do not vary very considerably and are nothing like as heavy as the load variation that will occur on, say, a heavy rolling-mill plant. I have seen, however, fairly large load variations take place over a period of time. I have seen a couch motor, for instance, taking as a normal load 125 h.p., go up quite unexpectedly to 160 and 170 h.p. without any apparent reason. The reason of course was something mechanically wrong in the bearings or the Fourdrinier part of the paper machine, or possibly increased suction, but with the interlock system the design of the equipment is such that we provide sufficient control and resistance to deal with very heavy overloads and to prevent suctions dropping out of step. In fact we can comfortably handle overloads as high as 200 per cent if desired. If you put into your control the extra ability to compensate for these big changes in load then it is an additionally desirable condition to have.

One discussor referred to the question of starting motors on full field. That of course we always do; in fact the motors are started on what we call "super-field," as they have the full normal shunt excitation and they have the additional heavy series turns in operation at the same time.

Another gentleman referred to the question of maintenance costs on the regulator faceplates and brush arms. All I can say in reply is that we have over 30 machines in operation in Canada alone, and we have not yet been called upon to supply any spare contacts or brush arms for these regulators. We have supplied, I think, probably along with the installations as spares, some new faceplates, and probably clients have put them into operation, but we have not known of it, nor have we ever been called upon to replace them. In fact, the amount of wear on the faceplates is practically nil. When we first went into this question in 1912 and 1913, this question of wear troubled us also, but the large equipment we installed in 1913 is still running with the original faceplates, and this question of wear on faceplates need not be taken into account.

In relation to the question of the use of direct-coupled motors of slow speed as against higher-speed motors geared to the sections, I can say that we are perfectly content to use either, and have used both with perfectly good results. All our motors are compound-wound, and the results obtained prove that the compound motors are quite capable of giving the service, and of dealing with the heavy starting torques without the necessity of inching motors. As a matter of fact I think it is one attribute to the interlock system that it will control large slow-speed compound-wound motors very satisfactorily.

Mr. White referred to an installation that had no voltage regulator. I agree with him that one is essential, and on this particular installation, I had recommended that this voltage regulator be installed. On the whole I believe voltage regulators do improve operation, but we have had some extraordinarily good results without voltage regulators. The Laurentide machines, which have operated over 1000 ft. per min. since August 1921, have no voltage regulators and I say without exception that the machines are among the safest in existence today.

The question has been asked as to the amount of draw control that can be allowed at each section to compensate for the change in roll diameter from, say, 22 in. to 26 in. This is entirely one of previous decision in the design of the equipment; usually, we allow 20 per cent, but if somebody wants 50 per cent it can be given. If they want to make the equipment so that they can change rolls with ease, it can be given. The average paper machine does not need such a condition as this; in fact, I think it is the first time that I have ever heard of such a condition as this being required.

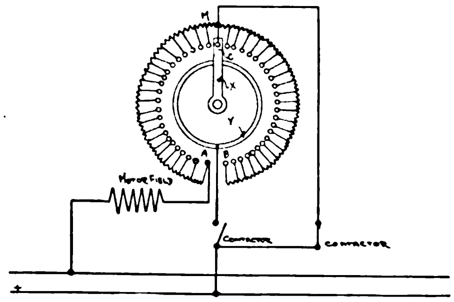

FIG. 1

Mr. Harvey referred to the question of finance and the application of the drive to the cylinder machine, and made the statement that he did not see where the increased cost of the sectional drive warranted its installation on book machines, or how its installation was warranted in taking out an old machine and replacing it with a sectional type.

I think the question of the cost of the drive is bound up with the results one can get. We have installed drives on book machines which have given so much satisfaction to clients that they say the installation is more than warranted by the results they have obtained.

Of course, where the book machines are going to be operated at higher speeds, sectional drive is the only thing. We have book machines on order today that go up to 850 ft. per min. I received an order recently for one book machine which is to have a speed variation of from 150 ft. to 850 ft. That is to be 170 in. wide, which is a pretty big book machine.

Mr. Crossly asked what I meant by saying that the machine was not "wild" when a certain master section was shut down.

This can be explained by reference to the accompanying diagram, Fig 1. *A* is the full field position; *B* is the weak field position with all resistance of the regulator in circuit. *C* is the normal working position of the arm. The arm *X* makes contact from *Y* ring to contact *C* through the carbon brush. Possibly *C* may vary one contact or two contacts, as the case may be, but it is only a very tiny bit and gives only a very tiny difference in field current.

When the master section shuts down the arm, *X* travels around, but the connection from the + busbar to *Y* is broken by an automatic contactor operated when the dryer motor is shut down, and, in place of the connection being made through the ring *Y* and arm *X* to the point *C*, connection is made through another contactor to what we call the "mid-point" *M* on the resistance itself.

As a matter of fact the two contactors are combined in one, one of which opens, and the other closes, when the dryer motors shut down.

The resistance connection *M* is adjustable in the right working position for the paper machine, and it is found that this always remains in about the same position, no matter in what position the paper machine is working, as the equipment is designed to operate at the same field current on high-speed machines all the time. Where variation of field current is required for wide-range machines the motors are designed so that, by the alteration of one combined rheostat, all field currents are operated at the same time in the same degree, and the arm remains in the same position.

I think the above remarks also apply to Mr. Staege's question as to what happens when the master shaft shuts down.

One gentleman referred to the question of thermal conditions in the mill. This opens up a very interesting phase of the whole subject of sectional electric drive, and one to which I have given a little thought, of late. It is a very interesting study, and I say that by the use of sectional electric drive it is possible to obtain a better heat balance than with any form of mechanical drive. My reasons for this statement are too long to enumerate here, but it is a subject which deserves considerable investigation.

One gentleman raises the question of carrying the paper through to the third press if the dryers are shut down. This is not an important matter in spite of what some paper makers may say, because, if you shut down the dryer sections for anything at all, it means a stoppage of several minutes. During this time, much the best place to let the paper go to is the pit at the couch, and, as a matter of fact, there has lately been installed in the mills of the International Paper Company at Three Rivers a device that, when the paper breaks at any section of the machine, will automatically break the paper at the couch. I think this is good practise.

Mr. Staege asked the order of frequency of oscillation for the various sections of the paper machine. The frequency of breathing of the regulator arm is an absolutely mechanical reflection of what is happening in the paper machine room, and it is therefore possible to count the oscillations and the time period in which they take place with the interlock equipment.

A feature which is of considerable assistance to the paper maker is an indication that the sectional drive is working satisfactorily. I would not call this oscillation; in fact there is no oscillation. The arm breathes quietly—and I emphasize "quietly"—from contact to contact, often taking a very considerable period of time to do it; in fact, I have personally sat and watched the arm work without seeing it move an amount appreciable to the eye, for over a quarter of an hour.

The average speed of movement over the working range of the arm, under normal operating conditions, varies a little, but when it is calculated into items of percentage of the variation in feet per minute of the paper, it works out, as I previously said in reply to Mr. Montgomery, to the order of 0.033 per cent.

Mr. Staege, in his description of the interlock drive, I think, has quite inadvertently used the past tense in reference to many of his verbs, when he says that the dryer shaft "was" driven, etc., etc.; and all I can say is that the present tense is more applicable, as the drives not only "were" working satisfactorily, but "are" working satisfactorily, and "will" in future work satisfactorily.

Then there is the question of this "backlash" which he visualizes, and this elastic master shaft, and with all this "backlash" and "elasticity," it is a wonder that the interlock drive has been able to do anything at all. But facts show that it *does* do it, and does it with remarkable success, and today holds unbeaten records for output in the way of tonnage on the machines, one machine having produced as much as 127 tons of newsprint in 24 hours, and having given an average, over a period of months, of 114 tons per day.

Furthermore, the average highest operating speed is held by the interlock, since August 1921, on the Laurentide machines.

Mr. Staege, in his description of the new system, uses the word, "automatic" regulation. I do not quite see how he claims that this is automatic. The regulator in itself cannot change the field, and the multiplicity of contact which he refers to is an endeavor to get slide-wire effect, but in my opinion is not necessary.

It is that which is at the back of the regulator which does the work, that is, the screw in the worm, which is in the nature of a mechanical differential, and I do not quite see how Mr. Staege can claimthat this entirely is an electrical differential.

I refer again to the question of having something in our equipment which the naked eye can see is happening, which is an instant reflection of what is happening on the paper machine roll, and that is the movement of the regulator arm. It doesn't matter whether you have 10 ohms in between stops, or 1000 ohms,—as long as the arm is only moving a short distance, it is an inner mechanical connection back to the regulator, unless the belt is slipping, and if the belt slips you couldn't make paper. There is something which is a mechanical indication to the eye independent of time lags of field, independent of back lash, independent of elastic shafts.

The question of the vernier on a rheostat is a matter of opinion, I think. Mr. Rogers described the interesting vernier they have employed on their regulator type. I think it is quite good. As a matter of fact we had also a vernier once upon a time, but we didn't carry it any further. We thought it was an additional complication, and we left it out.

Mr. Rogers referred to the question of the master shaft driving the high-speed machine. He says he has no objection to that. I quite agree with him. I think it is quite a sound scheme. If anybody insists on regulating it, it can be regulated.

On book-paper machines and kraft-paper machines I agree with Mr. Rogers that the calender can pull round the dryers through the paper alone. I have one kraft machine in mind which has a 75-h.p. motor on the calender and two 75-h.p. motors on the dryer. I have seen the calender pull 125 per cent full load, and the dryers practically no load.

We had another very interesting study once when we tried to drive a Harper machine. First, it gave us a lot of trouble simply because we did not appreciate (not being papermaking engineers) the conditions of a Harper-machine wet end. This machine has interconnecting felts between the couch and the first press, and the first press and the second press. The felts actually acted as belts and one would find that first, the press

motor was pulling the couch motor round as a generator; and then the couch motor would pull the press motors round as generators, depending upon the tension of the felts. Having discovered the difficulty, alterations were made within twenty-four hours, which enabled the machine to perform under all conditions required of it, and it is today running with absolute satisfaction.

A reference has been made by both Mr. Staege and Mr. Rogers to a new drive at the Empire Paper Mills in England, using a-c. commutating motors. This drive works, but it is very complicated and occupies a large amount of space.

Discussion at Madison

SOME INTERCONNECTED-SYSTEM OPERATING PROBLEMS[1]

(BOYCE)

MADISON, WISCONSIN, May 7, 1926

D. W. Roper: In Fig. 3 of the paper, the greatest reduction in the operating troubles is the reduction in the interruptions due to lightning. I would just like to ask Mr. Boyce how these reductions were brought about and to what extent the reductions shown were due to reduction in number of, or severity of, the lightning storms.

Carl Lee: In referring to chart No. 3 and Mr. Boyce's reference to that, there is one point that I don't believe was touched on; that is whether or not insulators are changed while the line is hot or whether the line is killed in changing insulators.

Carl Dodd: Some companies have constant average frequency control. What effect would that have on large interconnected systems? Would it be possible to have constant-frequency control, either automatic or manual, at any or all of the principal stations, and keep the system in step?

L. E. Frost (communicated after adjournment): Mr. Boyce's statements about the division of load between generating plants are applicable only to rather special conditions of generating-plant development.

Obviously, the use of hydroelectric plants for only the peak load of the day and operation of steam plants continuously at efficient loadings is a process desirable only on systems where the hydro plants are large in proportion to stream flow. It would not be economical to design hydro plants for this type of operation unless the cost of extra pondage and extra hydroelectric generating capacity compares favorably with the cost of equal steam-plant capacity, taking into account differences in operating cost.

May I call attention to the fact that in dividing load between any steam-driven units which are in operation, the loading of each machine at its own most efficient operating point does not necessarily result in the greatest possible over-all economy for the whole group.

As an example, let us suppose that we have two steam turbo generators side by side supplied from the same steam header. One has a capacity of 20,000 kw. with its best water rate at 15,000 kw.; the other is a 40,000-kw. unit with its best water rate at 30,000 kw. Suppose that for some reason the load assigned to these two machines is 45,000 kw. At first sight it may seem best to put 15,000 kw. on the smaller machine and 30,000 kw. on the larger, thus running each at its most efficient point; but as a matter of fact, if one machine has a water rate much better than the other (as is often the case) it may be more economical to carry a larger portion of the load on the more efficient machine. Even though this decreases the operating efficiency of each machine individually, it may improve the efficiency of the pair as a whole.

To secure the very best economy possible we would want to continue the increase of load on the 40,000-kw. machine (and a corresponding decrease of load on the 20,000-kw. machine) to the point where an additional kilowatt would add no less steam to one unit than it relieved from the other.

1. A. I. E. E. JOURNAL, May, 1926, p. 462.

Mr. Boyce's scheme of a load-limiting device set so as to secure the best possible efficiency from each individual steam turbine may be excellent if all units in operation are capable of about the same efficiency, but it is open to question if there are appreciable differences between the efficiencies of the various units.

F. G. Boyce: Regarding Mr. Roper's question concerning the graph on lightning, the reduction shown is not what you would probably think it is. It is not entirely an improvement in lightning protection. In 1920 our system was quite badly overloaded and during lightning storms, trouble on one transmission line would sometimes require that other lines be taken out of service due to lack of capacity. Correcting this condition represents part of the improvement shown, the balance being an improvement in lightning-arrester design.

We had quite a little trouble with electrolytic lightning arresters at that time and had to increase the insulation at the horn gaps and under the tanks. During this period I believe the lightning arresters caused about as many interruptions as they prevented. Since 1920 the arresters have been entirely rebuilt which has assisted in reducing interruptions due to lightning-arrester failures.

In the other portion of this graph classed as equipment defects, I think the greater portion of the improvement shown is due to improvement in quality and the use of a great quantity of insulation.

In answer to the question concerning the testing and changing of transmission line insulators while hot, we do not do very much of this kind of work, although we have used the buzz-stick method of testing insulators and have changed insulators while the lines are alive by the use of "hot-line tools." We now use the 60-cycle over-voltage method of testing insulators, changing the entire string of insulators when the line is dead.

In answer to the question of frequency control, we operate the system by means of Warren clocks. As seen from the map of the system, it is controlled from three points by means of system operators, one group at Saginaw at the lower end of Saginaw Bay on the east side of the state. These men are in touch with all plants in the north and from there south as far as Owosso. At Jackson there is another group of system operators who control the system south and west as far as Kalamazoo, and still another group of system operators who control the operation of the western portion of the system. The control is all centralized at Jackson, at which place the chief load despatchers are located who supervise the work of the system operators at the other locations. When the system becomes split, the system operators are in supreme control of their separate districts until the system is connected together again.

In answer to Mr. Frost, I would say that the combination of steam and hydroelectric plants in one system allows the most effective use of the kw-hr. capacity of the hydroelectric plants and that the load factor of the various units can be improved even with plants having moderate ponds; thus for a lower investment per kw. of installed capacity, a greater kw-hr. output can be obtained.

Regarding the operation of steam plants in combination with hydroelectric plants, it is possible to improve the load factor of the units in operation. An interconnected system permits the operation of units in the manner that Mr. Frost suggests, and is the way the operation of the system mentioned is usually carried out, namely, having units at their most efficient point at all times with reference to the rest of the system.

BEHAVIOR OF RADIO RECEIVING SYSTEMS TO SIGNALS AND TO INTERFERENCE[1]

(PETERS)

MADISON, WISCONSIN, MAY 7, 1926

Edward Bennett: In order to appreciate the significance of the point of view which has been developed in Professor Peters' paper, it may be helpful to review the sequence in which the knowledge of the properties of circuits has developed. Practis-

1. A. I. E. E. JOURNAL, August, 1926, p. 707.

ing engineers were first confronted with direct-current problems, and quickly obtained a very good understanding of the properties of complex networks or combinations of circuits, provided the problems related only to the steady flow of continuous currents in the networks.

Somewhat later came the realization of the possibilities of alternating current in the distribution of power. Engineers then became concerned with the performance of circuits when carrying alternating current. That situation was cleared by the adoption (largely through the writings of Steinmetz) of the method of the complex algebra for the calculation of the properties of alternating-current circuits.

In recent years, with the development of radio telegraphy and telephony, and with the development of extensive high-voltage transmission systems, engineers have become concerned, not so much with the performance of networks when carrying alternating currents in an undisturbed manner, but with the performance of these networks when they are subject to switching operations or when they are subject to disturbing electromotive forces,—the static impulses and so on.

Mr. Peters has developed and illustrated the application of the point of view that when we want to determine the effect of a transient disturbing electromotive force upon a receiving network, we may do this by replacing the transient electromotive force with the electromotive forces of suitably selected alternators which are conceived to remain in the circuit from the beginning of time to the end of time, and by calculating then the power delivery of these alternators to the receiving apparatus. The problem in the calculation of transient currents is thus reduced to the problem of calculating the steady-state values of alternating currents,—a calculation which is widely understood. It seems to me that the spread of this point of view will do for transient-current calculations what the spread of the method and notation of complex algebra did for the calculation of the steady-state values of alternating currents.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

LIGHTS TOTALING TWENTY-FIVE MILLION CANDLE POWER BURN NIGHTLY ON BROADWAY SIGNS*

With 25,000,000 candle power of light flashed against the sky each night, New York's Great White Way is a challenge to the imagination and ingenuity of the advertising artist. One has but to saunter up Broadway at night time to see how well this challenge is being met with every conceivable device for attracting the attention of the vast crowds that throng the brightest spot in the world every evening. Of all these various devices, animated lights, with the extensive variety of motions they make possible, are seen to be in predominance. For the great power of moving lights lies in the fact that they help to tell a story vividly, and the advertiser who can get his story across to the public can be sure of its attention.

Like the proverbial moth, people head straight for a light, and moving light attracts more people than still illumination. The recognition of this truth, and the fact that bright lights have a stronger attraction for the eye than ordinary light, lies back of nearly all the newest developments for producing brilliant color and startling movements in electric signs. The instinct that compels us to look toward moving objects and to observe any object that is intensely bright is probably as old as the human race. Many explanations of its origin have been offered by scientists, but the important thing to recognize from the selling point of view is that such instincts are facts that must be reckoned with in the creation of all effective advertising.

The annual Electric Sign Show held by the New York Edison Company in the spring of this year afforded a splendid opportunity to compare the powers of attraction in still lights, colored and moving lights in electric signs. This show, the fourth of its kind and even more brilliant than the exhibitions of previous years, presented the latest ideas of sixty-five manufacturers from every branch of the electric sign industry. Everything new in electrical advertising, from simple glass box signs to the latest developments in flash devices and two-color animated billboards, were demonstrated.

A few days after the show was opened to the public, a revolving disk of colored light that threw off constantly changing prismatic colors was placed under the ordinary poster in the showroom window announcing the exhibition. Immediately the number of passersby who stopped before the window was more than trebled. There was hardly a person who was not drawn to the window almost automatically by the revolving disk of colored lights. As a consequence, the attendance at the Electric Sign Show grew from the normal number expected to a record attendance. It was the brilliant changing colors that caught the eyes of the passersby, even without their being aware of the fact, and fastened their attendance on the poster announcing the Electric Sign Show.

Observation of the crowds attending the exhibition revealed that of two similar signs, one illuminated and the other plain, the lighted bulletin attracted more than twice as many spectators as the unlighted one. The still sign, however, though illuminated, did not have as strong an attraction on the crowds as the sign across the aisle in which the effect of motion was produced by using a flasher. There was something in the power of the moving lights that almost automatically caught the eye of the spectators and thus drew their full attention to the advertisements.

Approximately 5000 electric signs were added to New York's skyline during the last year, an average of about fourteen a day. The blaze of animated light that illuminates the Great White Way today is quite a different story from the first electric sign of 30 years ago, which startled New Yorkers by its daring innovation and immediately made its mark as an effective form of advertising. The first electric sign, with its two hundred lamps, would almost be lost on Broadway now.

*—Signs of the Times—August, 1926.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

Pacific Coast Convention

SEPTEMBER 6-9

Preparations are complete for an excellent convention at Salt Lake City, September sixth to ninth inclusive. A most interesting collection of papers dealing with a wide range of subjects will be presented and a most enjoyable program of trips and entertainment has been arranged. The program is as follows:

MONDAY, SEPTEMBER 6

9 A. M.

Registration at Convention Headquarters, Lobby Hotel Utah.

10 A. M.

Session of Counselors of Student Branches.

Meeting of Section Officers of Eighth and Ninth Geographical Districts.

12 M.

Organ Recital at Tabernacle.

2. P. M. OPENING SESSION

Address of Welcome, by Governor Geo. H. Dern.

Response by President Cummings C. Chesney.

The Space Charge that Surrounds a Conductor in Corona, by H. J. Ryan and J. S. Carroll, Stanford University.

110-Kv. Transmission Line Construction of the Washington Water Power Co., by L. R. Gamble, Washington Water Power Co.

A New 220-Kv. Transmission Line, by C. B. Carlson and H. Michener, Southern California Edison Co.

Effect of Unbalanced Tension in a Long-Span Transmission Line, by E. S. Healy and A. J. Wright, Electric Bond and Share Co.

2 P.M.

Ladies drive about city and nearby canyons.

4:30 P.M.

Excursion to Saltair; bathing, dinner and dancing.

TUESDAY, SEPTEMBER 7

10 A. M. TECHNICAL SESSION

The Circle Diagram of a Transmission Network, by F. E. Terman, Stanford University.

Calibration of Lichtenberg Figures, by K. B. McEachron, General Electric Company.

Stability Characteristics of Alternators, by O. E. Shirley, General Electric Company.

Synchronizing Power in Synchronous Machines, by H. V. Putman, Westinghouse Electric & Manufacturing Company.

11 A.M.

Ladies drive to Country Club for Luncheon, followed by Golf on picturesque links of the Country Club.

2 P.M. TECHNICAL SESSION

Vacuum-Switching Experiments at California Institute of Technology, by R. W. Sorensen and H. E. Mendenhall, California Institute of Technology.

Economical Power Factor Correction, by S. H. Litchfield.

Electrical Practise in Lead-Silver Mines in Utah, by Leonard Wilson, Consulting Engineer.

Engineering Education: Its History and Prospects, by H. H. Henline, Stanford University.

8 P.M.

Informal Reception, Ballroom Hotel Utah. Music and Dancing.

CONVENTION HEADQUARTERS, SALT LAKE CITY

WEDNESDAY, SEPTEMBER 8

10 A.M. TECHNICAL SESSION

Protection of Oil Tanks Against Lightning,, by F. W. Peek, Jr., General Electric Co.

Fire Protection of A-C. Generators, by J. A. Johnson, Niagara Falls Power Co., and E. J. Burnham, General Electric Co.

Variable-Voltage Equipment for Electric Power Shovels, by R. W. McNeill, Westinghouse Electric & Manufacturing Co.

Temperature of a Contact and Related Current-Interruption Problems, by Joseph Slepian, Westinghouse Electric & Manufacturing Co.

11 A.M.

Ladies Excursion to Pinecrest Inn, at the head of Emigration Canyon, for lunch.

2 P.M.

Golf Tournament on Links of Country Club.

6:30 P.M.

Dinner, Hotel Utah Ballroom, followed by:
Presentation of Edison Medal
Response by Dr. Ryan

THURSDAY, SEPTEMBER 9

10 A.M. TECHNICAL SESSION

Transcontinental Telephony, by B. B. Jacobs and H. H. Nance, American Telephone and Telegraph Co.

LIBERTY PARK LAKE, SALT LAKE CITY

Controlling Insulation Difficulties in the Vicinity of Great Salt Lake, by B. F. Howard, Mountain States Telephone & Telegraph Co.

Carrier-Current Communication on Submarine Cables, by H. W. Hitchcock, Pacific Telephone and Telegraph Co.

BINGHAM CANYON EXCURSION

On Thursday, September 9, starting at 12 o'clock, there will be an excursion to Bingham Canyon and Magna, visiting the famous Mine and Mills of Utah Copper Company. Basket lunch will be served. This is a novel and instructive trip and will be enjoyed by the ladies. The excursion will be timed so that afternoon blasting can be witnessed from the opposite side of the canyon.

FRIDAY, SEPTEMBER 10

8 A.M.

Excursion via automobile to Utah Power & Light Company's new 30,000-kw. hydro generating station at Cutler on lower Bear River. The trip will be over paved roads the greater part of the way, passing through the cities of Ogden and Brigham. Excursion will return to Salt Lake City in time to catch evening trains the same day.

8 A.M.

Excursion over celebrated Bear Lake-Bear River Development of the Utah Power & Light Company by automobile. This is a 400-mile trip and will require two days' time. Excursion will return to Salt Lake City Saturday evening. Comfortable hotel arrangements have been made for the night stop. Part of the trip is through wonderful mountain and canyon scenery and will be enjoyed as much for the scenic beauty as for the technical and educational benefits.

New York to Have Regional Meeting in November

A two-day Regional Meeting is planned to be held in New York City, November 11 and 12. There will be four principal technical subjects discussed; namely, secondary distribution networks, illumination, communication, and railroad electrification. A number of excellent papers on these topics has been promised. In addition to the papers, other interesting features will be arranged, including inspection trips, entertainment, etc.

The committee in charge of the meeting is as follows: Messrs. H. A. Kidder, Chairman; H. V. Bozell, Secretary; O. B. Blackwell, W. A. Del Mar, G. L. Knight, E. B. Meyer and G. H. Stickney.

Chemists in Convention September 6th

Foreign delegates to the coming convention of the American Chemical Society are beginning to arrive in New York preparatory to meeting with probably the largest contingent that has ever visited America in attendance at the convention to be held in Philadelphia, September 6th. Among these early arrivals are Sir James Colquhoun Irvine, principal of the Scottish University of St. Andrews and head of its department of chemistry, Fellow of the Royal Society, Davy Medalist in 1925, and an eminent investigator of carbonhydrates; Leonor Michaelis,* Professor of biological chemistry, University of Berlin; Professor Ernst Cohen, Physical Chemistry Dept., University of Utrecht; Dr. Camille Matignon, editor-in-chief of Chimie et Industrie and head of research laboratory in College de France; and Gabriel Bertrand, Professor of biological Chemistry at the Sorbonne, chief of the service of biological chemistry of the Pasteur Institute and internationally known as a devotee of research.

Denmark will send J. N. Bronsted, Professor of Physical Chemistry at the Royal Polytechnic Institute, Copenhagen. He is also author of several textbooks on inorganic and physical chemistry and famous in research work.

Switzerland will send Peter Debye, Professor of Theoretical Physics at Technische Hochschule, Zurich. Prof. Debye is the author of numerous researches in physical chemistry, and is the leading exponent of the theory of the electrical structure of matter as applied to the problems of specific heats, dielectrics, and X-ray analysis.

Heading the delegation from Italy will be Prince P. Ginori Conti, who will address the American Chemical Society at Philadelphia, Monday evening, September 6, on "The Development of Chemical Industry in Italy."

Nearly four thousand scientists are expected to attend the Philadelphia sessions, and hundreds of papers and addresses will be delivered.

Annual Convention of Civil Engineers in October

The fifty-sixth annual convention of the American Society of Civil Engineers will be held October 4-9, 1926, at Philadelphia, Pa. The fact that at this same time, the Sesquicentennial Exposition celebrating the 150th anniversary of the signing of the Declaration of Independence, will be in progress also at Philadelphia, will enhance the attractions of the Convention and permit of a program planned for participation in the spirit of the Exposition as well as in the pleasures and scientific progress of the Convention itself. A large attendance is expected.

*Biochemistry in the Aichi Medical University, Nagoya, Japan, and author of numerous research papers.

A. I. E. E. Directors' Meeting

The first meeting of the Board of Directors of the American Institute of Electrical Engineers of the administrative year beginning August 1, 1926, was held at Institute headquarters, New York, on Tuesday, August 10.

There were present: President C. C. Chesney, Pittsfield, Mass.; Vice-Presidents A. G. Pierce, Cleveland; W. P. Dobson, Toronto; H. M. Hobart, Schenectady; B. G. Jamieson, Chicago; Managers W. K. Vanderpoel, H. P. Charlesworth, H. A. Kidder, New York; M. M. Fowler, Chicago; E. C. Stone, F. J. Chesterman, Pittsburgh; H. C. Don Carlos, Toronto; National Treasurer G. A. Hamilton, Elizabeth, N. J.; National Secretary F. L. Hutchinson, New York. Present by invitation: Past-President William McClellan and Dr. C. H. Sharp, President, U. S. National Committee of the International Electrotechnical Commission.

The minutes of the Directors' meeting of June 23, 1926, were approved as previously circulated.

A report was presented of a meeting of the Board of Examiners held July 26, 1926, and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners the following actions were taken upon pending applications: 10 Students were ordered enrolled; 117 applicants were elected to the grade of Associate; 6 applicants were elected to the grade of Member; 2 applicants were transferred to the grade of Member; 1 applicant was transferred to the grade of Fellow.

Upon the recommendation of the Committee on Student Branches, authority was given for the organization of Student Branches of the Institute at Louisiana State University, Baton Rouge, La.; University of New Hampshire, Durham, N. H.; and Princeton University, Princeton, N. J.

Sections 46, 62, and 73 of the Institute by-laws were amended to read as follows:

"SEC. 46. The expenditures for transportation of Section delegates as referred to in the constitution shall be paid from the Institute treasury at the rate of ten cents (10c) per mile one way from the place of residence to the meeting place."

(This was done in order to place upon the uniform basis of ten cents per mile one way, the payment of traveling expenses of all delegates, officers, etc.)

"SEC. 62. The Board of Examiners shall consist of twelve Fellows of the Institute. The duties of this Board are defined in Section 44 of the constitution."

(To provide an increase in the number of members.)

"SEC. 73. The Committee on Award of Institute Prizes shall consist of the Chairman of the Meetings and Papers Committee acting as Chairman, and the chairmen of the Publication Committee, the Research Committee, and the chairmen of such other committees as the Board of Directors may designate."

(A change in personnel by the substitution of the chairman of the Research Committee for the chairman of the Committee on Power Transmission and Distribution.)

The Board approved plans for Regional Meetings, as follows: North Eastern District (No. 1), May 25-27, 1927, at a place to be decided by the District officers; Middle Eastern District (No. 2), April 14-16, 1927, at a place to be decided by the District officers; South West District (No. 7), February 14-15, 1927, Kansas City, Mo.

The appointment of committees, and of representatives of the Institute on various bodies, for the adminstrative year beginning August 1, 1926, was announced by President Chesney. (A list of these committees and representatives appears elsewhere in this issue.)

As required by the by-laws of the Edison Medal Committee, the Board confirmed the appointments by the President to the Edison Medal Committee, for the term of five years ending July 31, 1931, as follows: Messrs. John W. Howell, L. F. Morehouse, and David B. Rushmore; and the Board elected the following from its own membership to serve on this committee for the term of two years ending July 31, 1928: Messrs. B. G. Jamieson, H. A. Kidder, and G. L. Knight.

The following Local Honorary Secretaries were reappointed for the term of two years ending July 31, 1928: W. Eldson-Dew, for Transvaal; A. S. Garfield, for France; Carroll M. Mauseau, for Brazil; and F. W. Willis, for India.

A report was presented from a special committee appointed last year to consider the technical activites of the Institute, and upon the recommendation of that committee the Board adopted the following resolution:

"RESOLVED: That, effective with adoption of this resolution, the several Technical Committees shall assume a joint responsibility with the Standards Committee for the development and maintenance of such Institute Standards as come within their respective activities. Each technical committee shall report to the Committee on Standards such new standards or such changes in existing standards as are deemed desirable. Such recommendations shall be complete as to wording of any proposed standards. The Committee on Standards shall investigate and act on every such recommendation."

The Board approved a revision submitted by the Standards Committee, of Standards for Resistance Welding Apparatus (Section 39).

In acceptance of an invitation from the Committee of Award of the Kelvin Medal to nominate a candidate for consideration in the award of the 1926 Kelvin Medal, the Board voted that Sir Oliver Lodge be designated as the Institute's nominee.

The Secretary reported that the late Carl Hering had bequeathed to the A. I. E. E. and the Franklin Institute his books and professional apparatus, and that the matter had been referred to Director H. W. Craver of the Engineering Societies Library, who had arranged with the Franklin Institute for a division of this material.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

New Reports on A. I. E. E. Standards now Available

Three reports on proposed A. I. E. E. Standards are now available for purposes of criticism and suggestion before final adoption by the Institute. Copies may be obtained without charge by addressing H. E. Farrer, Secretary, A. I. E. E. Standards Committee, 33 West 39th Street, New York, N. Y. The reports referred to are as follows:

"Report on Lightning Arresters and Other Apparatus for Protection Against Abnormal Transient Voltages." This report was developed by a Working Committee of the Standards Committee under the chairmanship of F. L. Hunt, Chief Engineer, Turners Falls Power & Electric Company. This report covers service conditions, definitions, classification, rating, performance, earths and their resistances and dielectric tests for the following types of apparatus: Lightning arresters and diverters, lightning choke coils, high frequency absorbers, overhead grounded wires, earthing contacts and their resistances, length of connection between arresters and their earthing contacts or grounds.

"Report on Hard Drawn Aluminum Conductors." This report was developed by a Sectional Committee of the American Engineering Standards Committee under the sponsorship of the A. I. E. E. Mr. C. R. Harte, Construction Engineer, Connecticut Company, served as chairman.

"Report on Standards for Electrical Measuring Instruments." This report was prepared by a Working Committee of the Standards Committee under the chairmanship of G. A. Sawin, Westinghouse Electric & Manufacturing Company. The scope of the report is given as follows: Standards applying to the following kinds of indicating electrical instruments for direct current and alternating current; ammeters, voltmeters, wattmeters, reactive volt-ampere meters, frequency meters, power factor, reactive-factor and phase-angle meters, synchronoscopes.

Two New Swiss Standards Available

Standards for transformers not exceeding 500 volt-amperes and intended for interior installations. Special rules applying to transformers used in connection with bells, lock controls, and portable lamps, have been developed because of the conditions under which such apparatus is installed, often in damp inaccessible places and without intermediate circuit breakers.

Standards for insulated conductors for interior installations. The revision of the rules for erection and maintenance of interior installations has necessitated the working out of new standards for insulated conductors. To identify conductors that satisfy the new rules, a thread characterizing this quality has been introduced. Test methods are described in detail.

Both above standards may be obtained at office of General Secretary, Association Suisse des Electriciens, 301 Seefeldstrasse, Zurich, Switzerland.

American Engineering Standards Committee

A. E. S. YEAR BOOK FOR 1926

The 1926 edition of the American Engineering Standards Committee's Year Book is now ready for distribution and may be obtained by application to the secretary, P. G. Agnew, 29 West 39th Street, New York, N. Y. The Committee reports that the movement toward standardization of industrial products has shown marked progress during the past year, with over 200 definite standardization projects in process or completed, and with 365 national technical societies, government bureaus and trade associations collaborating through approximately 1600 representatives.

El Arte de los Metales

The Engineering Societies Library has to thank Mr. E. L. De Golyer, Vice-President of the Americau Institute of Mining and Metallurgical Engineers, for an unusually interesting addition to its collection of early engineering books. Mr. De Golyer's gift is a copy of the rare first edition of Albaro Alonzo Barba's "El Arto de los Metales," published at Madrid in 1640, the earliest work published on American metallurgy.

Barba was an Andalusian, born probably on November 5, 1561. He became a priest and prior to 1590 was sent to America. In 1615 we find him in Upper Peru (Bolivia), where he served various parishes for twenty-five years or more. He also became interested in mining, and in his book speaks of locating a vein of silver and erecting a mill. He claims to have discovered, in 1690, the method of pan amalgamation, and applied it successfully on a large scale.

His book is chiefly a detailed description of the metallurgical methods used in Peru, a topic on which his years of active work made him an authority. For many years it was in great demand, and French, German and Italian translations were published. In 1670 the Earl of Sandwich, then Ambassador Extraordinary of Great Britain, to Spain, published an English translation of the first two volumes of Barba's work, but his lack of technical knowledge made this of little value, and no adequate English translation appeared until 1923, when Messrs. Ross E. Douglass and E. P. Mathewson's translation was published in New York.

Copies of the first edition of the work are extremely scarce. Douglass and Mathewson state that they could locate but three copies, all of which were in the British Museum. Mr. De Golyer's copy is the fourth known here.

Among the various editions of Barba's book, another of special interest to Americans is one in German. This was published in 1763, at Ephrata, Pennsylvania. That the publication of a German translation, in Pennsylvania, over a century after the book was written, should appear a profitable publishing risk, is an evidence of the great esteem in which the work was held. The Engineering Societies Library is so fortunate as to possess a copy of this edition, in the original binding.

HARRISON W. CRAVER

Further Diesel Machinery Developments Sought

Plans to expedite experiments in dieselizing Shipping Board vessels were authorized by the Board on July 27th, according to official announcement made by T. V. O'Connor, Chairman, on the day following. Early arrangements will be made to work with William Francis Gibbs,—a nationally known marine engineer,—and others, for the purpose of making tests on vessels coming under control of the Board.

Coincident with this announcement, the American Marine Standards Committee held a meeting in New York City to discuss the care of diesel machinery. It is understood that the committee is working in cooperation with the Shipping Board, the Division of Simplified Practise of the Department of Commerce, and other interested government organizations.

Action Expected on Radio Measures

The radio bills known as the White Bill in the House and the Dill Bill in the Senate, both of which failed of enactment in the last session of Congress, are being sent to the members of the Conference Committee from both the House and Senate, and a meeting has been called for November in an effort to iron out the differences between these bills and to prepare a measure on which it is hoped both houses can agree early in the next session. In the meantime the Department of Commerce is continuing limited control of radio through the Bureau of Navigation. Technical problems concerning the development of the radio art from a scientific standpoint are centered in the radio laboratory of the Bureau of Standards.

Control of broadcasting through the licensing system has been relinquished but it is contemplated that the Department or the new commission will be able to bring these matters under control soon after the Law is enacted.

Civil Aviation Plans

Under the new civil aviation law, the Department of Commerce has taken jurisdiction over the lighting of postal airways, markings, and emergency landing facilities, and will take exclusive control of mapping of airways, charge of radio directional work, safety inspection of airplanes, licensing of pilots, and promote civil aviation generally.

This work will be under the immediate charge of William P. MacCracken, recently appointed Assistant Secretary of Commerce in Charge of Aviation under Secretary Hoover.

Divisions will be established in the Bureau of Lighthouses, Coast and Geodetic Survey and the Bureau of Standards to take up the highly specialized air development program. Under this arrangement, according to recent statements made by Secretary Hoover and Assistant Secretary MacCracken, early stimulation of civil aviation in the United States is confidently expected.

Study of Uses of Wood in Electrical Goods

A survey to determine the suitability of various grades of lumber for uses in the manufacture of electrical goods is to be made by L. N. Ericksen of the staff of the Forest Service's Forest Products Laboratory, as announced at the Department of Agriculture.

Deposits of Manganese Found

According to a statement just issued by the Geological Survey of the Department of the Interior, discovery of manganese ore deposits in the Olympic Mountain territory, State of Washington, lends color to the belief that other workable bodies of the ore will be found in that belt.

Manganese is used in the form of alloys in the production of steel and as a dioxide for the manufacture of dry-battery cells. The statement says that from preliminary figures it appears that in 1925 the new mines in Washington supplied approximately 11 per cent of the total high-grade metallurgical ore from domestic sources.

Developed Water Power in the United States

The Department of the Interior, through the Geological Survey, has just issued a report of the amount of developed water power in the United States as of January 1, 1926. This report shows that the capacity of water-wheels in plants of 100 h. p. or more on the first of this year was 11,176,596 h. p., an increase of 1,138,941 h. p., or about 11.5 per cent since March, 1925.

The total capacity in horse power of water-wheels in water-power plants in the United States for different years follows: 1908, 5,339,391 h. p.; 1921, 7,926,958 h. p.; 1924, 9.086,958 h. p.; 1925, 10,037,655 h. p.; 1926, 11,176,596 h. p. In the 17 years since 1908 the capacity of water-wheels in water-power plants has been more than doubled.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (JULY 1-31, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

BELT CONVEYORS AND BELT ELEVATORS.

By Frederic V. Hetzel. 2nd edit., revised. N. Y., John Wiley & Sons, 1926. 333 pp., tables, diagrs., charts, 9 x 5 in., cloth. $5.00.

The work of an engineer with thirty years of experience in the design and operation of elevators and conveyors, this book is intended as a practical guide to the selection and operation of suitable belt elevating and conveying machinery.

This edition has been revised to include the improvements of recent years, particularly in the design of idlers and elevator buckets.

THE BONBRIGHT SURVEY OF ELECTRIC POWER AND LIGHT COMPANIES OF THE UNITED STATES: arranged according to Geographic Divisions. 3rd edit., revised to May 1, 1926. N. Y., McGraw-Hill Pub. Co., 173 pp., tables, maps, 11 x 8 in., paper. $5.00.

A series of maps and tables which show the electric companies that serve the incorporated places having 2500 or more people, together with the unincorporated towns of that size in Massachusetts, Rhode Island and New Hampshire. The statistics for each state include the population, number of families, number of telephones, number of automobiles, number of domestic lighting customers, value of crops, number of factories and wage earners, value of products, the primary horse power, and the population of each urban center. Those for the companies include their capital stock, funded debt, gross and net earnings, interest, and the communities that they serve.

BRASS INDUSTRY IN THE UNITED STATES.

By William G. Lathrop. Mt. Carmel, Conn., The Author. 1926. 174 pp., port., 7 x 5 in., cloth. Price not quoted.

An interesting account of the beginning of this important industry and of its later development. The author traces the early industrial development of Connecticut, shows why brass manufacture became of interest in that locality, and traces the gradual development of the industry and of the important firms engaged in it.

COLLOID CHEMISTRY: Theoretical and Applied. Vol. 1. Theory and Methods.

By Jerome Alexander, editor, N. Y., Chemical Catalog Company, 1926. 974 pp., illus., diagrs., 9 x 6 in., cloth. $14.50.

In 1922, the editor of this work solicited the assistance of other investigators of the chemistry of colloid in the preparation of a comprehensive book on that subject. The first fruits of this collaboration are the present book, on theory and methods, which is to be followed by others on the biological, medical and technological applications of colloid chemistry.

Volume One contains sixty papers discussing a wide variety of subjects and representing many views on theoretical questions. No attempt has been made to select contributors whose ideas and opinions agree; but to give instead the views of those who are actively engaged in this work, and to leave to the reader the task of judging.

THE ENGINEER AND THE PREVENTION OF MALARIA.

By Henry Home. Lond., Chapman & Hall, 1926. 176 pp., illus., diagrs., 8 x 5 in., cloth. 13s 6d.

The author of this book, an engineer with experience of the problem in a number of tropical countries, has endeavored to summarize the results of modern research and its practical application to mosquito destruction for the benefit of other engineers.

The first section discusses the identification of the malaria carrier and the initiation of anti-malarial schemes. Drainage and malarial conditions in lowland country, in towns and in hill country is then taken up, followed by chapters on the details of preventive works, on the value of antimalarial works and on biological means of attack. Appendixes by other authors treat of mosquito netting, applied entomology and house flies.

GEOMETRY OF ENGINEERING DRAWING: Descriptive Geometry by the Direct Method.

By George J. Hood. N. Y., McGraw-Hill Book. Co., 1926. 290 pp., diagrs., 9 x 5 in., cloth. $2.50.

Presents a new method of teaching descriptive geometry, used by the author for the last six years. This method avoids the use of planes of projection, quadrants, etc., and directs attention to the object itself, in agreement with engineering practise.

HYDRAULICS.

By Joseph N. Le Conte. N. Y., McGraw-Hill Book Co., 1926. 348 pp., diagrs., tables, 9 x 6 in., cloth. $3.00.

A textbook on the theoretical principles of hydraulics, which directs the attention of the student to first principles for the solution of most problems, instead of to empirical rules or tables. The aim is to teach the student to reason out the basic equations

and to master the fundamentals of the subject first by the use of pure mathematics and mechanics.

LIGHTHOUSE SERVICE.

By George Weiss. Balt., Johns Hopkins Press, 1926. (Institute for Government Research. Service monograph no. 40). 158 pp., 9 x 6 in., cloth. $1.00.

A study of the organization, functions, equipment and cost of the Lighthouse Service, with a compilation of the laws governing it and a bibliography of sources of information about it. The book is descriptive, not critical; its purpose being to give officials, members of Congress and the public, an accurate account of the service in detail.

MATERIALS OF CONSTRUCTION: their Manufacture and Properties.

By Adelbert P. Mills. 3rd edit., edited by Harrison W. Hayward. N. Y., John Wiley & Sons, 1926. 419 pp., diagrs., charts, 9 x 5 in., cloth. $4.00.

A general text-book, somewhat elementary in character, on the manufacture, properties and uses of the more common materials. The endeavor has been to give a modern treatment in a form concise enough for class use by students of civil engineering. In this edition the text on the constitution of metals, alloy steels and alloys has been expanded, and the chapters on cement, concrete and timber have been revised.

METALLOGRAPHY AND HEAT TREATMENT OF IRON AND STEEL.

By Albert Sauveur. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 535 pp., illus., diagrs., table, 11 x 8 in., cloth. $8.00.

As might be expected after an interval of ten years, the third edition of this well-known textbook shows many changes from the second. About fifty pages of text have been added and the text has been rearranged. Much of the work has been rewritten, with the aim to make the book a satisfactory record of present views and of current practise.

ORGANIC SYNTHESES:

Edited by Henry Gilman and others. Vol. VI. N. Y., John Wiley & Sons, 1926. 120 pp., diagrs., 9 x 5 in., cloth. $1.50.

A collection of methods for the preparation of twenty-nine organic chemicals that are sometimes required by chemists and are not available commercially. These methods have been devised by various chemists and checked by others, to insure their practicability.

PRACTICAL COAL PRODUCTION: Mine Transportation and Market Preparation.

Compiled by Frank H. Kneeland. N. Y., McGraw-Hill Book Co., 1926. 354 pp., diagrs., 8 x 5 in., cloth. $3.00.

Covers the transfer of coal from the working face to the surface and its preparation for market. The compiler has selected the most approved methods from the literature on these topics and arranged the results of his investigations in a connected account.

LES PROGRES DE LA FONDERIE MOULAGE ET FUSION.

By C. Derulle. Paris, Masson & cie.; Gauthier Villars & cie, 1926. 256 pp., illus., diagrs., 8 x 5 in., paper. $0.88.

Not a treatise on foundry practise, but a review on broad lines of modern advances in founding and of the present state of the art. The author describes the methods of molding now in use, the furnaces, methods of casting and of finishing the castings. A chapter is devoted to foundry organization and cost-finding.

REFINING METALS ELECTRICALLY.

By Larry J. Barton. Cleveland, Penton Publ. Co., 1926. 414 pp., illus., tables, 9 x 6 in., cloth. $6.00.

A treatise on electric furnace practise in the foundry. The author discusses theoretical matters concisely, but devotes most attention to practical questions, such as the cost of electric melting, the choice of a furnace, preparing linings and making the various kinds of steel and iron. A selected bibliography is included.

WATER RATES AND STEAM CONSUMPTION OF MARINE MACHINERY.

By H. E. Brelsford and E. A. Stevens. N. Y., Simmons-Boardman Publ. Co., 1926. 169 pp., graphs, 8 x 5 in., cloth. $2.00.

The authors are respectively the Chief and the Senior Engineer of the Technical Section of the Emergency Fleet Corporation. While compiling standard performance curves for the ships of the Corporation they encountered great difficulty in establishing the fuel rates, which depend largely upon the water rates. A result of their experience is the present book, which presents a method for obtaining water rates and steam consumption with a reasonable degree of accuracy. The book discusses reciprocating engines, geared turbines and the auxiliary machines usual on ships. The necessary graphs and formulas are given and their use illustrated.

DIE WERKSTOFFE DES MASCHINENBAUES.

By A. Thum. Ber. & Lpz., Walter de Gruyter & Co., 1926. 2 v., illus., diagrs., 6 x 4 in., cloth. 1,50 r. m. each.

A textbook on the strength and properties of structural materials, written from the viewpoint of their use in mechanical engineering. The first volume discusses the qualities particularly needed in materials for machinery and the extent to which metals exhibit them. It also describes the methods of testing these qualities, and the varieties of iron and steel.

In Volume Two, the varieties of cast iron, structural steel, cast steel and non-ferrous alloys are described specifically, and the purposes for which each is suitable are mentioned. A chapter is devoted to such minor machine materials as wood, insulating materials, solders, etc.

PERSONAL MENTION

C. E. BURGOON has been appointed quarry manager of the Maule Ojus Rock Co., Ojus, Fla.

JACOB T. BARRON, formerly general superintendent of generation of the Public Service Electric and Gas Co., Newark, N. J., has been appointed general manager of the electric department of that company.

WILLIAM R. LYON, who has been in the System Operation Office of the Pennsylvania Power and Light Co. at Hazleton, Pa., recently resigned to go with the Products Protection Corporation of New Haven, Conn.

H. H. ROGGE has recently been selected by the Westinghouse Electric International Company to be special representative to the Philippine Islands. Mr. Rogge's territory will also include the Dutch East Indies, the Malay Peninsula, and Siam.

HERBERT S. SANDS, Vice-President of the A. I. E. E. for District No. 6 and manager of the industrial division of the Westinghouse Electric & Manufacturing Co. at Denver, has had the degree of Electrical Engineer conferred upon him by the University of Colorado.

HERMAN J. B. SCHARNBERG, formerly Chief Engineer of the Sugar Estates of Oriente, Inc., and Associated Companies, is now Chief Engineer of the Compania Azucarera Vertientes, Central Vertientes, Camaguey, Cuba. Mr. Scharnberg was elected a Life Fellow of the Royal Society of Arts last year.

IRVING E. BROOKE, formerly of Muir and Brooke, has opened an office at 1211 Security Bldg., 189 West Madison St., Chicago, for the practise of general engineering: design, supervision, investigation, and reports. He will specialize in power plants, heating, ventilating, plumbing and wiring systems, and mechanical equipment.

Obituary

Clifford Gray Linnell, born August 22, 1891, died July 2, 1926, after a short illness. Mr. Linnell joined the Institute in 1915. He was educated in the Brownville schools and later attended Clarkson College at Potsdam, N. Y. In 1913 he was given charge of the electrical and mechanical work for a large Massachusetts plant, but in 1915 joined the Aluminum Company of America, Massena, New York; he also spent some time with the Duquesne Light Company at Pittsburgh, Pa. In 1925 he resigned from the Duquesne Light Company to identify himself with the Westchester Lighting Company at Mount Vernon, New York, with which he was connected at the time of his death. He was chief of the Distribution Department, and valued for his diligent and capable service.

Henry Knox McIntyre, for seventeen years connected with the Electrical Department of the North Carolina State College,

and Professor of Electrical Application, died recently in the South. Professor McIntyre was a native of New York City,—born here April 25, 1877. He attended Lyon's Collegiate Institute and entered Columbia University, taking the regular four years' course in Electrical Engineering and obtaining his E. E. degree in 1899. He was first employed in the Testing Department of the Sprague Electric Co., of Bloomfield, N. J., but left them to enter the Engineering Department of the New York Telephone Company, where he did worthy work in their Research Department. One of the developments in which he assisted was the Gray Telautograph. Of recent years, he has been active in the development of electrometallurgical processes adaptable to the mineral resources of North Carolina. Professor McIntyre joined the Institute in 1902. He was a member, also, of the American Electrochemical Society.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary, at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance, and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—A. F. Buckley, 211 Sherman Ave., New York, N. Y.
2.—S. G. Guth, 419 Hampton Ave., Wilkinsburg, Pa.
3.—A. R. Henry, 20 St. Nicholas St., Montreal, Que., Can.
4.—M. E. Johnson, 133 Ardsley Road, Schenectady, N. Y.
5.—A. G. Corbin, 753 Crescent Ave., Buffalo, N. Y.
6.—D. F. McConnell, 402 N. Highland Ave., Pittsburgh, Pa.
7.—J. P. Ortiz, N. Y. Edison Co., 23rd St. & 4th Ave., New York, N. Y.
8.—I. T. Roberts, 2355 Prarie Ave., Evanston, Ill.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DISTRIBUTION ENGINEERS, technically trained and preferably with one or more years' experience with overhead or underground distribution or both. The work covers the engineering design, layout and estimate of costs of distribution systems, for a group of large power companies. Opportunity. Apply by letter with full particulars regarding past experience, salary wanted, date when available, and references. Location, Middlewest. X-453C.

GRADUATE ELECTRICAL ENGINEER, experienced in small electric motors, to establish sales department with company manufacturing electric appliances. Opportunity. Apply by letter with full details of age, past employment and salary, and lowest salary to start. Location, Middlewest. X-117.

ASSISTANT ELECTRICAL ENGINEER, 35-40, to take charge of drawing room. Experience in the design, construction and operation of power plant, substation and transmission line equipment. Switches and switchboard design experience essential. Married man preferred. Salary $3600-$4000. Apply by letter only. Headquarters, Philadelphia. X-584C.S.

ASSISTANT INSTRUCTOR in applied electricity and electrical machinery for large technical school. Apply by letter giving education, experience, age, religion and salary desired. Opportunity. Location, East. X-606.

MEN AVAILABLE

ELECTRICAL GRADUATE of class 21/22, 25 years of age, single, four years of practical electrical experience in installation, maintenance and repair, including testing of electrical systems, machinery and their operation. C-1115.

GRADUATE ELECTRICAL ENGINEER, 26, single, three years' experience in construction and operation of mine and mill electrifications, desires position with concern manufacturing mine electrical appliances. C-1714.

ENGINEER, who has had fourteen years' experience in electrical engineering is available. A position of maintenance engineer or switchboard design, layout and power circuits' engineer, or engineer in charge of factory equipment is desired. The fourteen years' experience takes in one year test course, two years drafting on switchboard, floor layouts, etc., three years as an assistant foreman on factory maintenance of testing equipment and eight years as engineer in charge of all testing equipment. All of the above time was spent with the General Electric Company, Schenectady, New York. C-1649.

ASSISTANT TO VICE PRESIDENT of large, progressive electric utility company desires position of increased responsibility. Graduate electrical engineer with fifteen years' design, operating, executive training in public utility work, including three years with well known consulting firm. Present duties consist of acting as engineering consultant to vice president and handling capital improvement program, including engineering, job scheduling, budget control, miscellaneous management problems. B-754.

ELECTRICAL ENGINEER, 1926 graduate Colorado, 30, married, desires position with public utility or electrical contracting company. Nominal salary. Location preferred, West or Middlewest. C-1746.

PROFESSOR ELECTRICAL ENGINEERING, ten years of teaching experience covering all the regular and many specialized electrical courses. Contact with the industry has been broad and covers design, construction and application. Well acquainted with the educational needs of the engineering profession. Change desired because present position does not encourage research. B-7083.

MECHANICAL-ELECTRICAL GRADUATE ENGINEER, 25, single, extensive training with Westinghouse people and General Electric Com-

pany, Schenectady, New York, desires permanent position in locality of Boston with manufacturing concern or power plant, preferably in connection with generators and transmissions. Available on reasonable notice. C-1740.

MECHANICAL ELECTRICAL ENGINEER, married, eighteen years' experience covering General Electric test, substation and power station design and operation for steel and wire mills, electrical cable manufacturing and sales. Executive and industrial development ability. A-4652.

YOUNG UNIVERSITY PROFESSOR desires research laboratory position. Degrees E. E. and M. E. E. Nine months' experience in research laboratory of automotive equipment electrical company, four and one-half years' teaching experience in electrical engineering department. Has attended teachers' summer conference with Westinghouse. 31, married. C-1037.

INVESTIGATIONS, 40, single. Experienced engineer desires investigational work, preferably of electrical and mechanical laboratory research or development type. Ability tested in many ways. Reports on problems requiring originality and resourcefulness, and the supervision of others, most satisfactory. Location preferred, Middlewest. B-6273.

ELECTRICAL ENGINEER, technical graduate, married, twenty years' experience, ten with construction and public utility companies on design, construction and economic investigations of central, substation and factory installations, desires position with industrial plant, public utility or construction company. C-581.

ELECTRICAL ENGINEER, 28, single, with technical education. Five years' general electrical work, two years as assistant production manager in a manufacturing plant. Desires position in production or similar work where there is an opportunity to advance. Vicinity of New York preferred. Available immediately. B-8056.

PRODUCTION ENGINEER, A. I. E. E., 30, married, Engineering and Arts graduate; qualified by experience for Production Schedule, Budget or Valuation Engineering; 5 years Utility, four years' Industrial experience; prefer Managerial to strictly technical. Available Oct. 15, 1926. B-9676.

ELECTRICAL ENGINEER, . B. and M. S. degrees, 27, single. Experience—G. E. test course and three years with Transmission and Distribution Department of a large utility. Especially familiar with cables, transformers and distribution network problems. Connection with another utility or consulting firm on engineering and economic problems desired. Location preferred, south or east. C-1750.

UNIVERSITY GRADUATE, (1916), 35, single, Electrical and Mechanical Engineering, all-round experience, one year illumination tests, four years drafting and designing, especially automatic machinery; two years writing of technical reports and patent disclosures with patent drafting, mathematical computations. Besides English, speaks and writes three other languages. B-7214.

EXECUTIVE ELECTRICAL ENGINEER, 27, married, educated Canterbury College, now located with a prominent firm in New Zealand, handling all classes of Electrical plant, including heavy machinery and also household appliances, would like a change to U. S. A. Been accustomed to buying and price-fixing and also acting in a consulting capacity to clients requiring plant. Considerable experience in Public tendering. Available on short notice. Prepared to start at anything offering good chances of advancement. Would prefer West coast location. C-1763

FACTORY MANAGER OR ENGINEERING EXECUTIVE, 37, Technical Graduate 1911. Balanced experience in necessary branches leading to management includes shop apprenticeship, general engineering, production and management. Successful record shows cost reductions and abilities in analysis, invention, vision, and judgment. Fullest investigation of record and references invited. C-1776.

ELECTRICAL ENGINEER AND EXECUTIVE, 35, Married, 16 years' experience in operation, engineering and design of electrical apparatus. Has accomplished complicated design work. Has handled a large number of men. Desires position with manufacturing company as representative, sales engineer or responsible executive position. Has New York State Professional Engineer's license. C-1579.

COMMERCIAL ENGINEER, technical graduate, seven to eight years' experience in the public utility business on power and lighting sales, rates, engineering and operation. Desires connection with holding or management company of public utilities or with power company. Age 32, excellent health. Available on reasonable notice. B-9782.

ELECTRICAL & MECHANICAL ENGINEER, 24, single, graduate of Cornell, two years' experience in electrical plant, doing A. C. & D. C. assembly work, A. C. design, foundry work in connection with elevators, desires position, not particular about hours, work or location, would like position with plenty of work and good future, min. salary $160 a month. C-1769.

ELECTRICAL DESIGNER, 30, single, technical graduate, three years' practical experience in power station operation and factory, six years design electrical machinery and transformers, power and substations. Desires position with electrical manufacturing concern or power company offering opportunities for advancement. Available after two weeks' notice. Location, anywhere. C-10.

ELECTRICAL ENGINEER, 34, married, twelve years' experience in the design and operation of generating stations, substations, and transmission systems, eight years with large public utility, and four with industrial corporations. Recent extensive experience on automatic substations and supervisory control. Available in one month. Location, any, but North Central States preferred. C-635.

RECENT GRADUATE IN ELECTRICAL ENGINEERING, desires opportunity for foreign service. Testing and research experience. Position need not be strictly technical. Available within reasonable notice. C-348.

GENERAL EXECUTIVE, 43, married, mechanical and electrical engineer; five years manufacturing and engineering; ten years' commercial, five years' financial experience. Three years in charge of industrial re-organizations for large financial institution; keen analyst; good organizer. Available at once. A-4098.

ENGINEER, age 30, single, graduate E. E. with 7 years' experience in design and construction of Central stations, substations, and industrial Plants; also, distribution, overhead and underground. Available immediately. Location, immaterial. B-4662.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED AUGUST 10, 1926

AIYANGAR, SRINIVASA RAJAGOPALA, Managing Engineer, Sri Brahmavidyambal Electric Supply Corp., Ltd., Ramachandrapuram, Trichinopoly Dist., S. India.

ALLEN, ROBERT LIVINGSTON, Chief Engineer, Archbold-Brady Co., Greeneway Ave., Syracuse, N. Y.

ANDERSON, CLARE, Miscellaneous Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

BAECKLER, WALTER, Electrical Engineer, National Carbon Co., Inc., West 117th St. & Madison Ave., Lakewood, Ohio.

BANKS, HAMPDEN OSBORNE, Electrical Inspector, Hartford Steam Boiler Inspection & Insurance Co., 80 Maiden Lane, New York, N. Y.

BARSE, JAMES HARPER, Elec. Draftsman, Engg. Dept., McKinney Steel Co., 3100 E. 45th St., Cleveland, Ohio.

BECKER, HUBERT, Jr., Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

BENNETT, R. S., Sales & Engineering, General Electric Co., 215 W. 3rd St., Cincinnati, Ohio.

BHUSARI, VASUDEO GANESH, Lecturer, V. J. Technical Institute, Matunga, Bombay, India.

*BLAKE, FRANK JEROME, Engineer, Outside Distribution Properties, Public Service Co. of Colorado, Gas & Elec. Bldg., Denver, Colo.

BOWEN, WILLIAM EARL, Asst. Valuation Engineer, Great Western Power Co., 375 Sutter St., San Francisco; res., Oakland, Calif.

BRAMBLETT, PAUL FRANCIS, Division Foreman, Northwestern Light & Power Co., Sibley, Iowa.

BRANSON, ALBERT KEMPER, Operator, Great Western Power Co. of California, 8425 Foothill Blvd., Oakland; for mail, Caribou, Plumas Co., Calif.

BROCKETT, NORWOOD W., Director of Public Relations, Puget Sound Power & Light Co., 860 Stuart Bldg., Seattle, Wash.

BURROW, PERCY, Supt. of Power Plant, Puget Sound Power & Light Co., Dryden, Wash.

BUTOW, F. W. C., Foreman, Electric Dept., Pacific Coast Steel Co., South San Francisco; res., San Bruno, Calif.

BUTTERWORTH, RUSSELL IRVIN, General Supt., Bristol Gas & Electric Co., Bristol, Tenn.

CAPRIN, VLADIMIR I., Electrification Dept., Illinois Central Railroad, Chicago, Ill.

CARRASCO-ZANINI, JUAN, Electrical Engineer, Mexican Light & Power Co., Donceles No. 80, Mexico, D. F., Mex.

CECCHETTI, FELIX, Testing Dept., General Electric Co., Erie Blvd., Schenectady, N. Y.

CHANG, ZUNG ZUE, Engineer, Engg. Dept., Westinghouse Elec. & Mfg. Co., Sharon, Pa.

CUNNINGHAM, KENNETH GEORGE, Trunk Engineer, Ohio Bell Telephone Co., 5300 Prospect Ave., Cleveland, Ohio.

CURTIS, HERBERT CRICHTON, Development Dept., Cutler-Hammer Mfg. Co., Milwaukee, Wis.

de LIMA, CLARENCE A., Radio Engineer, Westinghouse Electric International Co., Mexico D. F., Mex.

de MULINEN, EGBERT F. H., Electrical Engineer, American Brown Boveri Electric Corp., Camden; res., Haddon Heights, N. J.

DENNIS, EARLE M., Electrical Engineer, Bloedel Donovan Lumber Mills, Bellingham, Wash.

DICKINSON, ROBERT BIGLAND, Electrical Engineer, Engg. Dept., Duke Price Power Co., Ltd., Isle Maligne, Lake St. John, P. Q., Can.
DITESHEIM, GASTON J., Manager, Movado Co., 516 5th Ave., New York, N. Y.
DONALDSON, LESLIE JAMES, Asst. Engineer, Brown Boveri & Co., Ltd., Baden, Switzerland; for mail, Sydney, N. S. W., Aust.
DONOVAN, WALTER, Electrical Engineer, General Electric Co., Ltd., 6801 Glenwood Ave., Philadelphia, Pa.
DRAKE, RUSSEL ALONZO, Electrician's Mate, (3rd class), U. S. Navy, U. S. S. Arizona, San Francisco, Calif.
DUNKELBERG, PAUL R., Computor, Illinois Central Railroad Co., 109 E. Roosevelt Road, Chicago, Ill.
ENTEE, FRAMROZE DHUNJISHAW, Electrical Engineer, Century Mills, Parel, Bombay, India.
ESTRADA, JOSE FLORES, Asst. Electrical Engineer, Havana Central Railroad Co., Estacion Central, Havana, Cuba.
FOGG, LEIGH E., Cable Engineer, American Electrical Works, Phillipsdale, R. I.
GATTIKER, CARL H., Asst. Supt. of Construction, The New York Edison Co., 130 East 15th St., New York, N. Y.
GEARY, STEPHEN JOSEPH, Mains Supt., Municipal Electricity Dept., Christchurch, N. Z.
GILBERT, C. F., Chief Draftsman, Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
GILROY, JOHN R., Switchboard Operator, Commonwealth Edison Co., 25th & Quarry Sts., Chicago, Ill.
GRAY, WILBUR S., Draftsman, Stone & Webster, Inc., 147 Milk St., Boston, Mass.
GRONVOLD, INGVALD JULIAN, Electrician, Neil Electric Co., Isleton, Calif.
HAENTJENS, OTTO, President, Barrett, Haetjens & Co., Hazleton, Pa.
*HAMMOND, ROBERT JAMES, Supervising Engineer, The Pacific Tel. & Tel. Co., 1900 S. Grand, Los Angeles, Calif.
*HASTINGS, DONALD FRANCIS, Tester, Rossiter, Tyler & McDonell, 136 Liberty St., New York, N. Y.
HEINTZ, WILLIAM THEODOR, Sales Engineer, Automatic Electric Co., 427 Bourse Bldg., Philadelphia, Pa.
HEMSLEY, SYDNEY HENRICK, Power Transformer Designer, Messrs. Ferranti, Ltd., Hollinwood; for mail, Oldham, Lancashire, Eng.
HERNE, WALLACE WENDELL, Asst. Valuation Engineer, Great Western Power Co., San Francisco, Calif.
HILDEBRANDT, JOHN LAWRENCE, Research & Test Dept., Consolidated Gas, Electric Light & Power Co., Baltimore; res., Catonsville, Md.
HUDD, ALFRED ERNEST, Consulting Engineer, Automatic Electric Inc., 1033 W. Van Buren St., Chicago, Ill.
*HUMPHRIES, POWELL HORNER, Asst. in Elec. Engg. Dept., Harvard University, Pierce Hall, Cambridge; res., West Roxbury, Boston 32, Mass.
IRWIN, JAMES E., Elec. Constr. Foreman, Chile Exploration Co., Chuquicamata, Chile, So. Amer.
ISCHINGER, ALFRED ERNST, In charge of Engg. Dept., Joshua R. H. Potts, 929 Chestnut St., Philadelphia, Pa.
JAYNE, JOHN KENNON, Electric Representative, Autocar Co., 930 Bedford Ave., Brooklyn; res., New York, N. Y.
KEEFER, JOHN, Electrician, Pacific Coast Steel Co., South San Francisco, Calif.
KOHLHEPP, WILLIAM SAMUEL, Equipment Engineer, Cumberland Tel. & Tel. Co., Louisville, Ky.
LARKIN, JOHN J., Supt. of Signals, Brooklyn-Manhattan Transit Corp., 85 Clinton St., Brooklyn; res., Jamaica, N. Y.
LEON, CONSTANTINE, Jr., Electrical Engineer, Dept. of Electricity, Havana Central Railroad Co., Estacion Central, Havana, Cuba.
LESSING, OTTO, Cadet Engineer, Counties Gas & Electric Co., Penn & Markley Sts., Norristown, Pa.
LYDON, REGINALD JAMES BUNDY, Senior Instructor, Elec. Engg. Branch, Central Technical College, Brisbane, Queensland, Aust.
MacKAY, ALBERT TUTTLE, Inspector, Western Electric Co., 379 Summer St., Boston; res., Roslindale, Mass.
MacCORMICK, CHARLES M. C., Student Engineer, General Electric Co., Schenectady, N. Y.
*MADER, CLARENCE EDWARD, Student, Lewis Institute, 7704 Crandon Ave., Chicago, Ill.
MAHNKE, KURT, Draftsman, Pennsylvania Power & Light Co., 324 West St., Williamsport, Pa.
MAHONEY, JAMES FRANCIS, General Foreman, Brooklyn Edison Co., 14 Rockwell Place, Brooklyn, N. Y.
MARQUARDT, MAX, Electrician, 316 Rutherford Blvd., Passaic, N. J.
MARTINOV, VLADIMIR, Manager, Central & Substation Dept., State Electrotechnical Trust, 56 Prosp. of Oct. 25th, Leningrad, Russia.
MENDENHALL, WALKER HAMILTON, Asst. Engineer, Relay Dept., West Penn Power Co., 14 Wood St., Pittsburgh, Pa.
MERRITT, DAVID FRANKLIN, Electrical Mechanic, Famous Players Lasky Co., 1520 Vine St., Hollywood; res., Sherman, Calif.
METCALF, JAMES IRWIN, Reports Dept., Day & Zimmermann, Inc., 1600 Walnut St., Philadelphia, Pa., res., Bronxville, N. Y.
MILLER, NORBERT O. C., Owner, Schwall Electric Works, 429 E. Channel St., Stockton, Calif.
MOITINHO, RUBEN, Electrical Engineer-Government Inspector, Electrical Public Services; Secretaria Geral do Estado do Rio de Janeiro, Nictheroy, Brazil, So. America.
NAKAMURA, HIROSHI, Asst. Electrical Engineer, Toho Electric Power Co., Kaijo Bldg., Tokjo, Japan; for mail, Wilkinsburg, Pa.
PALLONJI, D., Managing Engineer & Proprietor, Marine Electrical Engineering Works, Examiner Press Bldg., Dalal St., Fort Bombay, India.
PALM, I. ROBERT, Squad Man, Sargent & Lundy, 1407 Edison Bldg., Chicago, Ill.
PATRICK, RICHARD A., Electrical Mechanic, Truckee River Power Co., 21 Front St., Reno, Nev.
PINCKERT, WALTER F., Draftsman, Pacific Gas & Electric Co., San Francisco, Calif.
POUGY, ADHERBAL M., Chief Electrical Engineer, Cia Docas de Santos, Seccao Electrica, Santos, Brazil, So. Amer.
RAYMENT, EDWARD GEORGE, Foreman, Bethlehem Steel Co., Dock Central, La Plata, Arg. Rep., S. Amer.
REID, ALEXANDER, Production Engineer, Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
REID, MATTHEW, Resident Electrical Engineer, St. George County Council, Kogarah, Sydney, N. S. W., Aust.
ROGERS, FREDERICK HELME, Student Apprentice, Elec. Div., Consolidated Gas, Electric Light & Power Co., Baltimore, Md.
ROSADO, ANTONIO, Asst. Electrical Engineer, Havana Electric Railway, Light & Power Co., Monto No. 1, Habana, Cuba.
RUDORFF, DAGOBERT WILLIAM, Mechanical Asst. Engineer, Mexican Light & Power Co., Ltd., Necaxa, Puebla, Mex.
SANCHEZ, URBANO C., Supt., Distribution & Meter Dept., Compania de Electricidad de Merida, Yucatan, Mex.
SCHARF, PAUL BERNARD, Instructor, Mathematics & Science Dept., Goodyear Industrial University, Akron, Ohio.
SCHIFREEN, CLEMENT S., Electrical Designer, Philadelphia Electric Co., 1035 Chestnut St., Philadelphia, Pa.
SCHLEGEL, ROY DAVIS, Asst. Supt., Conduit Div., Potomac Electric Power Co., 213 14th St., N. W., Washington, D. C.
SHARROCK, LEWIS LEE, Electrical Draftsman, St. Lawrence County Utilities, Inc. Potsdam, N. Y.
SKELTON, WILLIAM JOSEPH, Supervisor, Wisconsin Telephone Co., 1401 Clybourn St., Milwaukee, Wis.
SKINNER, ROBERT W., Construction Dept., Louisville Gas & Electric Co., Louisville, Ky.
STAGGS, NEWMAN K., Telephone Engineer & Contractor, The Telephone Engineering & Equipment Co., 216 Douglas Bldg., Seattle, Wash.
STEEL, EDWARD T., District Manager, Puget Sound Power & Light Co., Bremerton, Wash.
STEINMETZ, WILLIAM CLYDE, Supervisor, Telephone & Telegraph, The Alaska Railroad, Anchorage, Alaska.
SWANSON, EARL R., Division Engineer, Wisconsin Power & Light Co., Fond du Lac, Wis.
SYLVESTER, FRANK EDWIN, Supt., Substations, Great Western Power Co., 3729 Park Blvd., Oakland; res., Alameda, Calif.
TANDBERG, LEONARD G., Salesman, Wagner Electric Corp., 318 W. 15th St., Los Angeles, Calif.
TAYLOR, FRANK WARBURTON, Transformer Designer, Ferranti, Ltd., Hollinwood; res., Oldham, Lancashire, Eng.
TERHUNE, WALLACE IRVING, Engineering Assistant, Public Service Production Co., 80 Park Place, Newark, N. J.
THOMPSON, EUGENE PERCIVAL, Chief Electrical Engineer, St. George County Council, Kogarah, Sydney, Aust.
TILLQUIST, DAVID, Powerman, New York Telephone Co., 230 W. 36th St., New York, N. Y.
TORRES, SALVADOR EVARISTO, Foreman, Electrical Dept., Transcontinental Petroleum Co., La Barra Refinery, Tampico, Mexico.
VAN ETTEN, FRANK C., Manufacturers' Representative, 600 Joyce Realty Bldg., Columbus, Ohio; res., Chicago, Ill.
VAN WHY, FORBES WILLIAM, Radio Engineer-in-charge, Pasadena Star-News, 525 E. Colorado St., Pasadena, Calif.
VARLEY, HARRY, Managing Director, The Electric Motor & Stove Hiring Co., Ltd., Sweet St., Leeds, Yorkshire, Eng.
VONSOVICH, LEO J., Junior Engineer, Valuation Dept., Great Western Power Co. of California, Berkeley, Calif.
WALSH, FRANK, Supt. of Power, N. E. Dist., Puget Sound Power & Light Co., 3030 Colby St., Everett, Wash.
WARREN, PICKETT L., Salesman, Ohio Brass Co., 1714 Fisher Bldg., Chicago, Ill.
WATSON, STEWART CLARK, Switchboard Engineer, Switchboard Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
WATTS, WILLIAM EWART GLADSTONE, Elec. Engineer in charge of Colliery Elec. Plant, Luscar Collieries, Luscar via Edmonton, Alta., Can.
WAY, ROBERT S., Power Engineer, Worcester Suburban Electric Co., Main St., Uxbridge, Mass.
WEAVER, R. A., Plant Engineer, Cincinnati & Suburban Bell Telephone Co., 225 E. 40th St., Cincinnati, Ohio.
WELLS, DONALD V., Division Manager, Northwestern Light & Power Co., Sibley, Iowa.

WHISENAND, OMER BURTON, Chief Electrician, Citizens Gas Co., 47 S. Pennsylvania St., Indianapolis, Ind.

WOLLEBAK, THOR, Designing Engineer, Delta Star Electric Co., 2433 Fulton St., Chicago, Ill.

Total 114

*Formerly Enrolled Students.

ASSOCIATES REELECTED AUGUST 10, 1926

BOYERE, EMERY E., Electrical Specialist, Small Motor Applications, 708 State St., Erie, Pa.

REHWALDT, ARTHUR W., Electrical Engineer, Sargent & Lundy, 72 W. Adams St., Chicago, Ill.

STOTLER, EDWIN JOHN, Elec. Engg., Sears, Roebuck & Co., 11 Astor St., Newark, N. J.; for mail, Chicago, Ill.

MEMBERS ELECTED AUGUST 10, 1926

BUTLER, M. BAYORD, Jr., Electrical Engineer, American Chain Co., Bridgeport; res. Waterbury, Conn.

JONES, REGINALD ELSDON, Asst. Engineer, Elec. Engg. Dept., Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont., Can.

SCHUMAN, JOSEPH HENRY, Engineer, Construction Bureau, The Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston, Mass.

THOMPSON, CHARLES SCOTT, Consulting Engineer, 1207 Medical Arts Bldg., Oklahoma City, Okla.

WESTBYE, JOHN, Designer, Gibbs & Hill, Pennsylvania Station, New York; res., Brooklyn, N. Y.

WHITE, WILLIAM COLLINS, Div. Transmission Engineer, Cumberland Tel. & Tel. Co., Louisville, Ky.

TRANSFERRED TO GRADE OF FELLOW AUGUST 10, 1926

McQUARRIE, JAMES L., Chief Engineer, International Standard Electric Corp., London, England.

TRANSFERRED TO GRADE OF MEMBER AUGUST 10, 1926

NORRIS, ERIC D. T., Technical Electrical Engineer, Ferranti Ltd., Hollinwood, Lancashire, England.

THOMAS, HERBERT P., Chief Engineer, Southland Electric Power Board, Invercargill, N. Z.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held July 26, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Member

ANDREWS, HARDAGE L., Assistant Engineer, Railway Engineering Dept., General Electric Co., Schenectady, N. Y.

ANDREWS, JOSEPH F., American Tel. & Tel. Co., New York, N. Y.

AUTY, CLARENCE, Assistant Electrical Engineer, C. H. Tenney & Co., Boston, Mass.

BALE, LAWRENCE D., Supt. of Power, Cleveland Railway Co., Cleveland, Ohio.

BATES, LOUIS I., Engineer of Electric Distribution, Bronx Gas & Electric Co., New York, N. Y.

BENTON, JOHN R., Professor of Physics and Electrical Engineering, University of Florida, Gainesville, Fla.

BETTANNIER, EUGENE L., Electrical Engineer, Municipal Light & Power Department, Pasadena, Calif.

BOWMAN, HAROLD L., Service Engineer, Westinghouse Electric & Mfg. Co., New York, N. Y.

BROWN, HUGH A., Assistant Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

CAVE, JOSEPH, Electrical Superintendent, Canadian General Electric Co., Toronto, Ont.

DREW, ERNEST C., Assistant Engineer, Bell Tel. Co. of Pennsylvania, Philadelphia, Pa.

DUBOSE, McNEELY, Electrical Superintendent, Aluminum Co. of Canada, Ltd., Arvida, Que.

FISHEL, ANTHONY D., Sales and Electrical Engineer, A. D. Fishel Co., Cleveland, Ohio.

FROM, OWEN C., Telephone Systems Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

GILLILAN, P. M., Railway Engineer, General Electric Co., Schenectady, N. Y.

GRAY, ROBERT, L., Electrical Engineer, Tararua Electric Power Board, Eketahuna, New Zealand.

HAMILTON, HAROLD C., Asst. Supt., Standardizing & Testing Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.

HART, R. PHILIP, Manager, Cazenovia Electric and Cazenovia Tel. Corp., Cazenovia, N. Y.

HENLINE, HENRY H., Associate Professor of Electrical Engineering, Stanford University, Stanford University, Calif.

HIGHT, WILLIAM R., Assistant Compass Engineer, Sperry Gyroscope Co., Brooklyn, N. Y.

JOHNSON, FRANCIS E., Professor of Electrical Engineering, University of Kansas, Lawrence, Kans.

KONGSTED, L. P., Research Engineer, American Bosch Magneto Corp., Springfield, Mass.

KURTZ, EDWIN, Professor and Head, Dept. of Electrical Engineering, Oklahoma A. & M. College, Stillwater, Okla.

LaROQUE, HAROLD B., Switchboard Engineering Dept., General Electric Co., Schenectady, N. Y.

McMILLAN, FRED O., Associate Professor of Electrical Engineering, Oregon State Agricultural College, Corvallis, Ore.

MICHENER, HAROLD, Asst. to Executive Engineer, Southern California Edison Co., Los Angeles, Calif.

MILLER, JOHN H., Chief Electrical Engineer, Jewell Electrical Instrument Co., Chicago, Ill.

MONG, CLIFFORD E., Engineer, Pacific Tel. & Tel. Co., Seattle, Wash.

MONROE, WENDELL P., Assistant Engineer, Illinois Central Railroad, Chicago, Ill.

MORROW, ALLEN, Department Head, Power Department, Standard Oil Co. of California, Richmond, Calif.

NETHERCUT, DONALD W., Distribution Supt., Ohio Public Service Co., Sandusky, Ohio.

NYMAN, ALEXANDER, Director, Radio Patents Corp., New York, N. Y.

O'NEAL, J. P., Westinghouse Electric & Mfg. Co., Sharon, Pa.

PACKARD, ANSEL A., Division Manager, Connecticut Power Co., Middletown, Conn.

PETERS, LEO J., Asst. Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.

POTTS, LOUIS M., Electrical Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

READ, WALTER V., Telephone Engineer, American Tel & Tel. Co., New York, N. Y.

RODEY, BERNARD S., Jr., Engineer Accountant, United Electric Light & Power Co., New York, N. Y.

RYAN, FRANCIS M., Radio Engineer, Bell Tel. Laboratories, Inc., New York, N. Y.

SCHENCK, CHESTER, Materials Engineer, Elec. Engg. Dept., Commonwealth Power Corp., Jackson, Mich.

SHACKELFORD, BENJAMIN E., Chief Physicist, Westinghouse Lamp Co., Bloomfield, N. J.

THOMAS, RALPH L., Asst. to General Superintendent, Pennsylvania Water & Power Co., Baltimore, Md.

WORRALL, ROBERT H., Radio Engineer, U. S. Naval Research Laboratory, Bellevue, D. C.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1926.

Atkins, G. E., New England Tel & Tel Co., Boston, Mass.; for mail, New York, N. Y.

Atkinson, C. S., Shawinigan Water & Power Co., Montreal, P. Q., Can.

Bradt, A. W., (Member), Hamilton Hydro Electric System, Hamilton, Ont., Can.

Brandt, R., General Electric Co., Schenectady, N. Y.

Briggs, M. J., Stone & Webster, Tampa, Fla.

Brown, W. W., (Member), General Electric Co., Schenectady N. Y.

Campbell, I. S., Ohio Northern University, Ada, Ohio

Carter, T. E., Florida Power & Light Co., Miami, Fla.

Cosgrove, J. M., The Meaker Co., Chicago, Ill.

Cullwick, E. G., Canadian General Electric Co., Peterboro, Ont., Can.

Daniels, C. C., The Montana Power Co., Columbus, Mont.

de la Macorra, Jr., J., San Rafael Paper Co., Mexico City, Mex.

Duré, H. J. Edison Elec. Ill. Co. of Boston, Roxbury, Mass.

Finigan, W., Supt., Federal Trust & Clinton Bldg., Newark, N. J.

Fitzgerald, E. B., 28 Meridian St., Greenfield, Mass.

Foley, J. R., Appalachian Electric Power Co., Roanoke, Va.

Gatternigg, R., (Member), Pacific Portland Cement Cons. Co., Cement, Calif.

Gaylord, C. E., New York Telephone Co., Buffalo, N. Y.

Hall, H. M., American Copper Products Corp., New York, N. Y.
(Applicant for re-election.)

Huffman, G. A., New England Tel & Tel. Co., Boston, Mass.

Kempf, R. E., Pacific Oil & Lead Works, San Francisco, Calif.

Lucro, E. N., Public Service Production Co., Newark, N. J.

Lundgreen, S. O. G., General Electric Co., West Philadelphia, Pa.

Maiman, A., 2946 California St., San Francisco, Calif.

Max, C., Central Railroad Co. of New Jersey, Elizabethport, N. J.

Mayor, R., Jr., General Electric Co., Havana, Cuba

McLean, M. M. M., General Electric Co., West Lynn, Mass.

Miller, W. C., (Member), The Detroit Edison Co., Detroit, Mich.

Remaly, C. E., The R. Thomas & Sons Co., East Liverpool, Ohio

Remington, H. N., International Creosoting & Construction Co., Chicago, Ill.

Rienstra, A. R., Bell Telephone Laboratories, Inc., New York, N. Y.

Scanavino, S. A., Pacific Gas & Electric Co., San Francisco, Calif.

Schuler, Charles E., Asst. Chief Engineer, Elec. Dept., International Derrick & Equipment Co., Michigan & Buttles Aves., Columbus, Ohio

Stockwell, H. L., Tampa Electric Co., Tampa, Fla.

Storm, S. B., Marine Electric Co., Louisville, Ky.

Tefft, W. W., (Member), Commonwealth Power Corp., Jackson, Mich.
Wagner, H. H., Automatic Electric Co., Inc., Chicago, Ill.
Weissman, L. Hudson & Manhattan R. R. Co., New York, N. Y.
Wilson, H. R., Philadelphia Electric Co., Philadelphia, Pa.
Zuckerman, H., Wholesale Radio Equipment Co., New York, N. Y.
Total 40.

Foreign

Braudé, A. N., India Rubber Gutta-Percha & Telegraph Works Co., Ltd., London, Eng.
Campbell, F. W., Nottingham Corp., Nottingham, Eng.
Orbell, R. J., Thames Valley Power Board, Te Aroha, N. Z.
Peterson, A. W., Porto Rico Tel. Co., San Juan, Porto Rico
Poyitt, D. G., Municipal Council of Sydney, Sydney, N. S. W., Aust.
Stowers-Crowley, C. M. (Member), Opunake Elec. Pr. Board, Opunake, N. Z.
Sutherland, K., State Electricity Comm. of Victoria, Melbourne, Aust.
Total 7.

STUDENTS ENROLLED

Buckley, Chester F. Mass. Institute of Tech.
Feldman, Nikola, University of Latvia
Fluskey, Robert J., New York University
Gordon, Nathan B., Northeastern University
Lissner, Earle D., Massachusetts Inst. of Tech.
MacDonald, Hugh C., Northeastern University
Roake, Wilber C., Stevens Inst. of Tech.
Sanborn, John W., Mass. Inst. of Tech.
Veltre, Frank E. Jr., Georgia School of Tech.
Wheeler, Kimball L., Mass. Inst of Tech.
Total 10.

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*Alexander Graham Bell, 1891-2.
Frank Julian Sprague, 1892-3.
*Edwin J. Houston, 1893-4-5.
*Louis Duncan, 1895-6-7.
*Francis Bacon Crocker, 1897-8.
A. E. Kennelly, 1898-1900.
*Carl Hering, 1900-1.
*Charles P. Steinmetz, 1901-2
Charles F. Scott, 1902-3.
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H. W. Buck, 1916-17.
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Calvert Townley, 1919-20.
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*Deceased.

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Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
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(Terms expire July 31, 1927)

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(Terms expire July 31, 1928)

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(Terms expire July 31, 1929)

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(Terms expire July 31, 1930)

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(Terms expire July 31, 1931)

John W. Howell, L. F. Morehouse, David B. Rushmore.

Elected by the Board of Directors from its own membership for term of two years.

(Terms expire July 31, 1927)

W. P. Dobson, Farley Osgood, A. G. Pierce.

(Terms expire July 31, 1928)

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W. M. Dann,	J. A. Johnson,	R. F. Schuchardt,
L. L. Elden,	V. Karapetoff,	A. Still,
G. Faccioli,	A. H. Kehoe,	E. C. Stone
C. J. Fechheimer,		R. B. Williamson.

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A. N. Anderson,	F. A. J. Fitzgerald,	J. B. Whitehead,
T. C. Atchison,	Walter E. Holland,	J. L. Woodbridge,
Farley G. Clark,	F. A. Lidbury,	J. L. McK. Yardley.
	C. G. Schluederberg,	

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V. Karapetoff, Chairman, Cornell University, Ithaca, N. Y.

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V. Bush,	M. E. Leeds,	Chester W. Rice,
J. F. H. Douglas,	K. B. McEachron,	J. Slepian,
Charles Fortescue,	R. A. Millikan,	Harold B. Smith,
Carl Kinsley		J. B. Whitehead.

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A. E. Knowlton, Chairman, Dunham Laboratory, Yale University, New Haven, Conn.
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Perry A. Borden,	W. B. Kouwenhoven,	E. J. Rutan,
W. M. Bradshaw,	P. M. Lincoln,	B. W. St. Clair,
H. B. Brooks,	W. M. McConahey,	G. A. Sawin,
J. R. Craighead,	Wm. J. Mowbray,	I. B. Smith,
W. A. Del Mar,	H. A. Perkins,	H. M. Turner,
Melville Eastham,	R. T. Pierce,	Roy Wilkins.

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A. G. Pierce, Chairman, 1239 Guardian Building, Cleveland, Ohio

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A. C. Cummins,	R. H. Keil,	G. E. Stoltz,
F. B. Crosby,	W. C. Kennedy,	T. S. Towle,
J. H. Hall,	A. G. Place,	J. D. Wright.
	F. O. Schnure,	

PRODUCTION AND APPLICATION OF LIGHT

P. S. Millar, Chairman, Electrical Testing Laboratories, 80th St. & East End Ave., New York

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J. M. Bryant,	L. A. Hawkins,	F. A. Rogers,
J. R. Cravath,	H. H. Higbie,	B. E. Shackelford,
W. T. Dempsey,	C. L. Kinsloe,	C. J. Stahl,
William Esty,	A. S. McAllister,	G. H. Stickney.
	George S. Merrill,	

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R. A. Beekman, Vice-Chairman, Schenectady, N. Y.

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H. F. Harvey, Jr.,	Commdr. M. A. Libbey,	W. E. Thau,
Wm. Hetherington, Jr.,	E. B. Merriam,	C. P. Turner,
H. L. Hibbard,	I. H. Osborne,	A. E. Waller,
Edward C. Jones,	William H. Reed,	J. L. Wilson,
J. S. Jones,		R. L. Witham.

APPLICATIONS TO MINING WORK

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F. N. Bosson,	John A. Malady,	E. D. Stewart,
Graham Bright,	Charles H. Matthews,	F. L. Stone,
L. C. Ilsley,	F. C. Nicholson,	W. A. Thomas,
G. M. Kennedy,	H. F. Pigg,	E. B. Wagner,
R. L. Kingsland,	L. L. Quigley,	J. F. Wiggert,
A. B. Kiser,	Herbert S. Sands,	C. D. Woodward.

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E. W. Henderson,	K. A. Pauly,	W. C. Yates.
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Mailed to interested readers by issuing companies

Transformers.—Bulletin GEA-424, 72 pp. Describes G-E distribution and small power transformers. General Electric Company, Schenectady, N. Y.

Radio Frequency Ammeters.—Bulletin 810, 4 pp. Describes the Roller-Smith thermal ammeters and milli-ammeters for measuring radio frequency currents. Roller-Smith Company, 12 Park Place, New York.

Automatic Stations.—Bulletin GEA-90A, 48 pp. Describes G-E automatic stations. Numerous installations in various industries are pictured in the book. General Electric Co., Schenectady, N. Y.

Jagabi Rheostats.—Catalog 1140, 20 pp. Describes a line of adjustable resistances suitable for practically every need in electrical, physical, chemical, research and educational laboratories. A number of improvements have recently been made in these devices. James G. Biddle, 1211 Arch Street, Philadelphia, Pa.

Watthour Meters.—Bulletin C1753, 16 pp., "Registers of Revenue," is a Westinghouse publication dealing with the advantages of the watthour meter. The permanent accuracy of the meter, low costs of adjustments, tests and handling, ease in reading and saving of storage space are some of the points covered. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

NOTES OF THE INDUSTRY

Edgar S. Bloom elected President of the Western Electric Company.—Election of Edgar S. Bloom, a vice-president of the American Telephone and Telegraph Company, to the presidency of the Western Electric Company, has been announced. He succeeds Charles G. DuBois, who has been president for the past seven years, and who continues with the company as Chairman of the Board of Directors.

Harry S. Schott appointed General Sales Manager of National Carbon Company, Inc.—The appointment on August 1 of Harry S. Schott as general sales manager of the National Carbon Company, Inc. has been announced. He has been associated with the company since 1913, and has been identified with the manufacturing and jobbing end of the electrical industry for almost twenty-five years.

The Kuhlman Electric Company, Bay City, Michigan, manufacturers of power, distribution and street lighting transformers, announces the appointment of H. F. Darby, Jr., 1700 Walnut Street, Philadelphia, Pa., as direct factory representative in the Philadelphia district. For more than twenty years Mr. Darby was with the Cutter Electrical & Manufacturing Company and during the last six years he was sales manager of that organization.

The Jas. R. Kearney Corporation is Organized.—James R. Kearney, for the past fifteen years associated with the W. N. Matthews Corporation, is president of the new Jas. R. Kearney Corporation, manufacturers of utility equipment, located at 4224-32 Clayton Avenue, St. Louis, Mo. Mr. Kearney has had wide experience in specialty equipment manufacturing, plant engineering and pole line and underground construction. A number of well known specialties are manufactured under his patents. A group of engineers and well known figures in the electrical industry are associated with Mr. Kearney in his new enterprise.

Great Increase in Exports of U. S. Products.—The Bureau of Foreign and Domestic Commerce reports that exports of finished manufactures show an increase during the fiscal year just ended, of 16 per cent over the previous year. They were 60 per cent greater than in 1921-1922 and nearly three times as great in value as in the five year period before the war. Even after allowing for higher prices, they were more than double the pre-war average. Dr. Julius Klein, Director of the Bureau, states that this large growth reflects the ever rising efficiency of American industry and the energy and intelligence of American salesmanship in foreign markets.

The export of electrical machinery and apparatus amounted to over $80,000,000 in the fiscal year 1925-1926, as compared to $67,000,000 in 1924-1925 and $57,000,000 for the year 1921-1922. The total value of the exports of semi-manufactures and finished manufactures amounted to $2,573,000,000 for the fiscal year 1925-1926, an increase of 50 per cent in five years.

Equipment for Conowingo.—Three vertical-shaft hydraulic turbines, each of 54,000 horse power, will be constructed by the William Cramp & Sons Ship & Engine Building Company, of Philadelphia, in carrying out the great power development of the Philadelphia Electric Company at Conowingo, on the Susquehanna River. Though they are exceeded by a few installations in power capacity, on account of the lower head requirements the physical dimensions of the new units will exceed those of any hydraulic turbine yet constructed. The head at Conowingo will be 89 feet and the turbines will operate at a speed of 81.8 revolutions per minute.

The General Electric Company will supply thirteen transformers for the Conowingo project. These are to be used in transmitting 350,000 horse power of electrical energy over seventy miles of transmission lines to Philadelphia. Each of the transformers, all of the water-cooled type, has a rated capacity of 26,667 kilovolt-amperes. The voltage will be stepped up from 13,800, at which the current will be generated, to 220,000, at which it will be transmitted. The transformers have an efficiency of better than 99 per cent.

Two Million Dollar Turbine Generator Contracts for Westinghouse.—Substantial increases in electric power production, both central station output as well as industrial power, are reflected in several contracts for power generating equipment just received by the Westinghouse Electric and Manufacturing Company. The contracts aggregate a total of 120,000 electric horse power, of which approximately 90,000 will be for additional power company current, and when completed will represent an outlay of approximately $2,000,000.

The biggest contract was placed by the Duquesne Light Company for one turbine generator of 60,000 horse power, one 62,500 square-foot steam condenser with auxiliaries and three transformers, each rated at 31,400 kv-a. The equipment is to be installed at the Colfax Station at Cheswick. This station at the present time has four generator units of approximately 250,000 horse power.

A contract placed by the Binghamton Light Heat & Power Company, Binghamton, New York, calls for delivery of one 45,000 horse power turbine generator as well as three transformers rated at 11,765 kv-a. each. The equipment is to be installed at the company's power station at Binghamton.

The third contract was received from the Solvay Process Company of Syracuse, New York, and includes two high pressure turbine generators of unusual design and of a total of approximately 15,000 horse power. While ordinarily big steam turbines operate at a steam pressure of from 200 to 400 pounds, these turbines will have a gage throttle pressure of seven hundred and twenty-five pounds. The installation is intended primarily to obtain steam economies and utilize by-product power.

All the steam power equipment will be built at the South Philadelphia Works, while the electrical equipment will be supplied by the East Pittsburgh shops.

JOURNAL OF THE A·I·E·E·

OCTOBER 1926

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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American Institute of Electrical Engineers

COMING MEETINGS

New York Regional Meeting, New York, N. Y., Nov. 11-12

Winter Convention, New York, N. Y., February 7-10

MEETINGS OF OTHER SOCIETIES

American Society of Civil Engineers, Philadelphia, Pa., Oct. 4-9

National Electric Light Association, Kansas Section, Manhattan, Kan., Oct. 14-16

American Electrochemical Society, Washington, D. C., Oct. 7-9

National Safety Council, Detroit, Mich., Oct. 25-29

American Welding Society Exposition, Buffalo, N. Y., Nov. 17-19

Fifth National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y., December 6-11

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV | OCTOBER, 1926 | Number 10

Activities and Development of the Meetings and Papers Committee

Technical meetings of the Institute are held primarily for the purpose of bringing to the attention of the membership, current developments in the electrical art and of affording an opportunity for the interchange of views on electrical subjects. Responsibility for accomplishing these objectives rests with the Meetings and Papers Committee.

This committee is admirably fitted to keep in contact with electrical progress and to arrange for the presentation and discussion of papers. Its members include the chairmen of the sixteen technical committees and ten other members of the Institute.

The committee chairmen, through frequent meetings of their respective committees, and the remaining members through other contacts, keep in intimate touch with progress in all branches of electrical science.

The present policy with regard to conventions and the present organization of the Meetings and Papers Committee have evolved with the growth of the Institute and the accumulated experience of past years.

A system for handling papers and meetings became necessary at the very beginning of the Institute in 1884. At first these were handled by the Council, which corresponded to the present Board of Directors. In the first year one technical meeting was held and ten papers presented. In the same year the first predecessor of the present committee was appointed. It was called the Meetings and Exhibitions Committee and had three members. One technical meeting was held in 1885 and two in 1886. In the latter year it was decided to hold monthly meetings and a Committee on Monthly Meetings, consisting of three members, was appointed. The monthly meetings were started in 1887 and continued as Institute meetings until 1921.

As the Institute grew, it was found necessary in 1888 to appoint a Committee on Papers and Meetings, consisting of five members, and a separate Editing Committee, of three members. These two committees were combined in 1893, but were separated again in 1901.

The first two technical committees were appointed in 1906. In 1907 there were three technical committees and these were attached as subcommittees to the Meetings and Papers Committee, as it now was called.

In 1909 the technical committees, of which there were then six, were separated from the Meetings and Papers Committee, but in order to retain contact, their chairmen were made members of this committee. This plan is still in effect today, though the number of technical committees has increased to sixteen.

Institute meetings were held monthly, except during the summer, from 1887 until 1921. At first these were held in New York, but in later years many were held in other cities. In 1921 it was decided that there should be only three national Institute conventions and that monthly meetings should be classed as Section meetings. At that time there were forty-two Sections holding regular Section meetings.

The three national conventions were to be the Annual Convention, started in 1884; the Pacific Coast Convention, started in 1910; and the Midwinter Convention, started as such in 1913. Another national meeting, known as a Spring Convention, was initiated in 1922, but it was discontinued after 1925, principally because of the development in regional meetings.

The present yearly program of the Institute includes three national conventions and a number of regional meetings. The number of regional meetings is not fixed but depends largely on the needs and desires of the various geographical districts. Three regional meetings were held in the year 1925-1926 but it is expected that in future the number of such meetings will increase.

It is of prime importance that the programs for conventions and meetings shall treat electrical subjects from a broad viewpoint and present technical information of interest to a large institute membership which includes all branches of the profession. With a membership composed of specialists, consulting engineers, operators, executives and others it is necessary to weigh all factors if a well balanced program is to be developed.

Furthermore, the Meetings and Papers Committee, in addition to the preparation of technical programs, develops its convention programs with a view to cooperating with public officials, financiers, executives and industrial leaders, in order to advance the status of the profession.

When a convention is being planned, this committee is guided very largely by the advice and wishes of the local convention committee, which has jurisdiction over all arrangements excepting the actual selection of technical papers. The local committee has an intimate knowledge of local conditions and can best suggest those elements which will give greatest benefit to the membership in its general territory. In this regard the

ocal convention and regional-meeting committees have been most helpful and have given most valuable co-operation.

Technical papers are submitted by the authors without solicitation on the part of the committee or in case it appears desirable to present information on some specific branch of the art, are obtained as the result of solicitation or suggestion by one or more of the committee members.

Upon receipt of a paper submitted for presentation or publication, the usual course is to refer it to the technical committee or committees conversant with the subject, for the purpose of securing an opinion as to its worth.

As a result of these and other opinions a paper is either accepted, rejected or returned to the author with constructive suggestions for its revision.

Discussion of papers is almost as important as their presentation and consequently the Meetings and Papers Committee endeavors to secure intelligent discussion at all meetings by general invitation and individual request.

E. B. MEYER,
Chairman, M. and P. Committee.

Some Leaders of the A. I. E. E.

Calvert Townley, the thirty-second president of the Institute, 1919-1920, was born in Cincinnati, Ohio, Oct. 18, 1864. He prepared for college at Chickering Institute, that city, and was graduated from the Sheffield Scientific School of Yale in 1886. Returning there for a graduate course he received the degree of M. E. in 1888. A summer as a laborer helping to rebuild the burned station of the Brush Electric Light Co. of Cincinnati was followed by a seventeen year engagement with the Westinghouse Electric interests at Pittsburgh, Cincinnati, Boston and New York. Starting as road engineer, or trouble man, and later becoming designer of distribution systems he was shortly transferred to the sales department. Here, although officially free from engineering duties, his inclination led him to study the technical problems, first of electric light then of power and finally of traction. He was active in the Niagara Falls development, the equipment of the Boston subways, the New York and Brooklyn elevated systems and the New York subway. In 1904, he went with the N. Y. N. H. & H. R. R. as acting fourth vice-president, to electrify their line out of New York. About that time this railroad began acquiring utility companies, (largely trolley lines) and Mr. Townley was appointed first vice-president of the holding company to manage their utilities as a side issue. The "side issue" soon reached such magnitude that after completing electrification plans and drawing specifications, Mr. Townley asked to be relieved of construction duties and became consulting engineer for the New Haven Railroad thereafter devoting most of his time to executive management of the utilities. In 1911 he renewed his former connection with the Westinghouse Company as assistant to the president a position which he now holds. During the latter period, he has served as president of the Lackawanna & Wyoming Valley Railroad, vice-president of the Niagara, Lockport & Ontario Power Co., vice-president of the South Philadelphia Co., vice-president of the International Radio Telegraph Company and officer or director of many other companies. He has toured Europe and South America in professional capacity. During the war he superintended the erection of a turbine factory near Philadelphia, the output being very largely used for the Federal Government merchant and naval vessels.

Mr. Townley joined the A. I. E. E. as an associate in 1901 and became a Fellow in 1912. He was elected Manager in 1905, vice-president in 1908 and President in 1919. In 1923 he was chairman of the New York Section; for over five years he was chairman of the Public Policy Committee, for two chairman of the Finance Committee and, at various times, served on other Committees, including Executive, Meetings and Papers, Standards, Edison Medal and Constitution Revision. He served as vice-president and trustee of The United Engineering Society and on The Engineering Foundation Board. In 1919, Mr. Townley was chairman of the Special Committee on Development which studied the needs of the Institute and of the profession. Out of this study came the joint committee of the four Founder Societies on which he served, and then on The Engineering Council. Mr. Townley was chairman of the Organizing Conference of American Engineering Council at Washington, was elected a vice-president, later declining the presidency. He was a delegate and member of the Executive Committee of the American delegation to the World Power Conference in London in 1924 and a member of the American Industrial Mission to Mexico that same year. He has contributed many papers, mostly dealing with power and traction problems.

It is estimated that between 12,000,000 and 15,000,000 radio sets are in operation throughout the world, according to a survey recently made. Of these, the United States is believed to have nearly half, or more than 5,500,000 sets.

About 900 broadcasting stations are now operating, more than 500 being in the United States. The actual number of stations which may be operating is, of course, considerably less, owing to the number of divided-time agreements in force; this practise, however, is not common in foreign countries, as the stations are fewer and the distances between them greater. The wave bands used abroad are also much wider.

Carrier-Current Communication on Submarine Cables

Los Angeles-Catalina Island Telephone Circuits

BY H. W. HITCHCOCK[1]

Associate, A. I. E. E.

Synopsis.—*Seven telephone channels and one telegraph channel on one single-conductor deep-sea cable have been made possible by the employment of carrier current on one of the two submarine cables across Catalina channel. This is the only application of carrier telephony to deep-sea cables; the system is the shortest carrier system (26 mi.) in commercial operation; it provides more separate carrier channels (six) than has been previously attempted; and it differs in other important respects from other systems. This paper describes this carrier-current system.*

* * * * *

IN the commercial application of new developments in the electrical communication art, there are a few places which repeatedly call attention to themselves. Notable among these is Catalina Island, for it is probable that in providing telephone service across the short expanse of water which separates Catalina from the mainland, more novel improvements have been employed than at almost any other point.

The first commercial telephone communication with Catalina Island was established in 1920 when a radio system was placed in operation between Avalon and the mainland, the circuit being extended by wire to Los Angeles. This circuit was in use for several years and featured in a number of transcontinental demonstrations, including the one which was held at the opening of the service to Havana over the Key West-Havana cables.

The system is of considerable interest as it represents the only instance in which radio has been used, in this country at least, to form a portion of a toll telephone system for the general use of the public. That it was reasonably successful is demonstrated by the fact that on some days as many as 183 commercial telephone messages and a large number of telegrams were handled over it. The system also proved to be one of the first popular broadcasting stations and many letters were received from radio fans, often several hundred miles away, telling of some of the amusing conversations which were overheard.

In 1923 the radio was replaced by two single-conductor submarine cables. By that time the demands for service were too great to be met by a single circuit, while the growing interest in radio broadcasting, as well as the increasing interference from ship transmitters, rendered its continued operation very difficult and unsatisfactory. The submarine cables were of the single-conductor, deep-sea type, each providing a single-wire circuit. They are of interest for a number of reasons, chiefly, perhaps, because they represent one of the few instances of deep-sea cable manufacture in this country. From the cable hut at San Pedro, the circuit is extended to the office by means of a special lead-covered cable containing four individually shielded No. 13 B & S gage pairs for the telephone circuits and four 19-gage pairs for the telegraph circuits and other miscellaneous uses. Between the San Pedro office and Los Angeles, the circuit was composed of a No. 19 B & S gage cable phantom. At San Pedro a through-line repeater was inserted in order to secure the desired over-all equivalent between Avalon and Los Angeles. A description of these cables and their laying was given in a paper presented by the writer at the Pacific Coast Convention in 1923 and published in Volume XLII of the TRANSACTIONS.

Although the two circuits provided by the cables represented a great improvement over the previous condition as regards the quality of the service rendered and the number of messages which could be handled, it was realized that they would soon prove inadequate to handle the heavy summer business, for which eight or ten circuits would be required in a relatively short time. To provide for such a large increase by the laying of additional cables was deemed impractical, as the cost would be excessive. Furthermore, in water of this depth—3000 ft. (914 meters)—it is important that cables be laid at least a mile or two apart, so that in the event that trouble develops on one, it can be repaired without disturbing any of the others. For a total distance as short as the width of the Catalina channel—23 nautical mi. (6087 ft. or 1856 meters per nautical mi.)—such a separation between adjacent cables could not be maintained without materially increasing the length of the outer ones with a corresponding increase in their cost and in their transmission equivalents. In view of these facts, it was decided to secure as many more circuits as possible by operating carrier systems over the two cables already in use. This project was actively promoted with the result that on May 15, 1926, six carrier telephone circuits were placed in operation.

The use of carrier in the past few years has increased so rapidly that the mere addition of a new system is,

1. Transmission and Protection Engineer, Southern California Tel. and Tel. Co., Los Angeles, Calif.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

in itself, of hardly more than passing interest. In this instance, however, there are a number of factors which render the project of particular interest. It is the shortest carrier system—26 mi. (43 km.)—in commercial operation. It is the only application of carrier telephone to deep-sea cables; the system provides more separate channels (six) than has ever before been attempted, while the particular arrangement employed is different in many other important respects from anything which has been used in the past.

In order to better appreciate the reasons for adopting the system finally agreed upon, it may be of interest to review briefly the essential characteristics of carrier systems and the different types which are available. The general principles of carrier-current telephony are described at considerable length in a paper by Messrs. Colpitts and Blackwell which was published in Volume XL of the JOURNAL of the Institute.

Carrier systems may be divided into two general classes, namely, balanced or grouped, depending upon

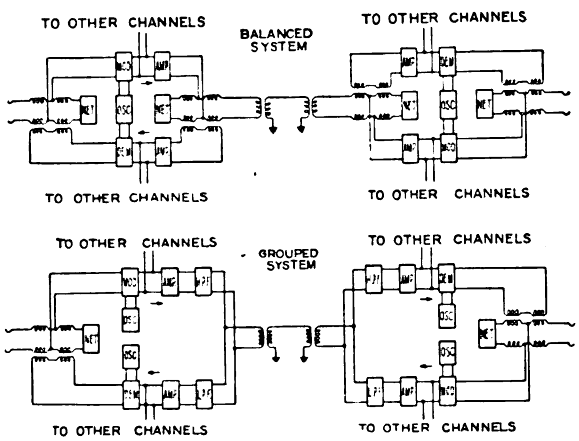

FIG. 1

the manner in which the currents in the two directions are prevented from interfering with each other at the terminals. In the balanced system this separation is accomplished by means of a three-winding transformer or hybrid coil together with a balancing artificial line such as is used with a voice-frequency repeater. In the grouped system, different carrier frequencies are used for transmission in the two directions and their separation at the terminals is effected by means of suitable band-pass filters. These two systems are shown diagrammatically in Fig. 1. The balanced system has the advantage that for each channel the same carrier frequency may be used for transmission in both directions so that there may be as many channels as there are separate carrier frequencies. On the other hand, the wire circuit must be very uniform throughout so that the impedance will be very regular over the entire carrier-frequency range, and may be simulated by an artificial line. The line must also be very stable so that the impedance balance, once having been secured, will not be disturbed. Furthermore, as transmission with the same carrier takes place in the two directions, the effect of the cross-talk between systems of the same type is very severe, so that it is usually impractical to operate two of these over wires which are in close proximity for any considerable distance. The grouped system has the advantage that a balancing line is not required and hence small circuit irregularities are relatively unimportant. Furthermore, the effect of

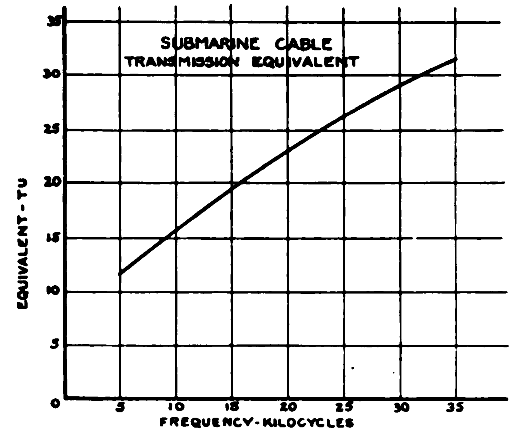

FIG. 2

cross-talk is much less severe, so that a number of systems may often be operated over adjacent circuits. One disadvantage is that two carrier frequencies are required for each channel so that fewer circuits can be secured with one system.

Carrier systems may also be divided into two classes depending upon the manner in which the carrier current is provided at the receiving end. In the carrier transmission system, the carrier current is supplied by the oscillator at the sending end and is transmitted over the circuit along with one or both of the side bands. In the carrier suppression system, the carrier current itself is not transmitted but is introduced into the receiving equipment from a local source. This latter system is proving to be superior for general carrier purposes because of the advantages which accrue from relieving

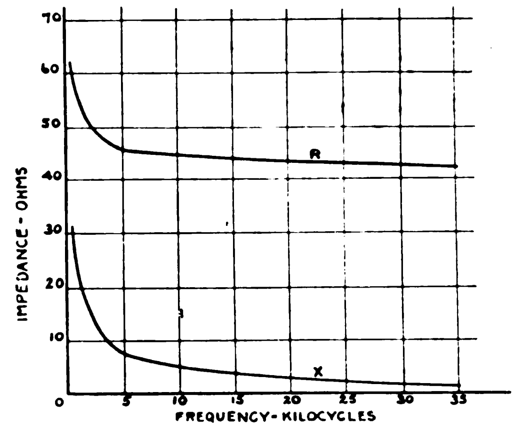

FIG. 3

the line and apparatus from the load of the carrier current.

Turning now to the electrical characteristics of the cables, we find that each one provides a circuit having a transmission equivalent which increases throughout the carrier range but is moderate in magnitude. The impedance, as is to be expected with a uniform, non-loaded cable, is very smooth, and since there is no opportunity for any change in the cable constants, the impedance has practically no variation. The transmission equivalent and the impedance of one of the cables are shown in Figs. 2 and 3 respectively. The cross-talk between the cables is small enough to be entirely negligible, regardless of the type of carrier systems employed.

In view of all the conditions outlined, a balanced system of the carrier suppression type was decided upon. Such a system provides the maximum number of channels per cable, while the usual difficulties of impedance balance and inter-system cross-talk are largely absent due to the unusual characteristics of the cables. The adoption of such a system also made possible the employment of standard units of equipment of the most recent design. The general nature of the system and the arrangement of the component parts is shown diagrammatically in Fig. 4. Fig. 5 is a simplified circuit diagram showing the filters for separating the various circuits at the terminals, together with the balancing arrangement. In Fig. 6 are shown the essential parts of one channel together with the amplifiers

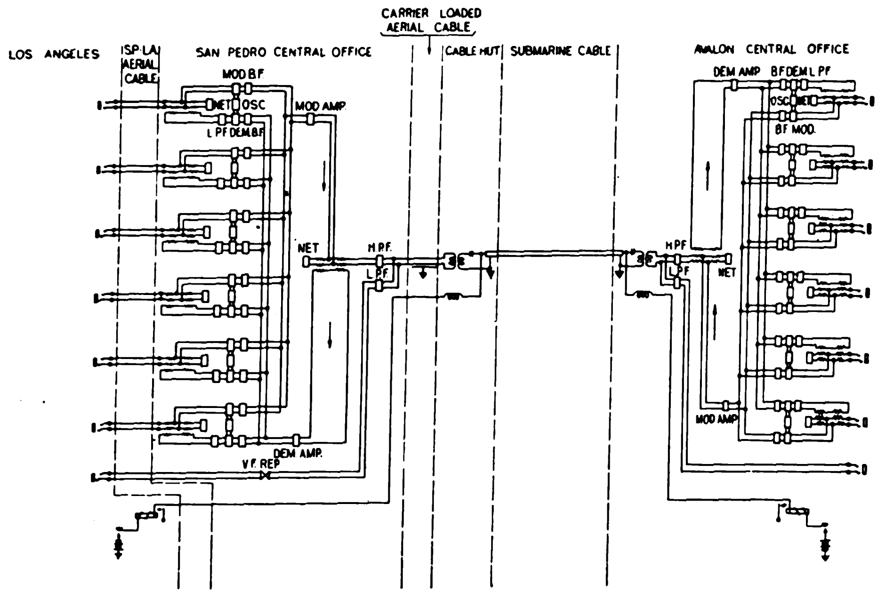

Fig. 4

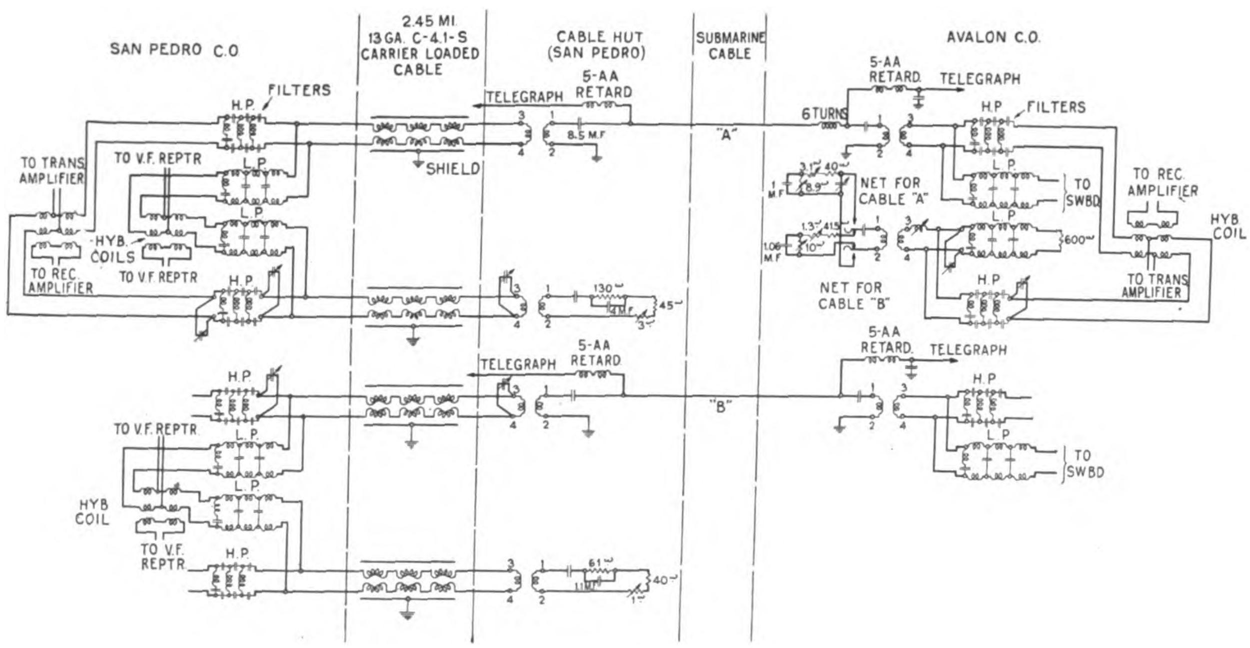

Fig. 5

and the hybrid coil which are common to all the channels. For convenience, some of the battery and auxiliary circuits have been omitted in the figure.

At the time the system was under development, it was uncertain that balanced operation of all channels over a single cable would be practicable, so that an alternative arrangement involving substantial four-wire operation over the two cables was provided for. With this arrangement, which is shown diagrammatically in Fig. 7, all transmission in one direction takes place over one cable, while transmission in the opposite direction is effected over the second cable. No balancing equipment or hybrid coils are employed. Such an arrangement would increase the system stability, if such were required, but would limit the total carrier capacity of the two cables to six channels. In the event of the failure of one cable, operation with such a system would be impossible, and it would be necessary, at that time, to revert to the two-wire arrangement as described above, with a possible reduction in the over-all gain or a reduction in the number of operating channels.

As may be seen from Fig. 4, a carrier-equipped cable provides a d-c. telegraph circuit, and one voice-frequency, and six carrier-frequency telephone channels. The separation of the various channels is effected by means of electrical filters. Fig. 8 shows the band of frequencies employed for each channel. For the d-c. telegraph this separation is effected at the terminals of the cable as is shown in Fig. 5. The telegraph circuit requires a continuous d-c. path, whereas the telephone channels require the insertion of an inequality ratio

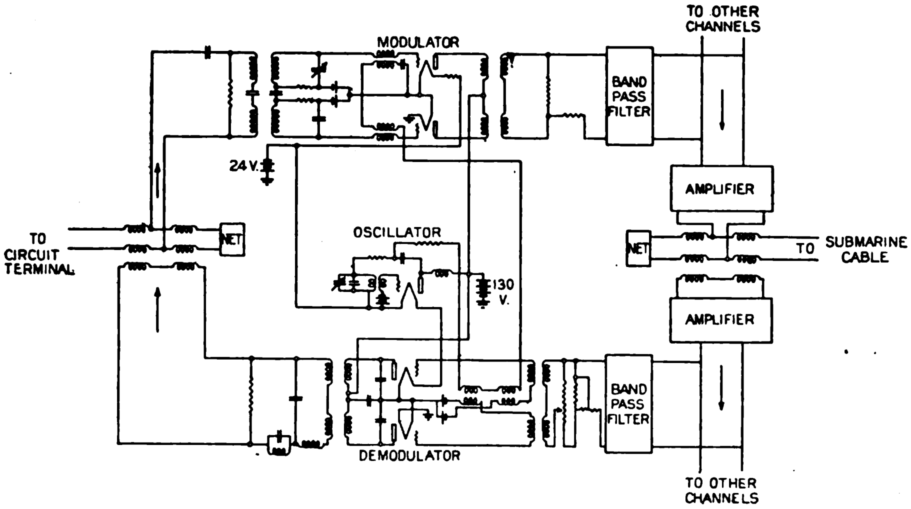

Fig. 6

insulating transformer at the ends of the cable in order to properly join the 43-ohm grounded cable circuit with the 600-ohm metallic circuit formed by the office equipment and intermediate cable. As this transformer must pass both the voice and carrier channels, it has been designed so as to have a high efficiency for all frequencies between 250 and 30,000 cycles. Separation of the voice-frequency circuit from the carrier system is performed by means of the usual high and low pass filters which are located at the central offices. These filters both have a cut-off frequency of 3000 cycles, the low pass transmitting all frequencies below this value and the high pass transmitting all above it. In the carrier system the transmitting and receiving currents are separated from each other by a hybrid

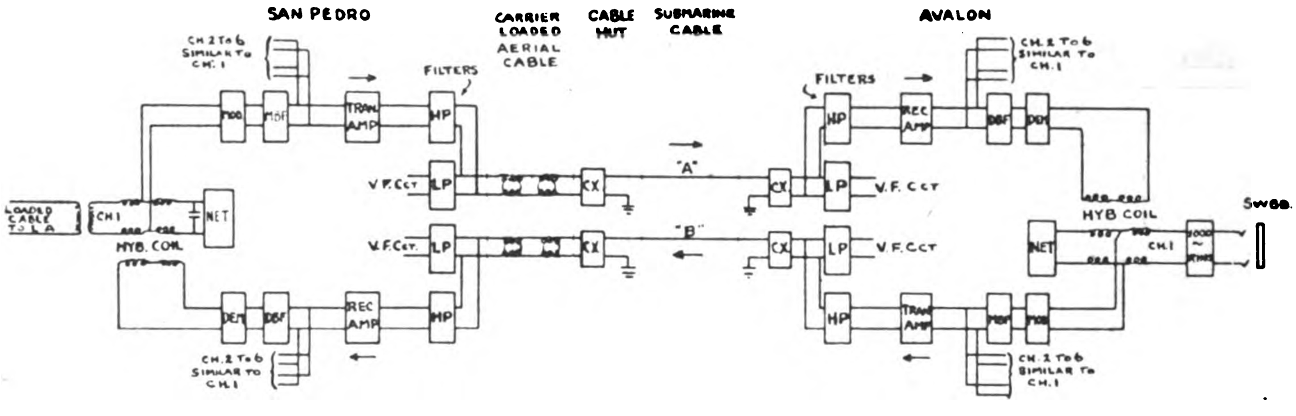

Fig. 7

coil and balancing network. Between the output of the six modulators and the common transmitting amplifier, individual band-pass filters are located. Each one of these filters is designed to transmit one of the side bands produced by the modulator associated with it and to suppress all other frequencies. The six receiving currents are separated in a similar manner. Each filter allows current of the proper frequency to pass to the corresponding demodulator and excludes all others. Each demodulator is also provided with a low

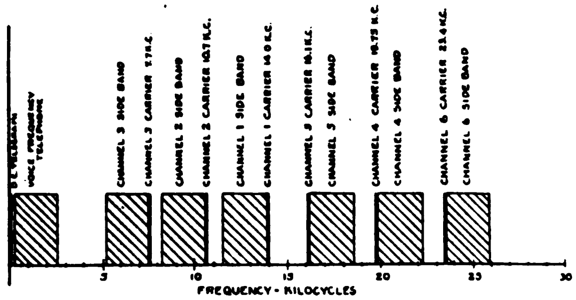

Fig. 8

pass filter which allows the passage of the resulting voice-frequency current but excludes all incidental higher frequencies which might be present and render the circuit noisy. The input of each modulator and the output of the corresponding demodulator are finally joined by means of a voice-frequency hybrid coil and extended to the circuit terminal as a two-wire circuit. At the San Pedro end, each two-wire circuit is extended to Los Angeles over a loaded cable circuit. Phantoms are employed for this purpose as they have a higher cut-off frequency than have the side circuits, with a correspondingly better quality.

Concerning the carrier system itself, the two ends are practically identical while the general equipment arrangement for an individual channel is the same in all cases except for the frequency of the band-pass filter. For this reason, a consideration of one channel is sufficient. Each channel is composed of a voice-frequency hybrid coil, a modulator with its band-pass filter, an oscillator, and a demodulator, together with its associated filters. In addition, there is, at each end, a carrier hybrid coil together with transmitting and receiving amplifiers which are common to all channels. The arrangement of this equipment is shown schematically in Fig. 6, as previously indicated.

The modulator the input of which is connected to the center taps of the hybrid coil line windings consists of two vacuum tubes arranged for push-pull operation. The carrier current which is supplied by the oscillator is applied to the two grids by means of a transformer. Such a circuit generates the two side bands but suppresses the carrier. In order that this suppression may be as complete as possible, the small condenser associated with the grid of one of the tubes is made variable and is adjusted until the carrier current in the modulator output is reduced to a minimum. The band-pass filter transmits one of the side bands and suppresses the other, as well as all miscellaneous resultant currents of a higher order which are produced by the modulator. It also prevents the output currents of the other channels from entering the modulator circuit as this would cause a reduction in their efficiency and give rise to undesirable frequencies.

The demodulator is very similar to the modulator. The tube arrangement is substantially the same and carrier current is supplied from the one oscillator. In the demodulator a complete suppression of the carrier is unnecessary as this is accomplished by the low pass output filter. For this reason, the small balancing grid condensers are omitted. In order to adjust the over-all gain of the channel, the demodulator is provided with an adjustable potentiometer graduated in two transmission unit steps, and in addition, fixed pads are provided for making further gain adjustments. The output of the demodulator is connected to the series winding of the voice-frequency hybrid coil.

The oscillator which supplies the carrier current to the modulator and demodulator is of the usual type. The tuning condenser includes a small variable unit for making small adjustments in frequency. Separate oscillators are used at the two ends for each channel, and as these are in no way connected together, it is occasionally necessary to make slight adjustments in order to keep the frequencies at the two ends substantially equal. The oscillators are very stable, however, and such adjustments are seldom required.

The individual channel filters are all of the band-pass type as previously indicated and have a free transmission range of approximately 2500 cycles. Outside

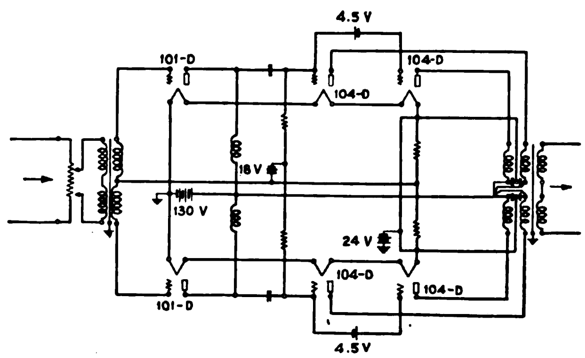

Fig. 9

this free range they have a high impedance so as not to act as a shunt for the other channels. They are all of substantially the same construction, although the constants of the component parts necessarily vary as the filters for the different channels transmit different frequencies.

The transmitting and receiving amplifiers, which are practically identical, are shown schematically in Fig. 9. They consist of two push-pull stages connected in tandem. Each half of the second or output stage con-

sists of two parallel tubes of high output capacity. In this way a comparatively high gain and a large energy output may be secured without overloading. This is very important as these amplifiers are common to all six channels and any tendency to overload would produce objectionable distortion and inter-channel modulation. In order to adjust the over-all gain for the entire system, each amplifier is provided with an input potentiometer.

As has been previously indicated, the transmitting and receiving circuits are joined to the cable by means of a hybrid coil. Probably the most difficult problem encountered in the installation of this system was the securing of an adequate balance. The difficulty of doing this may be better appreciated when it is realized that this balance must cover all frequencies from 3000 to 30,000 cycles, and must have a value of from 30 to 45 T. U., the higher value which represents an impedance unbalance of approximately one per cent being required at the upper frequency. In order to secure

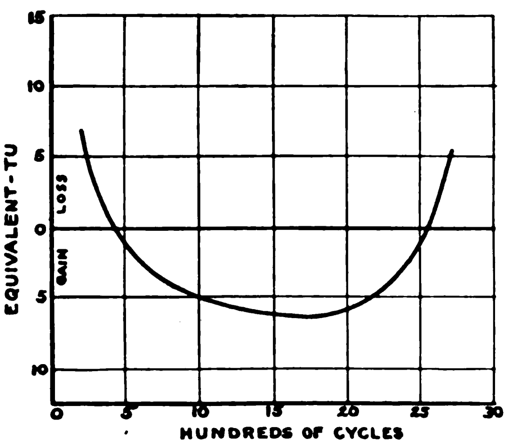

FIG. 10

such a balance, every part of the line circuit was matched by a similar part in the network circuit. All filters and transformers on the line side of the hybrid coil were duplicated in the network, and on the San Pedro side a 13-gage carrier-loaded cable pair was included in the network circuit between the office and the cable hut, and the inequality ratio transformer and basic network simulating the cable were located at the latter point. In addition to providing a balance within the carrier range, it was necessary at the San Pedro end for the network circuit to balance the cable within the voice-frequency range as a through-line repeater is employed on the voice-frequency circuit. Not only was it necessary to duplicate all parts in the line and network circuits but in addition they were carefully selected and paired so that the two parts associated would have, as nearly as possible, the same electrical characteristics. All wire pairs within the office which appeared in the carrier frequency circuits were individually shielded by means of a grounded metallic covering. The 13-gage carrier-loaded pairs in the cable joining the hut and the office were also individually shielded by means of a lead foil wrapping. This was done in order to preserve the balance and prevent cross-talk with another system which may be placed on the second cable at some future time.

Although extreme care was exercised in making the refinements described, the balance was still lower than was desired so that small variable auxiliary impedances were inserted at suitably chosen points in the line and network circuits. By the adjustment of these elements, it was found that the balance could be raised to any desired value for any particular channel, but that in so doing, the balance on some of the others would be impaired. By careful adjustment, however, it was possible to secure a balance for all channels within the range previously mentioned. As the transmission equivalent of the cable increases with the frequency, the over-all channel gains must be increased in the same manner in order that all circuits may have the same over-all equivalent. The networks were therefore arranged so that the higher frequencies would have the better balance, as in that way the margin of balance over gain could be made substantially the same for all channels. Since this margin should not be allowed to fall below a fairly definite minimum if the circuit is to have the desired stability, it is evident that the balance which may be secured determines the over-all gain which is possible. In this case the circuit equivalent for all channels between Los Angeles and Avalon was set at five T. U. As the loaded cable between Los Angeles and San Pedro is approximately nine T. U., it may be seen that the carrier system actually introduces a gain and performs the function of a repeater besides increasing the number of circuits. Fig. 10 gives a frequency characteristic of one of the channels which is typical of all of them. Balancing equipment has been provided for both cables as is shown in Fig. 5. With this arrangement, the carrier system may be operated over either cable. The transfer from one cable to the other is so simple that it can be made with practically no traffic interruption.

Signaling over the carrier channels is effected by means of 1000-cycle ringers which are connected to the circuits at the two terminals. As the ringing current is within the voice range, it is transmitted over the regular carrier channel so that no additional signaling equipment is necessary.

In order to insure satisfactory operation, all necessary testing facilities are included. Meters and keys are provided for measuring the voltages of the plate, grid and filament batteries as well as the plate and filament currents of all tubes. Individual rheostats are inserted in all filament circuits for making any adjustments that may be necessary. Alarms are provided to indicate any abnormal condition which might develop on any tube. Thermocouples and artificial lines have been conveniently arranged for checking the efficiency of all units such as the modulators and demodulators.

Jacks are located at suitable points so that any changes which may be necessary can be quickly made.

The general appearance of the carrier system may be seen from Figs. 11 and 12 which show the equipment at

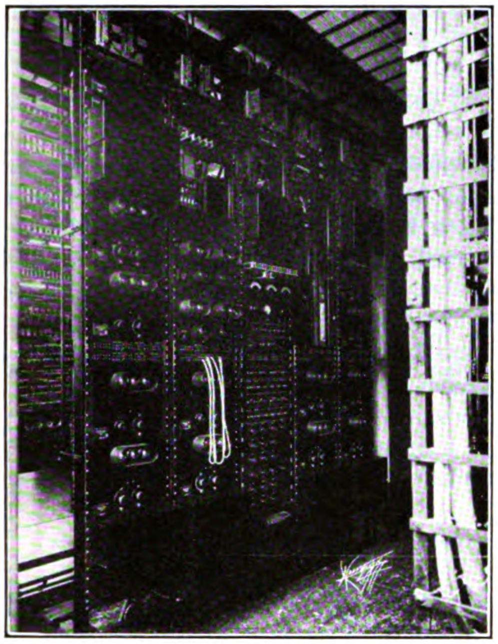

Fig. 11

San Pedro and Avalon respectively. Fig. 13 is an interior view of the San Pedro cable hut showing the cable terminals, together with the insulating trans-

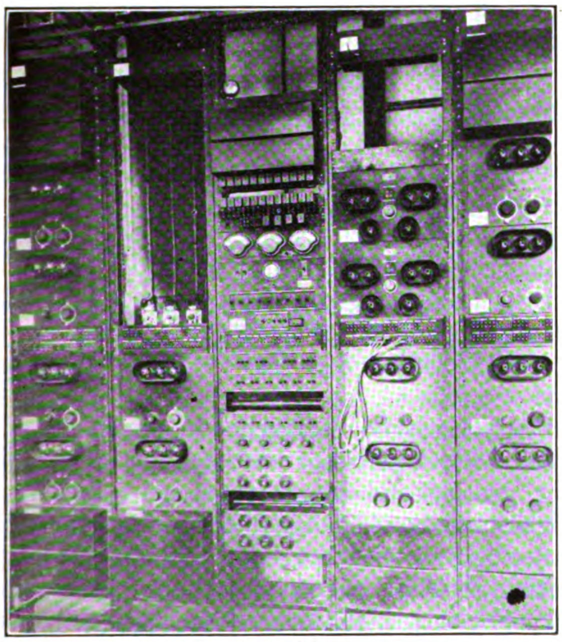

Fig. 12

formers, telegraph composite sets, and basis networks. Referring to the central office equipment, the first bay contains the equipment for two complete channels. At the top are the terminal strips for making all connections with the equipment below. On the next two small panels are mounted the hybrid coils and the other miscellaneous apparatus associated with the voice-frequency ends of the two channels. Below these are the modulator and demodulator band filters which are covered with dust proof cases. Next comes the modulator and demodulator panels for one channel. Below the two jack strips is mounted similar equipment for a second channel but arranged in reverse order. In the upper half of the second bay is located a small panel mounting the carrier hybrid coil and associated equipment. Below this appear the transmitting and receiving amplifiers. The lower half of the bay is similar to the lower half of the first one. In the third bay is mounted all the battery supply and testing apparatus. The first two units contain the battery retard coils. Below these are the alarm relays and auxiliary resistances. Next come the meters for measuring the tube currents and voltages, and below these are the

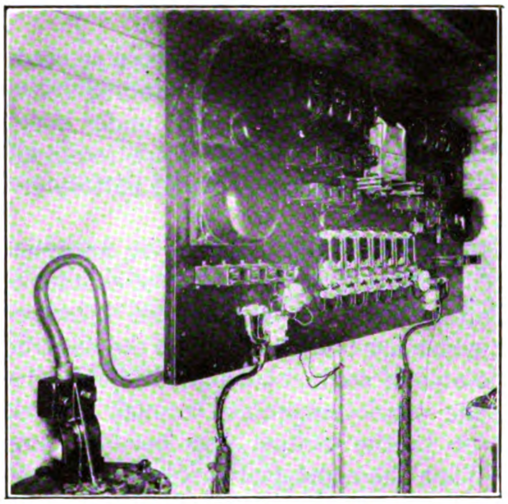

Fig. 13

thermocouples and artificial lines for making high frequency measurements. Below the jack strip are the keys for opening and closing the individual filament circuits used for measuring the plate and filament currents. Alarm lamps are also associated with each of the filament circuits. The fourth bay is similar to the second except that the upper half is vacant. As may be seen from the photographs, the amplifiers appear on the second bay at San Pedro and on the fourth at Avalon. The fifth bay is an exact duplicate of the first.

The new system has now been in successful operation for the past five months. In the light of its performance thus far, we feel assured that when more circuits are required a second system of six channels can be added to the second cable, thus providing a total of fourteen telephones and two telegraph circuits over the two single-conductor cables. Such a circuit group, we believe, will meet the traffic requirements for quite a number of years.

Temperature of a Contact
and Related Current-Interruption Problems

BY J. SLEPIAN[1]

Associate, A. I. E. E.

Synopsis.—*A formula is derived for the temperature rise of the last contact point of a pair of separating electrodes. The relation of this to arcing at a switch, brush drop, and commutation, is discussed.*

Experiments on the interruption of current by a switch in vacuum are described.

* * * * *

Low-Voltage Sparking at a Contact. It is a matter of common knowledge that when a circuit carrying current is opened at a pair of contacts, a flash of light which may be a spark or an arc results, even though the voltage of the circuit may be quite low. For example, if the blade of a knife is drawn across the terminals of a dry cell, a shower of sparks is thrown off, even though the cell gives only $1\frac{1}{2}$ volts. This phenomenon calls for explanation, since to start or maintain a discharge in gases or metal vapors in general calls for certain minimum voltages.

To start a discharge in a gas between separated electrodes requires in general several hundred volts, and to maintain an arc discharge, except under very special conditions, fifteen volts or more are required. How is it that the short-circuited, 1.5-volt battery gives such brilliant sparks?

Temperature at the Last Contact. An analysis of the thermal conditions at the last point of contact of a pair of separating electrodes suggests an answer to this question which has been raised. As the electrodes separate, the area of contact becomes smaller and smaller, so that the ohmic resistance through the electrode material up to the contact area becomes larger and larger. When the contact area reduces to a geometric point, this ohmic resistance becomes infinite. Hence, if a discharge does not start, all the voltage of the circuit must ultimately concentrate on this last contact. With metal electrodes, this means that there is an enormous concentration of current and power at the last contact so that a very high temperature is attained.

In the appendix, an approximate formula is derived for the temperature rise of a small contact between large electrodes when E volts are applied to it. It, is

$$T = \frac{E^2}{33.5\, k\, \rho} \tag{1}$$

where ρ is the electrical resistivity (ohms/cm.^{3}) and k the thermal conductivity (calories/cm.^{2}/deg. cent/cm.). Table I shows the temperatures for different electrode materials and voltages.

Thermionic Emission and Thermal Ionization. The very high temperatures indicated in Table I for metal electrodes permit a ready explanation of the discharge obtained at separating electrodes, for there are two ways known by which the minute gap between the electrodes will be made conductive by a sufficiently

TABLE I
TEMPERATURE RISE OF CONTACT

Electrodes	1–Volt	10-Volt	100–Volt
Metal $\rho = 10^{-5}$ $k = 1.0$	3000 deg.	3×10^5 deg.	3×10^7 deg.
Carbon brush $\rho = 0.01$ $k = 0.05$	60 "	6000 "	6×10^5 "
Autovalve arrester disc. $\rho = 100$ $k = 0.02$	0.015 "	1.5 "	150 "

high temperature. One is by thermionic emission from the electrode which is cathode. It is well known that at sufficiently elevated temperatures, current may be

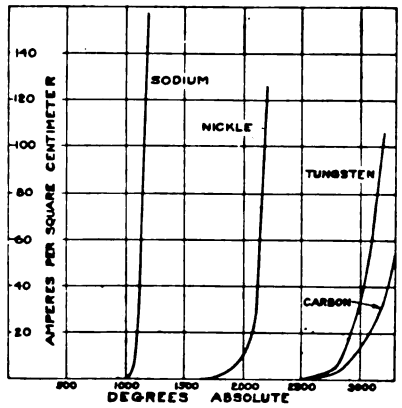

FIG. 1—THERMIONIC CURRENTS FROM METALS

passed from a cathode into space by means of emitted electrons. Fig. 1 gives the relation between thermionic current density and temperature for a few metals.

Another way in which a high temperature may make the space between the electrodes conductive is by thermal ionization of the gas or vapor there. Saha[2] showed that at sufficiently high temperature, gases will undergo a spontaneous ionization which will render them conductive. Fig. 2 gives for various gases the current density at the cathode as a function of temperature calculated from Saha's equation and the theory of

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2. *Phil. Mag.*, **40, p. 472, (1920).**

Langmuir[3]. Since the vapor given off by a metal has the temperature of the metal, if the last contact is sufficiently hot, the vapor which it gives off will be highly conductive.

Examination of Figs. 1 and 2 shows that, to obtain high current densities, either by thermionic emission or by thermal ionization, temperatures in excess of the boiling points of the electrodes will be required. At first sight this presents a difficulty, as it may be thought that the rapid vaporization of the electrodes with the accompanying absorption of latent heat would prevent further rise of temperature of the contact. However, at any particular temperature, the rate of vaporization from a surface is finite, whereas the energy input density into the contact becomes infinite as the contact area approaches zero. Hence the vaporization cannot limit the temperature of the last contact point. The temperature of the last contact will be prevented from reaching the values of Table I only by current being diverted from it into the surrounding space or vapor.

Opening of Switch Carrying Current. The preceding

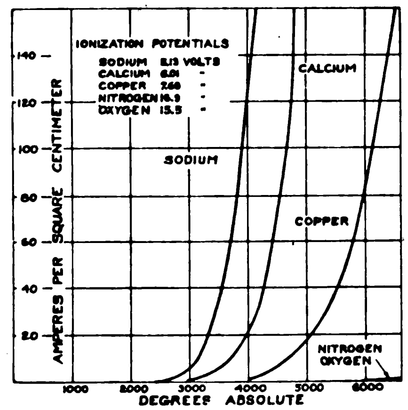

Fig. 2—Thermal Ionization Current Densities

considerations show that the opening of a switch with metal or other low-resistivity electrodes will always be accompanied by a discharge if there are more than a few volts in the circuit, and this will be true regardless of the medium in which the switch is placed, whether it be air, oil, or even high vacuum. If the circuit voltage is more than 15 or 20 volts, this discharge will change over into an arc discharge when the contacts become completely separated. This arc will be stable with very small electrode separation, but may become unstable when the electrode separation is increased.

As Table I shows, it is possible to increase the voltage necessary to start an arc at a switch contact by raising the electrical resistivity of the electrode material. This was mentioned in a paper on the "Autovalve Arrester"[4] and Fig. 3 is reproduced therefrom. The parabolic form of this curve is predicted by equation (1).

Switch in High Vacuum. Before these considerations were appreciated, the author believed that in a sufficiently high vacuum, arcless operation of a switch could be obtained even with relatively high voltage. Accordingly some experiments were carried out under his direction by Mr. W. J. Cahill. The tube was constructed as shown in Fig. 4. The contacts were held together by one of the supporting arms being a steel spring, and they were pulled apart by the action of the coil shown upon the iron armature

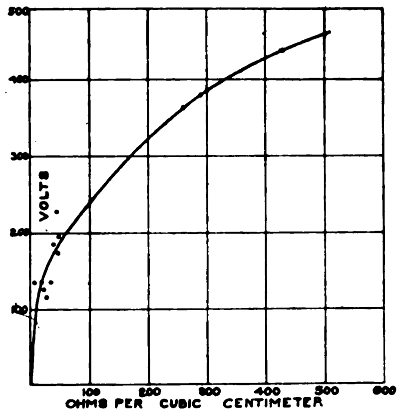

Fig. 3—Voltage to Draw an Arc by Contact

connected to the movable contact. The contacts could be changed, being held in place by a screw and nut.

The following combinations of electrodes were tried: Cu-Cu; Fe-Fe; Ni-Ni; Ni-Fe; Ni-Cu; C-Fe; C-Ni; C-Cu. The contact was placed in a 110-volt, d-c. circuit, with

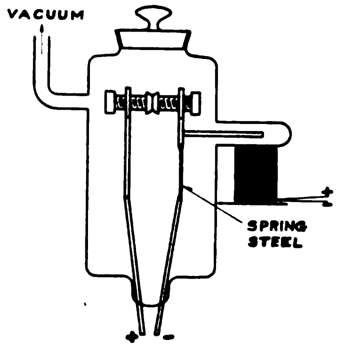

Fig. 4—Vacuum Switch

current controlled by a rheostat. In no case was inductance purposely introduced.

The tests showed that even with a vacuum of 0.001 mm., a luminous flash was produced with currents as low as one or two amperes. As the current was increased in strength, the flash became more intense, and appeared to persist for a longer time. The contacts quickly roughened under repeated service, and usually failed at from 40 to 50 amperes by welding together on closing. The best results were obtained with the carbon nickel combination, which could be made to work at 45 amperes at the rate of five or six times a minute.

The reason for the disappointing results is quite evident. It was impossible under the conditions of the

3. G. E. *Review*, 27, p. 449, (1924).
4. A. I. E. E. Journal, January, 1926, p. 3.

test to avoid a high temperature at the last contact. This meant volatilization of the electrode, and momentarily an arc carried in the electrode vapor. This arc would be very rapidly extinguished by the quick condensation of the electrode vapor, so that the principal obstacle to the practical application of the vacuum break was the consumption and roughening of the electrodes, and the difficulty of getting enough pressure upon the contacts to overcome the effect of this roughening.

Sparkless Commutation. The commutation of current in the ordinary d-c. generator and motor is perhaps the best example of continual opening and closing of heavy current circuits without arcing. It is interesting to consider present practise in the way of voltages and brush resistivities in the light of Table I. The voltage per bar on d-c. machines is usually from 15 to 20 volts, and in the commutating zone this is reduced by means of interpoles to less than a volt or two. Carbon brushes for d-c. service have resistivities from 0.001 to 0.01 ohm per cm.[3] Looking at the second example in Table I, we see that one volt gives a temperature rise of 60 deg., whereas 10 volts gives a prohibitively large temperature rise. Thus it appears that the limits for successful commutation are determined by the temperature of the last contact of brush and segment.

Contact Drop of Brushes. In the usual theories of commutation, the property of brushes considered is the contact drop of potential. That is, it is found experimentally that when less than a certain (usually rather erratically varying) voltage is applied between brush and commutator or slip ring, only a small current flows,

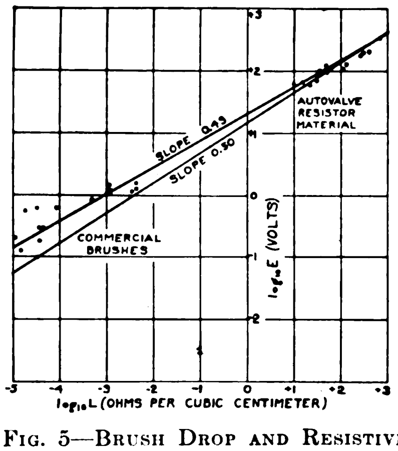

Fig. 5—Brush Drop and Resistivity

whereas if this voltage is exceeded very large current flows. The preceding paragraph suggests that this property of contact drop has a thermal origin, and that the contact drop is that voltage at which the relatively few points of intimate contact reach such high temperatures that conductivity is given to the space around them.

If this were so, then by formula (**1**), for brushes of the same thermal conductivity, there should be proportionality between the square of the contact drop and the brush resistivity. Mr. C. F. Wagner has collected data on commercial brushes, and also data on contact drop of high resistivity material such as is used in autovalve disks. These he plotted on double log paper as is shown in Fig. 5. The best straight line which can be drawn through these points has a slope of 0.43, indicating a quadratic law and supporting a thermal theory of contact drop.

Appendix

Calculation of Temperature Rise of a Contact

Let the line $O\,O$, Fig. 6, indicate a section of the face of one electrode, and let $A\,A$ be a diameter of

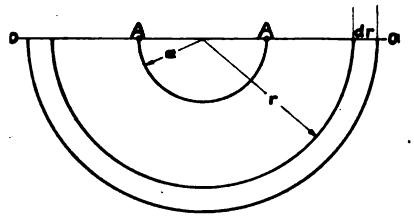

Fig. 6

contact spot, assumed circular. Then one-half of the ohmic drop across the contact will occur between the circle $A\,A$ and the rest of the electrode. It will make the calculation easier and introduce only a small error if we assume that the voltage $\frac{E}{2}$ is applied not at the circle $A\,A$, but between a hemisphere constructed on $A\,A$, and the rest of the electrode. Let the radius of this sphere be a.

The potential at the surface of this sphere is $\frac{E}{2}$, and within the electrode at a distance r from the center of this sphere the potential will be

$$V = \frac{E}{2}\,\frac{a}{r} \qquad (2)$$

The potential gradient will be

$$-\frac{\partial V}{\partial r} = \frac{E}{2}\,\frac{a}{r^2} \qquad (3)$$

The Joulian heat will therefore be

$$\frac{1}{4.19}\,\frac{1}{\rho}\left(\frac{\partial V}{\partial r}\right)^2 = 0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^4} \quad \text{calories/cm.}^3\text{/sec.} \qquad (4)$$

The heat evolved in a hemispherical shell of radius r and thickness $d\,r$ will be

$$2\,\pi\,r^2\,d\,r \times 0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^4} = 2\,\pi\,0.059\,\frac{E^2}{\rho}\,\frac{a^2}{r^2}\,d\,r \quad \text{calories/sec.} \qquad (5)$$

Letting k be the heat conductivity of the material and T the temperature at any point, the heat flowing into the shell from the inner surface will be per sec.,

$$-k \times 2\pi r^2 \left(\frac{\partial T}{\partial r}\right)_{r=r} \text{ calories/sec.} \tag{6}$$

The heat flowing out of the shell from the outer surface will be

$$-k\, 2\pi (r + d\,r)^2 \left(\frac{\partial T}{\partial r}\right)_{r=r+dr} \tag{7}$$

In the steady state, (5) = (7) − (6), hence

$$k\, 2\pi r^2 \left(\frac{\partial T}{\partial r}\right)_{r=r} - k\, 2\pi (r + d\,r)^2 \left(\frac{\partial T}{\partial r}\right)_{r+dr}$$

$$= 0.375\, E^2 \frac{a^2}{r^2} d\,r \tag{8}$$

Hence, dividing by $d\,r$ and passing to limit,

$$-2\pi k \frac{\partial}{\partial r}\left(r^2 \frac{\partial T}{\partial r}\right) = 2\pi \times 0.059 \frac{E^2}{\rho} \frac{a^2}{r^2} \tag{9}$$

Integrating with the boundary condition $T = 0$ and

$\frac{\partial T}{\partial r} = 0$ when $r = \infty$,

$$T = \frac{E^2}{33.5\, k\, \rho} \frac{a^2}{r^2} \tag{10}$$

Letting $r = a$,

$$T = \frac{E^2}{33.5\, k\, \rho} \tag{11}$$

RELATIVITY IN OBLIQUE COORDINATES

During the past three years Professor Vladimir Karapetoff has given talks on "Straight-Line Relativity in Oblique Coordinates" before several Institute Sections, as well as at some conventions of other societies, and has demonstrated his "blue and red" mechanical model of Einstein's fundamental relations. Institute members and readers of the JOURNAL will be interested to know that an article by Professor Karapetoff, containing a detailed elementary theory of restricted relativity in his oblique coordinates and a description of the model, has appeared in the August issue of the *Journal of the Optical Society of America*. Professor F. K. Richtmyer, Cornell University, Ithaca, N. Y., is the Business Manager of the *Journal*; the price of single issues, as long as they last, is 60 cents.

ELECTRICITY TO KEEP TRAINS SAFE

Making 7770 miles of railway in the United States safe against train collisions is no trivial task The accomplishment, as announced by the Interstate Commerce Commission July 28, marks the progress of the first quarter century of automatic train control in this country. This announcement registers the fact that after many years of heartbreaking experiment with all sorts of strange devices for stopping trains from running into danger, electricity has proved the only agency whereby this can do it. Hence the Commission has now given approval for train control schemes protecting 7770 track miles. How fast the Commission may order the rest of the country's mileage under automatic train control remains to be seen.

Most of the automatic control and stop devices in service consist of a magnet, about rail high, beside the track at the point where it enters each signal block. Suspended from each locomotive is another type of magnet. When they pass, a flash of electric current opens a relay which actuates an air mechanism in the engineer's cab so as to set the brakes at once and bring the train to a stop.

It is provided that the engineer can forestall this brake setting by touching a button or small lever as his engine passes over each of the track magnets. He must, therefore, be alert at all times or his train will be taken out of his hands and brought to a standstill whether or not there is immediate danger ahead. This is electricity's guarantee that train operation in the future will be safer.

In 1914 the first permanent installation of a device to stop trains automatically was made on the Chicago & Eastern Illinois which runs south out of Chicago. Since then a vast amount of study and test has produced four or five general types which are now in use. Some exercise only intermittent control over trains operating only at given points. Others are continuous. Some merely apply brakes once, so as to bring a train to a stop with what is known as a "service" or ordinary application of air. Others begin by slowing down a train at one point, setting the brakes up tighter if the train passes another point and finally clamping down the shoes for an "emergency" stop.

Nearly all of them operate in connection with the block signal system. Since electric block signals, after long years of use, have proved that they fail only once in 40 million operations, the attached train control device is not going to suffer much instability by reason of signal system failure. But none of the devices that have been approved are considered beyond the possibility of improvement. Thus the 7770 miles of track and the 3700 engines equipped with the new appliances are considered a vast experimental laboratory to prevent many wrecks and save many lives while loading up to a closer approach to perfection in automatic train control.

Measurement of Transients by the Lichtenberg Figures

BY K. B. McEACHRON*

Member, A. I. E. E.

Synopsis.—*The paper gives the results of a comprehensive study of the effect of transients on the size and appearance of Lichtenberg figures. Sixteen different rates of voltage rise were used, varying from about 20 minutes to 0.1 microsecond to reach a crest value of 25 kv. Results were obtained with transients the crest voltages of which ranged from 5 to 25 kv. The steeper wave fronts were checked with the Dufour cathode-ray oscillograph.*

Calibration curves are given, showing that the positive figures are not much affected by changes in wave front, while the negative figures vary considerably with changes in wave front, especially at the lower voltages.

The positive figures are divided into three types according to their appearance which is found to depend on the rate of voltage rise. It is concluded that for most conditions the size of the positive figures will give a determination of the crest voltage of the applied transient to within approximately 25 per cent.

UNTIL the cathode-ray oscillograph was applied to the measurement of transient phenomena, engineers were unable to determine accurately by experiment the form of a transient voltage or current, the wave front of which occupied only a few millionths of a second of time. Such transients may occur on transmission or distribution circuits during periods of disturbance,—as, for instance, during a lightning storm,—and may cause considerable damage to unprotected apparatus.

Although the cathode-ray oscillograph can be arranged to show the volt-time, ampere-time or volt-ampere relations, yet there is need of a device which may be used to record these disturbances with fair accuracy at the same time involving a small amount of equipment so that a large number of them can be spread over the systems of the country at a comparatively small cost.

Lichtenberg Figures

If a sheet of insulating material, such as hard rubber or glass, is placed on a metal sheet and an electrode of any shape is allowed to rest on the upper surface of the insulating material, a Lichtenberg figure will be formed by the application of voltage between the electrode and the metal sheet. The figure may be made visible by the use of chalk dust which may be applied to the insulating surface before or soon after the application of voltage. A permanent photographic record of the figures can be made by placing a photographic film between the electrode and the insulating plate with the emulsion side in contact with the electrode.

A large amount of work has been done with these figures in the effort to discover their exact meaning and the variables which control the figures. Among those who have experimented with them may be mentioned P. O. Pederson[1], Toepler[2], Przibram[3], and others[4], all of whom have made notable contribution to the solution of the problem of the proper understanding of the Lichtenberg figures. Peters[5] applied the Lichtenberg figures to the study of transmission line transients, and suggested means for making connections to the transmission line to determine supplementary information about the transient. In order that the surges might be recorded with respect to time, Peters made use of a moving electrode, the complete instrument being termed the klydonograph.

Cox and Legg[6] later described some of the results obtained on transmission systems by using the revolving electrode type and described an improved klydonograph which made use of a roll film. As a result of tests with the klydonograph, Cox and Legg concluded that the relation between the size of figure and crest value of the transient was not appreciably influenced by the wave front between the limits represented by a 25-cycle wave and a wave whose crest is reached in 5 microseconds.

All investigators have found that the positive and negative figures were different in appearance and that when the electrode was positive a larger figure was formed than when the electrode was negative. At times the figures are complicated by tree-like growths which have been ascribed by some to over-loading the film, but this does not always seem to be the case as they are sometimes found at lower crest voltage than that which at other times does not produce them. In the practical interpretation of the figures, it seems to be necessary to neglect these effects until their meaning is known.

Effect of Wave Front

The author is not aware of any systematic work that has been done having for its object the calibration of the figures with respect to the form of the voltage transient. Up to the present time, the figure has been regarded as not being much affected by rate of voltage application and therefore the present investigation was undertaken to determine, if possible, the relation between the size of the figure and the rate of voltage application, as well as the crest value.

A transient, such as that shown in Fig. 1, consists of three major parts; the front, and the part we may call

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*Lightning Arrester Engineering Department, General Electric Company, Pittsfield, Mass.

[1]For all references see bibliography.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

the body for want of a better name, and the tail. In the simple wave of this kind, presumably each of these parts may play a role in the production of the Lichtenberg figure. The investigation to be described in this paper is concerned altogether with the front of the wave, as the rate of voltage rise and the crest value of voltage appear to be the dominant factors in determining the characteristics and the size of the figures.

To make the work as complete as possible, tests have been carried out covering a wide range of wave fronts, the slowest being slower probably than any ever obtained in practise, while the fastest are probably as fast as any that ever occur in service, being but a few hundred feet in length. Sixteen different wave fronts at five different voltages were used and, except at the very slowest, oscillograms were taken of each voltage application. Every care was taken with the shorter waves to eliminate the effect of reflection and to keep the oscillation on the wave front to a minimum. This has been possible only through the use of the Dufour cathode-ray oscillograph[7] the voltage dividing system of which was connected directly across the electrodes producing the Lichtenberg figures, using leads only two or three feet in length.

It would have been desirable perhaps to have used

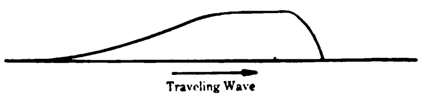

Fig. 1

a wave throughout having an initial value of de/dt kept constant up to the crest value of voltage; yet, with the steepest wave this limitation would have complicated the test seriously without adding much to the practical value thereof.

Voltage and Time Calibration

The sphere-gap was used as the primary means of determining the crest value of voltage of the transient. With the slower waves the crest potential of which was reached in times longer than 10 seconds, it was possible to check the sphere-gap against a static voltmeter and also against meters located in some of the low tension circuits. The time for the slow waves was conveniently determined with a stop watch.

Within its range, the electromagnetic oscillograph record gave the time calibration of the transient, the time being based on a 60-cycle wave recorded on the same film. The transients above the range of the electromagnetic oscillograph were recorded with the Dufour cathode-ray oscillograph with time scale calibrated by the use of a wave meter. With the type of circuit used, the wave front could be calculated quite accurately and, except for the oscillations which in most cases were successfully removed, the oscillograms checked the calculations within the experimental error in practically every case except for the steepest waves where stray capacities become of importance. In all such cases, the oscillogram after being checked carefully was assumed to be correct.

Circuit Arrangements

The slowest waves were obtained with the circuit given in Fig. 2 in which the condenser C was charged slowly by the use of a motor driven regulator connected in the primary of the charging transformer. The

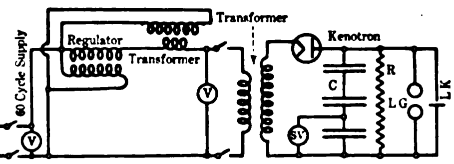

Fig. 2—Connection Diagram for Slow Waves Using Motor-Driven Regulator
Time to reach crest 20 min. 55 sec.

reduction gears were such that, for the longest wave front, 22 minutes were required to reach a crest value of 25 kv. The limit of this method was about a 12-second front.

Other circuits used were similar to that shown in Fig. 3, in that a capacity C_1 was allowed to discharge in another capacity C_2. By varying the amount of capacity employed, together with appropriate values for series resistance connected between the condensers, the desired changes in wave front were obtained. A sphere-gap was used in series between the two condensers for the steeper waves, while with the slower waves, using this type of circuit, a kenotron was connected between the two condensers and the transient initiated by heating the filament at the proper time.

Considerable difficulty was experienced with the steepest waves in decreasing the amount of oscillation on the wave front. The rate of voltage rise was ex-

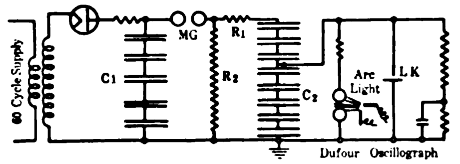

Fig. 3—Connection Diagram for Voltage Transients
Time to reach crest 1.0 sec.—0.1 microsecond

tremely rapid, being 100 kv. per microsecond. The final circuit used was physically quite small with all connections made with conductors having a high uniform resistance to aid in damping out the oscillations. Such a wave front is shown in Fig. 13.

Results—Effect of Changes in Wave Front

The Lichtenberg figures were taken, using a piece of plate glass 20.3 cm. × 25.4 cm., 3.8 mm. thick, with a cylindrical brass electrode 1 cm. in diameter in contact with the photographic film. The films, which were East-

man's super speed portrait films, were placed on the glass plate with the emulsion side in contact with the electrode. On the reverse side of the glass plate and opposite the electrode was a lead foil so connected that the electrode and foil was of opposite polarity. The parts were arranged in a light-tight box with the electrode projecting, to which connections were conveniently made, as shown in Fig. 4.

The results are plotted in terms of the radius of the

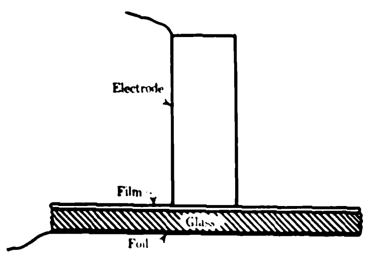

FIG. 4—ARRANGEMENT OF PARTS OF LICHTENBERG CAMERA

figure plotted against slope of the wave front in volts per microsecond for five voltages, 5.5 kv., 9 kv., 12 kv., 17 kv., and 25 kv. (All voltages are crest values). The curves for the positive figures are given in Fig. 5 and for the negative figures in Fig. 6.

Notwithstanding the precautions taken to control all of the known variables, the plotted points show considerable variation which is most marked with the shorter waves and at 17 kv. and 25 kv. For all voltages, the positive figures increase in size as the wave becomes steeper, until a rate of rise of between one kv. per

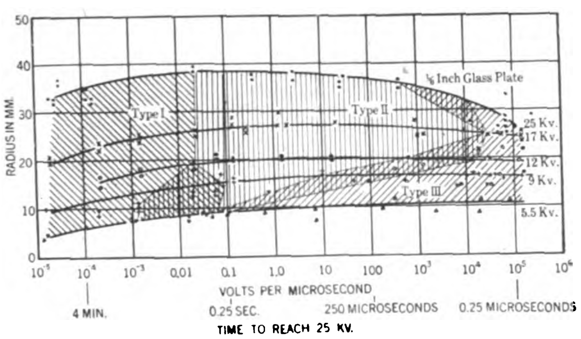

FIG. 5—VARIATION OF POSITIVE LICHTENBERG FIGURES FOR DIFFERENT CREST VOLTAGES AND RATES OF VOLTAGE RISE

microsecond and 10 kv. per microsecond is reached. With wave fronts steeper than this, which corresponds to about a 60-cycle front, the lower voltage figures remain constant in size while the 17-kv. and 25-kv. figures decrease somewhat at the steepest points. Fig. 5 has been divided into three zones which are determined from the appearance of the positive figures and will be discussed in connection with the different types of figures.

The negative figures were less satisfactory at the slow rates of voltage rise than were the positive figures, it sometimes being difficult to separate what appeared to be corona from the Lichtenberg figure. The results do indicate a rather abrupt increase in the size of the negative figure between 0.001 volts per microsecond and 0.01 volts per microsecond. As the voltage rises faster and faster, the negative figure increases in size, the greatest percentage change occurring with the lower voltages. For instance, the figure at 5.5 kv. increases from about 0.2 mm. to 13. mm. when the front changes from 0.01 volts per microsecond to 100,000 volts per microsecond. At 9 kv. the radius changes from 0.5 mm. to 2.4 mm. when the wave front changes through a similar range. The radius at 25 kv.

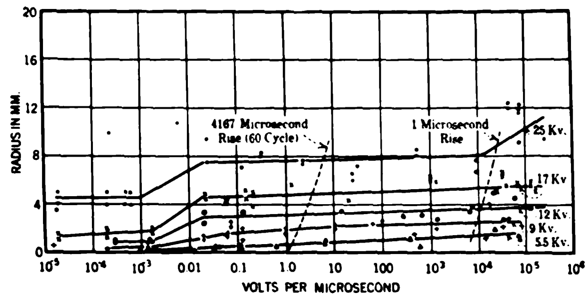

FIG. 6—VARIATION IN SIZE OF NEGATIVE LICHTENBERG FIGURES FOR DIFFERENT CREST VOLTAGES AND RATES OF VOLTAGE RISE

shows a sudden increase for fronts steeper than 10,000 kv. per microsecond.

Using the curves in Figs. 5 and 6 as representing the average values from the data, calibration curves have been drawn as given in Fig. 7. These curves show that the average positive figures are not appreciably affected by wave front except for the highest voltage and steepest front. The variation between the slowest and fastest waves for the negative figures is much

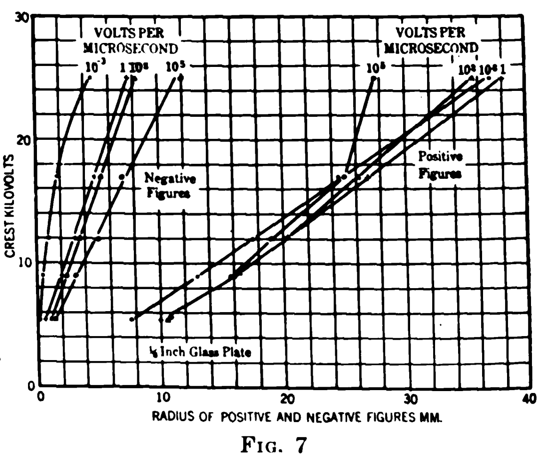

FIG. 7

greater than for the positive and should be considered when determining the voltage from a negative figure. At 17 kv., an increase of nearly 50 per cent takes place when the wave front changes from that corresponding to a 60-cycle wave to one which rises to 17 kv. in 0.1 microsecond, while, for lower values of crest voltage,

the variation is much greater. Some idea of the wave front may be determined by the comparative sizes of the positive and negative, but there is sufficient variation among pictures at the same wave front to make such a procedure doubtful for everything except very approximate results.

Appearance of the Figures

It is possible to divide the positive figures according to appearance into three definite type forms with respect

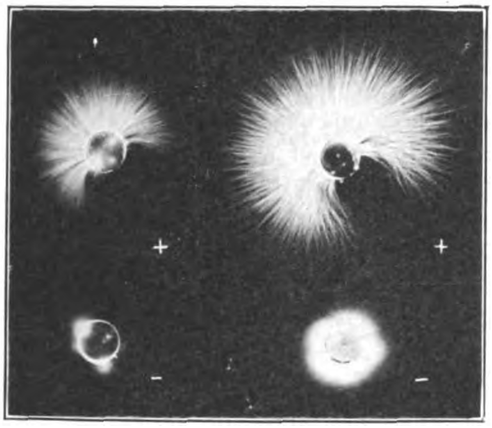

Fig. 8—Lichtenberg Figures Produced by a Very Slow Rise in Voltage (Type I—Positive Figures)

A. *P L*—20519 *R* 17 kv. in 840 sec. B. *P L*—20512 *R* 25 kv. in 85 sec.

to rate of voltage rise on the electrode. These three types are shown in Figs. 8, 9, and 10, type I being the slowest while type III represents the greatest rates of voltage rise.

Type I consists of fine straight lines emanating from

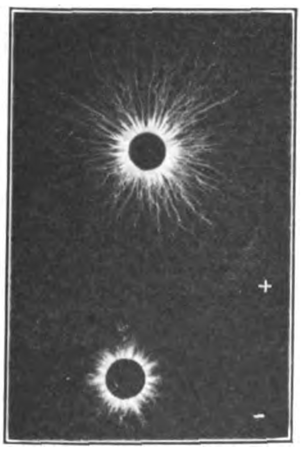

Fig. 9—Lichtenberg Figures Produced by a Fast Transient (Type II—Positive Figure)

P L—20573 *L*—21.6 kv. in 48 microseconds

the center and perhaps extending only partially round the entire electrode. The appearance is much like that of fine hair being blown out by some force at the center. As the rate of voltage rise becomes smaller, both the number of hairs and their length decrease until, in one case with a 6-second wave at 5.5 kv. crest, only five hairs were found, their length varying from 7.5 mm. to 8 mm. However, with a 6-minute front at the same crest voltage, the length of the hairs had been reduced to 4 mm., while the number of hairs had increased to perhaps 30 or 40, bunched in two or three small tufts. Some representative type I, positive figures are shown in Fig. 8.

The negative figures become smaller and smaller with decreasing rates of voltage rise until they disappear altogether or become so indefinite and indistinct that they cannot be measured.

In appearance, type II figures are quite different from type I being characterized by crooked lines which are likely to have sharp turns or elbows near the ends and usually split or branching. Sometimes short projections like thorns appear, but these belong more

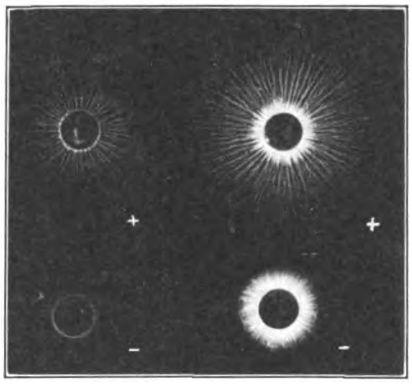

Fig. 10—Lichtenberg Figures Produced by Very Fast Transients. (Type III—Positive Figures)

A. *P L*—20607 *L* 7.3 kv. in 0.1 microseconds. Produced by transient shown in Fig. 12 B. *P L*—20605 *R* 17.8 kv. in 0.15 microsecond. Produced by transient shown in Fig. 13

to type III than to type II. Fig. 9 shows a typical figure of this type. The so-called slips are quite likely to have type II figures at the ends, even though the body of the figure is of another type. It should be noticed, also, that with type II figures, there is almost no crossing of lines even though the voltage was sustained for an appreciable length of time compared to the wave front.

The figures which have been called type III exhibit characteristics very different from either type I or type II. Type III figures as shown in Fig. 10 are recognized by their straight radial lines, having rather broad bases with splits and thorns. In type III figures, the lines do not cross and once seen it is not difficult to recognize a figure of this type indicating as a rule waves of quite steep fronts.

The voltage and frequency at which the three different types of figures are found are shown in Fig. 5 where the three types of figures are indicated. Some overlapping takes place where two types are found in the same

figure. At the 5.5 kv., it is interesting to note that the range of wave fronts over which type II figures appear is very small, and in fact they are not found alone at this voltage, always being mixed with either type I or type III figures.

The negative figures undergo considerable change in appearance as the wave front becomes steeper, but the change is gradual and it is not possible, using the data now available to draw definite limits or to divide them

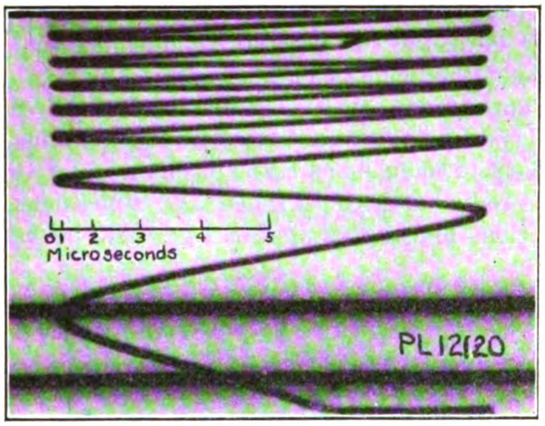

Fig. 11—Dufour Oscillogram of Transient Voltage
21.6 kv. in 48 microseconds. Corresponding to Lichtenberg Figure shown in Fig. 9.

into types. In Figs. 9 and 10 representative negative figures are given, corresponding to the wave fronts shown in Figs. 11, 12 and 13. The slow negative waves as in Fig. 8 show a rather hazy indefinite outline

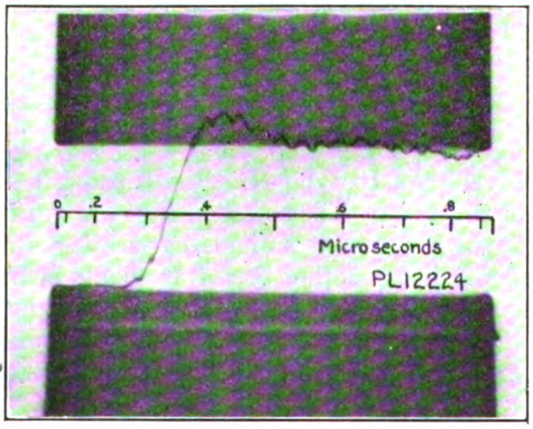

Fig. 12—Dufour Oscillogram of Transient Voltage Retouched
7.3 kv. in 0.1 microsecond. Corresponding to Lichtenberg Figure shown in Fig. 10.

with a tendency to concentrate in tufts. These figures are difficult to measure and look much like photographs of corona.

With steeper waves, as in Fig. 9, radial sectors of exposed film appear with more or less definite unexposed space between. Superimposed, many short crooked lines are frequently found not often extending beyond the exposed radial portion. While this form of negative is easier to measure than that obtained with the very slow waves, yet the limit of the figure is not sharply defined.

Very short waves produce a negative as in Fig. 10 in which the radial sectors are clearly defined and the limit of the figure is quite definite. Not only are the sectors more sharply defined but the width at the circumference of the figure is reduced, the space being occupied by a larger number of sectors. While crooked lines superimposed on the figure appear frequently, they are often less prominent than those seen with slower waves as in Fig. 9.

Oscillograms

Three oscillograms are shown in Figs. 11, 12, and 13 to indicate the form of waves actually applied to the photographic film when taking the Lichtenberg figures.

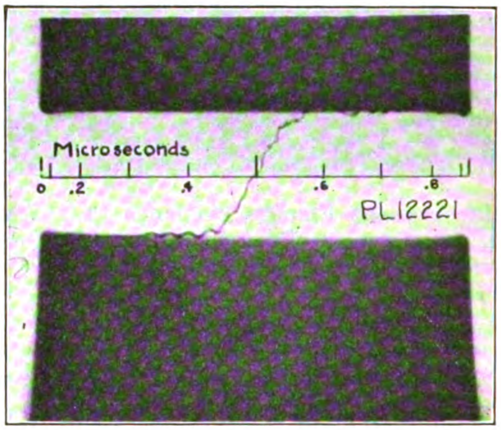

Fig. 13—Dufour Oscillogram of Transient Voltage
17.8 in 0.15 microseconds. Corresponding to Lichtenberg Figure shown in Fig. 10.

These oscillograms were taken with the Dufour cathode-ray oscillograph and show some of the wave fronts used in making the Lichtenberg figures shown in Figs. 8, 9, and 10. In Fig. 11 is shown an oscillogram of the wave taken at the same time as film PL-20573L shown in Fig. 9. This film shows that the voltage rose to its maximum (21.6 kv.) in 48 microseconds the average rate of voltage rise being 450 volts per microsecond while the maximum rate is 1800 volts per microsecond. The film shows that the final voltage was attained without oscillation and that the voltage dropped very slowly compared to the front after reaching its crest. All of the waves used in this investigation, as a rule, had long tails as compared with the front, so as to be sure that the tail did not disturb the results.

As the time to rise to maximum voltage was reduced, the difficulty of getting a smooth wave increased, but that a fair degree of success was finally attained is seen in Fig. 12. This film shows that a voltage of 7.3 kv. was reached in 0.1 microsecond which is equiva-

lent to an average rate of rise of 73,000 volts in one millionth of a second (Lichtenberg figure PL-20607L, Fig. 10). While some oscillations are present, their amplitude does not appear to be sufficient to make them a matter of importance.

Another film in which a still greater rate of voltage rise is recorded is shown in Fig. 13. Here the average rate of rise of potential is 120,000 volts per microsecond. The Lichtenberg figure corresponding to this wave front is shown in Fig. 10 film PL-20605R.

Films similar to these were taken for every voltage application when making Lichtenberg figures and it can be stated that for waves having a longer front than 10 microseconds any oscillations which were present were negligible and that for the shortest waves such oscillations did not exceed 20 per cent of the crest voltage.

It is interesting to note that when working with these figures the impression is gained that the presence of oscillations increases the distinctness and clarity of the figures and that this is particularly true of the negative. While this as yet is only an impression, yet the cleanest figures always were associated with the waves having oscillations on the wave front.

Conclusions

As a result of this investigation, it can be definitely stated that the size and appearance of both positive and negative Lichtenberg figures are dependent on the wave front as well as on the crest voltage.

Throughout the range of wave fronts probably found in service, the size of the positive figure is not much changed by a change in wave front only, except at voltages close to the upper limit of potential where a decrease in the size of figure is indicated with very abrupt fronts.

The positive figures may be divided into three type forms which are partly determined by wave front and partly by the value of the crest voltage. It is possible to gain some idea of the steepness of the front from the appearance of the positive figure.

The size and appearance of the negative figures are considerably affected by changes in wave front, the steepest waves always giving the largest figures. The percentage change with a constant crest voltage applied is greatest for the lower voltages. The change seems to be great enough so that it cannot be neglected. The negative figures change in appearance with increasing steepness of wave front, but the changes are so indefinite that it is only possible to state that a particular negative figure probably represents a fast wave or a slow wave.

No value is given for the possible variation in radius of figures with identical wave front from the average, although the usual variation is probably not greater than 25 per cent. Occasionally, one will be found where the figure is 50 per cent or more, larger or smaller than the average for that particular wave. There seems to be some tendency for the greatest variations to occur with the steepest wave fronts.

The curves which have been given apply to apparatus of certain characteristics and should not be applied to figures taken with a different dielectric than used here or for other different conditions. It seems likely, however, that similar results will be found with other apparatus constants although the values would be different.

Additional work is being done with the cathode-ray oscillograph in an effort to determine how the Lichtenberg figures grow and the reasons for the various characteristics which they exhibit.

The author wishes to express his appreciation of the work of E. M. Duvoisin and T. Brownlee, who have supplied all the figures and most of the oscillograms, and to E. J. Wade for his valuable assistance, particularly in arranging the circuits so as to avoid oscillation.

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CORRESPONDENCE

To the Editor:

On page 783 of the issue of the Journal of the A. I. E. E. for August, 1926, there is an obituary notice of the late Charles E. Scribner, from which I quote as follows: "Mr. Scribner was a well-known electrical inventor, having taken out almost 500 patents during the course of his active service. After the death of Steinmetz, he was credited with holding more patents in the electrical field than any other man, save his friend, Thomas A. Edison," etc., etc.

In the interest of accuracy, I wish to state that Professor Elihu Thomson, of the General Electric Company, has approximately 700 United States patents alone, most of them, of course, relating to the electrical field.

John A. Mc Manus

Electrical Machinery

Annual Report of Committee on Electrical Machinery*

BY B. L. BARNS, Chairman of Subcommittee on Annual Report

To the Board of Directors:

The activities of this committee during the past year have been carried out on a plan of organization comprising a number of subcommittees as outlined in Mr. H. M. Hobart's report to the President and Board of Directors on the Development of the Activities of the A. I. E. E. Technical Committees under date of January 19, 1925. This report is under consideration by the Committee on Technical Activities to determine the advisability of recommending it in whole or in part for all of the technical committees. The scope of the Electrical Machinery Committee's activities has been based on the recommendation contained in a report made by Mr. A. W. Berresford as chairman of a Special Committee to Review Technical Activities of the A. I. E. E. under date of January 23, 1924.

During the past year the Electrical Machinery Committee has been more active in standardization work. A subcommittee on standardization has been organized under the chairmanship of Mr. J. C. Parker which is functioning in an advisory capacity to the Institute's Committee on Standardization in matters concerning electrical machinery. The committee on Electrical Machinery, through a subcommittee under the chairmanship of Prof. V. Karapetoff, is also sponsoring research work affecting standardization and advancements in the art and is collaborating with the Committee on Research.

That part of the Electrical Machinery Committee's work which has resulted in the most tangible accomplishments has been the procuring and reviewing of suitable papers on various subjects which have been presented under the auspices of this committee at the regular and regional meetings. The following table shows the number of papers under different classifications that have been presented during the year.

Factors which affect design of electrical machinery...	5 papers
Generator design and construction................	8 papers
Motor design and construction.....................	4 papers
Transformer design and construction..............	2 papers
Total........................	19 papers

*Committee on Electrical Machinery:

H. M. Hobart, Chairman, General Electric Co., Schenectady, N. Y.
J. C. Parker, Vice-Chairman, Brooklyn, N. Y.

C. A. Adams,	L. L. Elden,	P. M. Lincoln,
H. C. Albrecht,	G. Faccioli,	A. M. MacCutcheon
B. F. Bailey,	W. J. Foster,	F. D. Newbury,
B. L. Barns,	Harold Goodwin, Jr.	N. L. Pollard,
B. A. Behrend,	J. I. Hull,	R. F. Schuchardt,
A. C. Bunker,	V. Karapetoff,	C. E. Skinner,
James Burke,	A. H. Kehoe,	A. Still,
Walter M. Dann,	A. E. Kennelly,	R. B. Williamson.

Presented at the Annual Convention of the A. I. E. E., at White Sulphur Springs, June 21-25, 1926.

In preparing a review of the development or advancement of the electrical machinery art one is inclined to turn first to those new types of machines that have developed and those machines which represent new records for high rating or size or voltage. The research work, whether it be mathematical, chemical, or physical, by which new types and high ratings are made possible is less spectacular but of fundamental importance. The enumeration of new high water marks of ratings may not of itself appear to be an index of an advancement of the art but there are often many details and problems involved in the successful design and manufacture of such machines involving real pioneer work. Nor is all the engineering pioneer work confined to setting new records of large size. If we would but examine them carefully we would find research and ingenuity written all over the smaller apparatus that we see about us every day and take for granted.

It is, of course, beyond the scope of this report to record even briefly the solution of the many problems involved in the perfecting of new developments, for time and space would not permit, nor is such detailed information available for that purpose. In considering the remarkable things that have been accomplished in building huge machines we should not overlook the importance of the development and improvement of the small apparatus upon which the expansion and growth of the electrical industry is so largely dependent.

Again we take a considerable measure of satisfaction in recording new attainments reached in higher ratings of machines which have been put into successful operation. New records have been made for large capacity all along the line. Larger ratings than ever before obtained have been built in transformers, synchronous motors, induction motors, d-c. motors, horizontal-shaft alternators and turbo alternators.

The following review is classified under headings for convenience in preparation and reference and an attempt has been made to include under each a bibliography of the more important articles that have been published during the year. An attempt has also been made to cover the more important developments that have taken place in Europe as well as in America (the United States and Canada). An apology is offered if important articles or developments have been omitted. Such omissions are entirely accidental.

RESEARCH

This committee now has the following subjects under consideration and it is probable that as investigations advance sufficiently to mention definite results they will be described in the form of papers for presentation at

Institute meetings. These topics are mentioned not so much to record the actual progress made by the Committee as to indicate problems of importance brought to the Committee's attention.

Effect of Altitude on the Dielectric Strength of Insulations. An investigation has been proposed to determine whether it is desirable to draw a distinction between apparatus that is to be used at sea level and high altitudes as regards the insulation tests.

Influence of Expansion and Contraction of Conductors on Insulation Deterioration in Long Machines. This subject has already received a great deal of attention and some valuable experimental work has been done. This subject is becoming of greater importance with the increasing capacities of turbo alternators. Further investigation has been suggested as desirable.

Surge Tests of Insulation. An investigation of this subject is being undertaken to determine whether it is desirable or practical to standardize a test of this sort on the insulation of machines that may be subjected to transient high-voltage conditions.

Hot Spots in Cores of Alternators. Observations made by engineers in Europe have indicated that higher temperatures may be reached in the slots at the ends of a turbo generator core than in the slots at the center of the core. Manufacturers in the United States have reported that they have been unable, from tests made on machines of American make, to substantiate this statement. This may be due to the difference in the design of end windings in Europe and in America.

Evaluation of Conventional Losses. The present A. I. E. E. Standards assign conventional values to certain losses that are known to exist. It is felt that methods should be devised by which these losses may be determined by tests so that the design and tests may be reduced to a more exact science and due credit may be given to designs that are especially meritorious in this respect.

Calorimetric Method of Determining Losses in Alternators. The feasibility of determining the losses and efficiency of alternators by calorimetric methods which are based on the temperature rise of the cooling medium is being investigated.

Stability of Alternators. As distribution systems increase in size and the use of long, high-voltage transmission lines is extended, the subject of stability of generators becomes of greater importance. A study of the possibility of the evaluation or definition of generator stability is being made so that this characteristic may be specified.

Relation between Dielectric Tests on New and Used Machines. This subject has arisen from a consideration of recommended practise in checking the condition of the insulation of a machine that has been in operation for some time.

Non-Destructive Physical Tests on New and Used Insulation. Physical tests of insulation have been suggested as being desirable; accordingly, the subject is being investigated.

During the past year research work has been done on the following subjects that come within the scope of this committee's activities:

Effect of Altitude on Ratings of Electrical Machinery. This investigation was undertaken for the purpose of providing a satisfactory revision of the present A. I. E. E. rules which have been recognized as not being entirely satisfactory.

Copper Eddy-Current Losses. A theoretical foundation for the calculation of no-load copper eddy-current losses in machines has been presented.

Motor Band Losses. Methods of calculating losses in the binding bands of armatures of direct-current machines have been made practicable.

Heating Curves of Electrical Machinery. A further study of the prediction of the heating curves of machines has been presented.

Alternator Short Circuits. The calculation of the transient phenomena resulting from short circuits of the armature windings of alternators has been a subject of study for many years and an accurate method of predetermining the value of the short circuit current is becoming more and more important as the generating capacity of power systems increases from year to year. Two papers have been presented to the A. I. E. E. during the past year dealing with this subject. One of these papers treats the subject on the basis of Kirchoff's law that the vector sum of all the currents at a junction is equal to zero. The other paper is based on the constant linkage theorem, viz: "In a circuit having zero resistance the algebraic sum of the flux linkages of the circuit must remain constant."

Measurement of Stray Load Losses in Alternators. A paper has been presented which has suggested a different method of determining stray load losses than that specified in the present standards, and results of tests have been given.

Ventilation of Turbo-Alternators. During the year this work has been carried forward to a conclusion by the use of small models. Previous calculations and empirical formulas have been checked so that now a complete solution of the complex problem of measuring static pressures in a fluid moving at considerable velocity can be successfully obtained.

Theory of the Synchronous Induction Motor. This subject has received considerable attention in Europe and a number of excellent treatises have been written.

Hydrogen as a Cooling Medium. A further investigation of the problems incident to the use of hydrogen as a cooling medium has been undertaken.

Characteristics of Synchronous Machines. Blondel's theory of two reactions has been extended to include the effect of harmonics and of field excitation in the quadrature axis.

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VENTILATION OF ELECTRICAL MACHINERY

Ventilation, one of the fundamental considerations in the design of electrical machinery, has been a subject of very active study and experimentation. Because the design of turbo alternators involves a relatively greater need of a knowledge of the phenomena incident to the flow of gases through irregular passages, experimental work has been carried out to determine the forms of fans, bafflers and internal ducts which would give the desired cooling effect with a minimum of windage losses by introducing into new machines alternative ventilation schemes which were tried out when they came to test. In this way much valuable and accurate information has been obtained which has been free from some of the uncertainties of theoretical considerations of a very complicated problem. Nevertheless, considerable help has been obtained by building small models and testing them under laboratory conditions to check and verify principles that have been deduced by a theoretical treatment of the problem. Models have been constructed to represent the vent ducts and air passages in the stator core of a turbo alternator and tested to determine the drop in pressure in the several parts of the passage ways. In this way data was obtained by which close approximation can be made of the amount of pressure required to force a given quantity of air through a given machine. Other models have also been tested to determine the most efficient shapes of slot retaining wedges in stators and the best arrangement of spacers in the internal ventilation ducts. All of this work has contributed toward better designs not only of turbo alternators but also of other types of machines.

This committee's report of last year made mention of an investigation into the use of hydrogen as a cooling medium for rotating machinery. The results of this have been published and this method seems to have many advantages that would make it desirable for commercial application and some operating engineers are looking forward to the time when it will be found feasible to use hydrogen for this purpose. Some of the new machines that are now being purchased are being arranged so that they may be readily adapted to the use of hydrogen when the problems peculiar to its use are finally solved.

A few years ago the recognized need of providing clean air for the ventilation of machines, especially large capacity turbo alternators, was met by the use of air cleaning and air washing apparatus which took air from outside the building, cleaned it, and discharged it outside again after it has passed through the machine, probably cleaner than when it came from the washer. This veritable throwing away of perfectly clean air appeared to be an uneconomical procedure and during the past year or more a more rational arrangement of a closed system has been used particularly for large turbo alternators. This system recirculates the same air, cooling it by passing it over water cooling pipes. The advantage of this arrangement has been recognized during the past year for application to other types of machines, it having been adopted for hydroelectric plants and substation equipment. The closed ventilating system necessarily presupposes an abundance of cooling water at low cost.

During the past year an ingenious arrangement has been devised for cooling heavy duty bearings of substation machinery where the water supply for such purposes is expensive. This scheme consists of a closed water circulating system so arranged that the water is cooled by the air used to ventilate the machine.

Although for a number of years sales campaigns have been carried on advocating the use of small fans to increase the heating capacity of radiators in very cold weather this idea has not been applied to the cooling of transformers until this year. By the use of jets of air directed over the surfaces of self-cooled transformers the convection of heat has been greatly accelerated. This development gives promise of many possibilities.

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TESTING ELECTRICAL MACHINES

A renewed interest has been shown in the accurate determination of load or stray losses of rotating machines. The assumption that is made in the present A. I. E. E. Standards that the measured short circuit core loss is equal to the load loss is generally considered to be far from correct in certain types of alternators and there is a general desire for a more accurate method of determining these losses that would be suitable for application to commercial testing. A paper which was presented at the Midwinter Meeting advocated a method of test which was based on measuring the synchronous motor power input when running light under conditions of leading and lagging currents. The discussion of this paper indicated that a calorimetric method of measuring losses has been in use in one of the large factories for several years and that this method is being studied by others. The calorimetric method makes use in different ways of the observed temperature rise of the air passing through the machine. Since closed ventilating systems are being more generally used the determination of the losses by the measurement of the heat absorption by the air cooling equipment seems to offer a satisfactory method of test. These calorimetric methods do not, however, offer means of direct measurement of the so-called load losses but are more suitable for the determination of the total losses under actual load condition. This committee is desirous that suitable commercial test methods be developed for a more accurate determination of the efficiency of large synchronous machines than is now described in the A. I. E. E. Standards.

The testing of large machines on power house settings such as water wheel driven alternators often involves the measurement of losses by the deceleration method. During the past year a chronographic method has been devised for obtaining a simultaneous record of time and revolutions on a paper ribbon.

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TURBO-ALTERNATORS

In this Committee's report of last year, mention was made of a 62,500-kv-a. 1200-rev. per min. turbo generator which had recently been put into operation as the largest single-shaft unit that had been built. During this year two machines of this capacity but of 1800 rev. per min. have been put into successful operation. The step up from 1200 rev. per min. to 1800 rev. per min. has been made possible by the more skillful design of the electrical parts, a better proportioning of the mechanical parts, and more extended multiple ventilation. This increase in speed makes it possible to further extend the upper limit of rating for single-shaft machines to such an extent that two 60,000-kw. units are now under construction and 75,000-kw., 80 per cent power factor generators are being considered. A machine of this rating at 1200 rev. per min. would present difficulties in manufacture because of the great weight of the rotor. Another large turbo alternator that was put into service the past year is rated 66,660 kv-a., 1500 rev. per min., 25 cycles. In France one of 60,000 kv-a., 1500 rev. per min., 50 cycles, is about ready to be put into operation. The description of this generator in a paper presented before the Institute brought out in the discussion some interesting information on the relative design practises in Europe and the United States. The French machine employed deep slots in the stator core for the dual purpose of increasing the reactance and providing axial paths for ventilation. Another feature is the much smaller ratio between saturation and impedance ampere turns than has been considered good practise in America. American practise has considered it necessary to maintain this ratio at near unity while European practise allows it to be as low as 0.5. This difference may possibly be accounted for by the difference in operating practise on the two continents. In America the apparent desire of the operators is to get the maximum output from the generator throughout its period of life, while in Europe, it is said, a generator is usually operated at slightly less than its rated capacity. Another factor has been the general practise in Europe to employ voltage regulators to care for the swings in load and supply the necessary excitation to prevent the

generators from falling out of step while in the United States operating people have insisted upon generators that may be hand regulated and which are not dependent upon automatic regulation for their stability.

It is interesting to note that designing engineers now predict the possibility of building machines having ratings of 75,000 kw., 80 per cent power factor at 1800 rev. per min., 100,000 kv-a. at 1500 rev. per min., for 50 cycles and 40,000 kv-a. at 3000 rev. per min. for 50 cycles. A 25,000-kw., 3000-rev. per min. machine has been built in Europe. It is the opinion of a leading engineer that if greater capacities than 75,000 kw. are demanded by the operating companies they will be obtained by advances in the design and materials applied to the four-pole generator rather than a return to a six-pole design. For very large units there are advantages in the cross-compound arrangement or multiple-shaft design involving two or more generators. A unit of this type having a house generator, in addition to the two main generators and with a total rating of 77,000 kw. has been completed during the past year and another of 80,000 kw. is under construction. An order has recently been placed for a two-generator unit rated at 90,000 kw. Triple shaft units with three generators of combined capacities of 160,000 kw. and 200,000 kw. are being considered.

These very high generator ratings have involved problems concerning mechanical stresses in the rotor due to centrifugal forces and deflection, insulation of the rotor windings and ventilation of the stator. Centrifugal stresses have been provided for by the development of special alloy steels. The limitations of rotor deflection in its relation to critical speed have been largely eliminated by a better knowledge of the mechanics of the problem. Whereas before this was so well understood it was believed that the rotor speed should be well below the critical speed, now the designers are concerned only that the normal speed must not approach any multiple of the first critical speed. Experience has shown that the critical speed is not dependent only on the weight and length of the rotor but that it is influenced by the type and proportions of the stator frame and bearing supports and the design of these parts offers a means of control. The very great pressures on the rotor winding insulation coupled with the expansion and contraction resulting from changes of temperature has necessitated the development of types of insulation for the end coils that will withstand these destructive conditions. In the matter of ventilation, schemes of providing a number of multiple paths have been devised to obtain the equivalent of a short core machine. In some cases as many as 28 parallel paths are provided. For the ventilation of the smaller generators fans mounted on the shafts inside the end bell housing have been used although separate motor driven fans would be more efficient. This arrangement has the advantage, however, of eliminating a separate auxiliary which if it failed to operate would cause the removal of the generator from service. The fan capacity required for the very large generators has exceeded the limit of the type that can be mounted on the rotor and separate fans or blowers are now a necessity. With well designed external blowers, having an efficiency of 65 per cent, a saving in the total losses of the machine would amount to approximately 0.1 to 0.2 per cent at rated load. On the larger machines it is often feasible by the use of external blowers to build them with smaller diameters than would be possible with fans on the rotor. Under such conditions the external blower ventilated machine may show an efficiency of from 0.3 to 0.4 of a per cent higher than the machine with fans attached to the rotor. Besides the better efficiency this arrangement affords another important advantage in that the air passes through the air coolers of a closed system after leaving the fans and before it enters the generator thus extracting the heat put into it by the fans. A material reduction in the temperature of the air entering the generator is obtained as compared with its temperature when the fans are assembled on the shaft. The closed ventilating system with fin-type radiator coolers is now being used almost universally for turbo alternators.

During the year there have been improvements in the Emmet mercury turbine with resulting higher efficiencies.

The 3000-kw. 3600-rev. per min., 20-stage turbine for operation at a steam pressure of 1200 pounds which was mentioned in our report of last year has been put into successful operation.

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WATER-WHEEL DRIVEN ALTERNATORS

American hydroelectric practise still favors the vertical shaft arrangement of alternators to such an extent that about 80 per cent of the water wheel

generators are of this type and the arrangement is more or less standardized with a spider or bridge spanning the top of the armature frame for supporting the thrust bearing which carries the weight of the generator rotor and the water wheel runner. Two years ago several units were built with the thrust bearing beneath the revolving field and no bearing or superstructure above the rotor except a cover or housing. Although there seemed to be a number of advantages to be gained by this so-called umbrella type no further machines have been built 'til this year. A 6250-kv-a., 138½ rev. per. min. generator of this type is now under construction. One manufacturer is using a fabricated construction of welded steel plate to a large extent for the armature frames. The closed ventilation system has been adopted in one large water power station.

During the year a rather formidable number of large capacity alternators both horizontal and vertical shaft have been under construction or installed and the following incomplete list will serve to indicate to what extent machines of large ratings are being used.

3-37,500 kv-a.	12,000 volts,	120 rev. per min.	vertical shaft
3-18,750 kv-a.	6,600 volts,	100 rev. per min.	vertical shaft
2-29,000 kv-a.	.... volts,	300 rev. per min.	vertical shaft
2-25,000 kv-a.	13,200 volts,	450 rev. per min.	vertical shaft
2-20,000 kv-a.	11,000 volts,	200 rev. per min.	vertical shaft
1-17,000 kv-a.	6,600 volts,	375 rev. per min.	vertical shaft
1-17,500 kv-a.	6,600 volts,	100 rev. per min.	vertical shaft
2-25,000 kv-a.	6,600 volts,	90 rev. per min.	vertical shaft
2-54,000 kv-a.	12,000 volts,	187½ rev. per min.	vertical shaft
2-13,500 kv-a.	6,600 volts,	277 rev. per min.	vertical shaft
4-16,000 kv-a.	11,000 volts,	133 rev. per min.	vertical shaft
3-20,000 kv-a.	11,000 volts,	330/360 rev. per min.	vertical shaft
2-15,625 kv-a.	11,450 volts,	257 rev. per min.	vertical shaft
2-25,000 kv-a.	12,000 volts,	300 rev. per min.	vertical shaft
2-18,750 kv-a.	12,000 volts,	150 rev. per min.	vertical shaft
2-15,000 kv-a.	6,600 volts,	171 rev. per min.	vertical shaft
1-21,000 kv-a.	11,000 volts,	138½ rev. per min.	vertical shaft
1-12,000 kv-a.	12,500 volts,	128½ rev. per min.	vertical shaft
1-12,000 kv-a.	2,400 volts,	250 rev. per min.	vertical shaft
8-12,500 kv-a.	14,000 volts,	100 rev. per min.	vertical shaft
2-10,600 kv-a.	12,000 volts,	120 rev. per min.	vertical shaft
2-36,000 kv-a.	6,600 volts,	100 rev. per min.	vertical shaft
2-30,000 kv-a.	6,600 volts,	112½ rev. per min.	vertical shaft
2-10,000 kv-a.	6,600 volts,	180 rev. per min.	vertical shaft
2-33,000 kv-a.	11,000 volts,	360 rev. per min.	horizontal shaft
1-33,000 kv-a.	13,200 volts,	360 rev. per min.	horizontal shaft
2-25,000 kv-a.	11,000 volts,	450 rev. per min.	horizontal shaft
1-20,000 kv-a.	11,000 volts,	375 rev. per min.	horizontal shaft
1-14,444 kv-a.	6,600 volts,	600 rev. per min.	horizontal shaft
1-13,000 kv-a.	12,000 volts,	500 rev. per min.	horizontal shaft
1-13,125 kv-a.	4,400 volts,	225 rev. per min.	horizontal shaft

Although the 65,000-kv-a. units at Niagara Falls are still the largest machines that have been built, larger alternators have been under consideration and will probably be built in the near future. The manufacturers are prepared to build the following maximum rated water-wheel driven alternators of the vertical shaft type and designed to meet the usual run-away speed requirements:

10,000 kv-a. at 720 rev. per min.
20,000 kv-a. at 600 rev. per min.
30,000 kv-a. at 514 rev. per min.
55,000 kv-a. at 400 rev. per min.
80,000 kv-a. at 300 rev. per min.
110,000 kv-a. at 200 rev. per min.
130,000 kv-a. at 100 rev. per min.

The use of welded steel plate stator frames and the substitution of a few separate sole plates for a continuous base ring has appreciably reduced vertical shaft generator weights. Comparisons of construction and actual weights indicate that American designs are at least twenty-five per cent lower than similar European machines.

The past year has set a new record in the maximum capacity of horizontal shaft water-wheel driven generators. Two alternators rated 33,000 kv-a. at 360 rev. per min. were built in the United States for a Brazilian plant and a third was built for a California plant. In Europe a 30,000-kv-a., 500-rev. per min. horizontal shaft alternator has recently been built which has an unusual rotor construction consisting of twin rotors each with its pole pieces and windings mounted side by side on the shaft in a common armature core. This construction was adopted to conform with certain shop and transportation facilities.

The use of automatic or remote control of hydroelectric units is extending. During the past year some 9000 kv-a. units have been put into successful operation being the largest yet constructed for this type of control.

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Diesel Engine Driven Alternators

There has been considerable activity during the past year in exploiting the use of Diesel engines as prime movers for stand-by plants. An installation of this type which is worthy of note consists of three 3125-kv-a, 80 per cent power-factor, 25-cycle, 125-rev. per min. units for the Panama Canal which are probably the largest generators driven by this type of engine.

Transformers

An important consideration in transformer work is the provision of means of dissipating the losses with sufficient rapidity to keep the temperature of the trans-

former within safe limits. In the past this has been accomplished by one of four methods, *viz:*

1. Air-blast, in which air is blown around and through the core and windings.

2. Self-cooled, in which the heat is transferred from the core and coils to the casing by an oil bath and then dissipated principally by radiation.

3. Water-cooled, in which the heat is removed from the oil bath by water cooling coils.

4. Oil-cooled, in which the oil bath is circulated through a cooling apparatus independent of the transformer.

A new method involving an old principle has gained much favor this year. This consists of directing jets of air upward and over the radiating surfaces thereby removing a larger part of the heat by convection than can be done by the natural circulation of air. Some very large transformers arranged for cooling by air jets have recently been completed. The rating of these oil-insulated, air-cooled distributed core type transformers is 30,000 kv-a., 220,000 volts Y, 125,000 volts Y, 10,640 volts delta at 60 cycles and 55-deg. cent. temperature rise by resistance.

The method in which the oil is cooled outside of the transformer tank is more generally used in Europe than in America. This year, however, some very large transformers arranged for this method have been built and installed in America. They are rated 20,000 kv-a., 50 cycles, 72,000-Y, 11,000-volt single-phase, and sea water is used as the cooling medium. Although air-blast transformers are not used to as great an extent as they were many years ago there is still a demand for them for installation in certain localities where the presence of large quantities of oil is considered to be a fire hazard. The largest air-blast transformer yet built was installed this year. It was rated 18,500 kv-a., 25 cycles, 11,800-3,300 volts three-phase and weighed about 43 tons.

The largest self-cooled single-phase transformers ever built were completed this year. They are rated at 20,000 kv-a, 72,450-Y, 13,800 volts, 60 cycles. Likewise the largest water-cooled transformers both in point of rating and physical size have been built this year. These are rated 28,866 kv-a., 220,000-Y, 66,000-Y, 10,750 volts, 60 cycles, single-phase. As will be noticed in the ratings of the above self-cooled and water-cooled transformers tertiary windings are being used to a large extent in large high-voltage power transformers. The tertiary windings being connected delta permit using the star connection for both primary and secondary windings. The tertiary winding also provides a means of connecting a condenser into the system for transmission line voltage regulation without using an independent transformer where the secondary voltage is too high for a condenser winding.

During the past year the largest and highest voltage transformers ever built in the British Empire were completed in Canada. These are designed for a rating of 25,000 kv-a., single-phase, 60 cycles, 154,000 volts and weigh 80 tons each. Twelve of these transformers were built on one order.

A German manufacturer has built the largest capacity transformer ever constructed. By removing the aluminum windings of a 60,000-kv-a. transformer that had been in operation for several years and substituting copper windings a three-phase transformer having a rating of 75,000 kv-a., 110,000 volts was produced. This transformer is now in successful operation.

Probably the most important development pertaining to transformer construction has been the further improvement of and extended use of transformers equipped with load ratio control or devices for changing taps without interrupting the load. Transformers of this type are being extensively used to regulate circulating currents between systems where the flow of energy is in either direction and where each system must maintain its voltage independently of the direction of the flow of energy.

One of the largest units of this latter type is a three-phase self-cooled auto-transformer rated 36,000 kv-a., 66,000 volts, 60 cycles. It is used as a tie between two 60,000-volt systems. The taps are arranged to give 10 per cent buck and 10 per cent boost in nine steps. The total weight of this transformer with operating mechanism and circuit breakers is about 73 tons.

The electrical circuit of this unit is novel in that double transformation is employed to secure voltage control. Electrically, the unit consists of two distinct transformers each provided with a high-voltage and low-voltage winding. The high-voltage windings of each transformer are connected to the 66,000-volt line, one being connected in shunt to the line and the other in series to the line. The shunt transformer contains the necessary taps and ratio adjusters by means of which fractions of the low voltage winding on the shunt transformer can be connected to the low-voltage winding on the series transformer. By varying the taps the desired amounts of voltage either bucking or boosting can be inserted in the high-voltage line through the series transformer. By thus placing ratio adjusters in a separate low-voltage circuit the switching apparatus is protected from abnormal voltages which may arise in the high-voltage lines.

It sometimes becomes desirable for the sake of greater insurance against interruption of service to separate the regulating function into a separate transformer. An interesting example of this consists of banks of three single-phase, self-cooled, power transformers rated 20,000 kv-a., 12,600-13,800 volts, 60 cycles, a three-phase, self-cooled, regulating transformer of 60,000 kv-a. capacity.

Transformers having arrangements for tap changing under load are also being extensively used for electric furnace work.

The extension of the idea of rural electrification has opened up a new field of design in small distribution

transformers for very high voltages. Some 100-kv-a., 110,000-volt transformers have recently been built for this purpose.

During the past year the largest potential transformers were built for use in America. These were designed for use between line and neutral of a 144,000-volt system. They have only one high-voltage bushing, the neutral being grounded to the cover.

The development of successful high-voltage transformers is assisted greatly by accurate knowledge of very high-voltage phenomena which can be obtained only by experimentation at voltages much higher than the actual transformer potentials. During the year a study has been made of transformer and other high-voltage insulation with a 2,000,000-volt lightning generator for the purpose of obtaining practical information in designing apparatus to resist the effects of voltages induced in transmission lines by lightning. High-voltage testing sets to provide voltages as high as 2,100,000 volts have been constructed. These consist of 350,000-volt transformers connected in series or in chains, each succeeding unit being insulated from ground by supporting it on insulating cylinders.

Improvements have been made in the temperature-indicating devices that are being used more generally to check the actual operating conditions of service transformers. A model has been produced which is suitable for use with subway transformers.

Of special interest to radio telephone engineers and enthusiasts is the development of a transformer for use with the ignition systems of oil heaters which successfully eliminates radio interference trouble, a serious objection to electric ignition in these devices heretofore. This transformer is provided with an internal magnetic blocking filter as well as low-voltage and high-voltage filters. During the past year the largest high-voltage oil-immersed reactors were constructed that have ever been built. They were rated 1300 kv-a., 3000 volts for operation on a 73,000-volt, 60-cycle circuit. A distinctive feature of these reactors is that they were provided with shielding coils to prevent the stray magnetic field entering the steel tank and setting up additional losses. Air-cooled reactors have presented a serious difficulty due to the fact that they would flash over when a failure occurred on the circuit in which it is connected if any conducting material were lodged between the turns. An investigation has been carried out to determine a suitable insulation for the conductor of this type of reactor which indicates that a heavy asbestos covering will prevent flashovers from this cause.

A new transformer connection having 100 per cent apparatus economy for transformation from two-phase to three-phase, or vice versa, has been devised which has been described in a paper presented to the Institute.

Some very large single-phase transformers that are quite novel in certain respects have been built recently in Europe for 16⅔-cycle railway work. They have three windings so arranged that power may be supplied from any one winding to either one or both of the other two. One of the two cores carries a 132,000-volt winding, the other carries a 66,000-volt winding and a 15,000-volt winding is divided into four parallel sections on both cores. It is stated that with this arrangement the bus bars and oil switches are not necessary on the 15,000-volt side. These transformers are rated 11,000 kv-a. and the total weight including oil is 117 tons.

A new protective device for large transformers has been developed in Germany which is called the Buchholz Relay. The operation of this relay is based on the fact that practically any trouble in an oil-insulated transformer will create gases which rise to the surface of the oil. A small amount of gas will cause the relay to operate. This relay will detect incipient troubles that will not actuate a current operated device and will disconnect the transformer before great damage is done. This relay can be used where the differential relay scheme cannot be applied.

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D-C. Machines

A new record has been set in direct-current motor capacity by the construction of an 8000-h. p., 40-rev. per min., single-armature blooming mill motor. Several 7000-h. p. reversing mill motors have been built and the power for the first edging rolls to be equipped with electric drive is supplied by two motors of 2000 h. p. each. The simplicity and flexibility of speed control of

direct-current motors make them very desirable for variable speed drives and there has been considerable activity in the construction of large motors for steel mill work.

A new type of armature winding has been developed and applied to many commercial machines. This winding, because of the shape of the coils, is called "Frogleg" and is a combination of a wave winding and a multiple winding arranged so that the armature is cross-connected by the wave winding and all cross connections at the commutator and at the back of the armature are eliminated. This type of winding provides complete cross connection which is very desirable for good commutation. The winding is arranged so that each slot contains four bars, two of which are in the wave winding circuit and two in the multiple winding circuit, and each commutator bar is connected to both circuits.

At a recent exhibition in Europe a direct-current generator rated at 12,000 amperes and 5 volts was shown.

The use of multiplex windings has, in general, been avoided due to the failure of these types to properly commutate in certain instances and to the uncertainty of satisfactory results. A paper has been presented calling attention to certain rules that must be observed when multiplex windings are used.

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Frequency Changer Sets

During the year a 40,000-kw. frequency changer set of the cascade induction motor type has been built and put into service and two sets of this capacity having both machines of the salient pole type are under construction, one of which is arranged with a spring support for the 25-cycle generator so that it may be used for single-phase power. A 7500-kv-a. set for converting from 60-cycles three-phase to 25-cycles single-phase is being built with the stator of the single-phase generator spring supported. The purpose of the spring support is to minimize the effect of the vibration incident to single-phase operation at low frequencies.

An automatic control equipment has been arranged to remove the field excitation of the motor and reduce that of the generator of a frequency changer set when a disturbance occurs on the motor circuit and again to restore the excitation when the line voltage is normal. This type of control called for a special design of the pole face winding to enable the motor to resynchronize while the generator is carrying part load at the reduced voltage. The benefit of this arrangement has been a greatly improved service due to a material reduction in the length of the interruptions.

Synchronous Condensers

Considerable advancement has been made recently in the design of synchronous condensers toward the reduction of losses. In sizes above 5000 kv-a., the losses are now as low as from 1.75 per cent to 2 per cent. The extension of high-tension distribution systems and higher transmission voltages has expanded the field of line voltage regulation by the use of synchronous condensers very rapidly. The largest condenser ever built, rated at 40,000-kv-a., 600 rev. per min., was recently put into operation in connection with a 220-kv. transmission line. The important consideration of keeping the losses down to a minimum has resulted in a strong tendency toward higher speeds. A considerable number of machines of 25,000 kv-a. to 40,000 kv-a. at 600 rev. per min. and of 15,000 kv-a. at 720 rev. per min. have been built. The disadvantage of the noise at these high speeds has been overcome largely by a totally enclosed construction.

An interesting development in the automatic control of synchronous condensers for line voltage regulation has been an installation of a 1000-kv-a. condenser provided with a voltage regulator arranged to start and stop on voltage indication. The condenser is at the end of a long transmission line and remains connected to the line through the starting tap in case of complete failure of power, thus providing a reactance for line protection when power is restored.

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Synchronous Motors

The past year has been marked by a further extended use of synchronous motors for many applications where induction motors have formerly been considered necessary. This extended use has been reflected in the development of complete lines of general purpose synchronous motors. The construction of a 9000-h. p., 6600-volt motor is of particular interest because of its application to the main roll of a steel mill and because it is the largest continuous rated motor of any type to be applied to industrial purposes. About 1½ per cent higher efficiency and the absence of about 4000 reactive kv-a. are the principal advantages obtained over a corresponding induction motor.

Another interesting development is a single-phase synchronous motor as part of a motor-generator set for use on heavy duty electric locomotives to supply direct current power to the main motors of the locomotives. These motors are rated 1200 kv-a.,

2300-volt, 25-cycle, single-phase for the freight locomotives, and 500 kv-a. for the smaller switching engines. These sets are brought up to about 80 per cent of synchronous speed by a starting motor of the repulsion type and then the motor is connected to the line at full voltage after which it quickly comes up to full speed and the excitation is automatically applied by a relay actuated by the current induced in the field during the starting period.

Induction Motors

No outstanding developments in the electrical design of general purpose induction motors have been brought out during the past year but the attention of designing engineers has been directed more particularly to the improvement of constructional features as relating to mechanical design and economical manufacture. A number of manufacturers have developed complete new lines with improved mechanical features.

The relative merits of sleeve and ball or roller bearings is a subject over which there is considerable discussion and difference of opinion. While a few manufacturers feature ball or roller bearings exclusively, the larger firms are prepared to supply either type according to the preference of the purchaser. New lines having tapered roller bearings have been developed which have overcome the assembly difficulties that previously made this type of bearing appear to be impractical for this application. General improvements have been made in the construction of the sleeve type of bearings to overcome the oil throwing and to exclude dirt and dust from entering the bearing which were objectionable features of the older design.

One manufacturer has adopted a fabricated construction of the mechanical parts of induction motors to the exclusion of cast parts except for the end bells. Another is using pressed steel end frames and riveted feet for moderate and small size motors. The motor manufacturers have in general retained the conventional casting construction for standard lines. General purpose motors having cast steel parts have been featured by one manufacturer while another has used the welded construction for large special motors.

Improvements in the power factor characteristics of induction motors have been accomplished by the adoption of more precise manufacturing methods. For instance, a grinding process has been adopted for finishing the stator and rotor cores of small machines to obtain uniformity of air gap. The use of larger bearings and shafts has permitted reductions of the air gaps resulting in better power factor. However, there is a strong conviction among designing engineers that better practise in application engineering presents the greatest possibilities for the improvement of power factor conditions in general power distribution systems. It is particularly important to avoid over-motoring, *i. e.*, installing motors of needlessly large capacity and operating them at low loads and consequently low power factor.

The ever extending use of electric power is presenting new and more severe conditions affecting the insulation of motor windings. Improvements in insulating materials and processes are being continually sought for the purpose of minimizing the destructive effects of dust, vibration, acid and alkaline vapors, and moisture. Form wound coils which are completely insulated before they are assembled in the slots present the least difficulties in that the interior of the coils can be completely filled with varnishes or compounds, but the so-called random wound coils in which the wires are not bonded together have presented a more difficult problem. A recent improvement in this type of winding has been obtained by encasing the complete end windings outside of the slots in a plastic insulating material.

During the year considerable attention has been given to theoretical studies of the performance characteristics of the synchronous induction motor and the compensated induction motor which combine the power factor characteristics of the synchronous motor with the starting torque characteristics of the wound rotor induction motor. For a number of years a type of synchronous induction motor arranged to receive its excitation from an external source has been in general use in Europe.

As mentioned in this committee's report of last year two new types of synchronous self-excited, induction motors have been developed in America. Another type of compensated motor has been developed this year in Europe which uses the Leblanc principle with one rotor having separate windings in separate slots. Although the use of the self-excited synchronous induction motor is being extended in America it has not reached anywhere near the proportions of the use of the separately-excited motor in Europe. American practise accepts the ordinary induction motor for general use supplemented by a relatively few synchronous machines for the purpose of maintaining good power factor conditions.

A European manufacturer is building a complete line of induction motors up to 225 h.p. with centrifugal-operated starters which have the same efficiency and power factor characteristics as the usual wound rotor type. This arrangement offers greater simplicity of starting than the ordinary manually operated compensator or controller. Compared with this the general practise in America has been to avoid the use of centrifugal devices and built-in resistances in polyphase motors. A recent European development has been a line of water cooled, totally enclosed motors primarily for pump drives. These motors are capable of being rated up to 70 per cent of the rating of the open type frame of the same size.

An interesting new development has been the design of a high-resistance squirrel-cage motor used largely for driving sugar centrifugal hydro extractors, etc.

The principal part of the load on this machine being the starting and stopping of a load of high inertia, it follows that the principal part of the losses in the motor are in the squirrel cage winding. The rotor of this motor has been designed with a high resistance section to the squirrel-cage winding which is built in the form of a fan to effectively dissipate the heat developed in the squirrel cage without communicating the heat to the rest of the motor.

A notable step in large size induction motors has been the building of a blooming mill motor having a continuous rating of 8000 h. p. at 13,200 volts. This is the largest continuous rating at the highest voltage yet obtained in induction motors.

Full voltage starting of induction motors is being urged by some engineers who claim for it greater efficiency, greater simplicity and lower cost, but there is a marked reluctance to abandon the time honored use of auto-transformers for reduced voltage starting. The so-called double squirrel-cage motors or those having high reactance rotor windings for full voltage starting or applications requiring high starting torque seem to be growing in popularity especially for high-speed ratings where the inherent reactance of the standard construction is low.

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High-Frequency Machines

During the past year a new development in high-frequency alternators has resulted from relatively new developments in the use of high-frequency power. The successful operation of air-core induction furnaces for melting copper, brass and nickel, and silver alloys has called for the development of generators suitable for supplying power at about 480 cycles for one type of furnace and at about 2000 cycles for another type. Current of 2000 cycles is also used for heating long objects of small sections such as boiler tubes. Generators for these purposes have been built in capacities up to 600 kw., single-phase, 480 cycles, and 150 kw., single-phase, 2000 cycles.. A further application of high-frequency power has been to obtan very high motor speeds for wood cutting and grinding operations and generators for three-phase power up to 420 cycles have been built for this purpose. These generators have been of the standard salient pole type, which is preferred to the inductor type because of the better characteristics. The high speeds and large number of poles has necessitated some special types of windings and mechanical details. A consideration of the fact that with a limiting peripheral velocity of 15,000 feet per minute the pole pitch of a 2000-cycle alternator is only ¾ inch will give some idea of the limitations of the field structure of such an alternator. The use of two-pole induction motors on frequencies of from 300 cycles to 420 cycles producing speeds of 18,000 rev. per min. to 25,000 rev. per min. has presented problems in motor construction more of the mechanical nature than of an electrical nature. The present limitation of speed is due to bearing troubles but the problem of the lubrication of high speed bearings is being studied with the hope that higher speeds can be used successfully if they are found desirable.

A recent European development for obtaining high motor speeds for wood working machinery consists of a combination motor having two stators and two rotors which are concentric. This motor develops a speed of 6000 rev. per min. on 50-cycle current. American practise has used the simpler high frequency motor supplied with power from frequency changer sets.

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Synchronous Converters

Conditions in England have led to a careful study and development of motor-converters and apparent success has been obtained with a larger output per pole than has been obtained with d-c. machines in America. Ameri-

can practise has pinned its faith to the conventional six-phase synchronous converter. The largest capacity converter set that has been installed for heavy duty, 1500-volt, d-c. traction service was built during the past year and consists of two 1500-kw. rotary converters connected in series. Limitation of space available for the installation of a 4200-kw. synchronous converter led to a rather unique arrangement. It was desired that the transformer should be set on the base of the converter at the collector end. In order to make use of the space on both sides of the shaft, the transformer was split into two units each of half the total capacity and each connected six-phase and the converter was built with twelve collector rings for twelve-phase operation, taking advantage of higher efficiency, smaller space and lower cost. This is the largest twelve-phase converter of which we have knowledge.

An ingenious arrangement for obtaining a stepless voltage control of a direct-current power supply for crane motor operation has been devised by a European manufacturer which consists of a small three-phase synchronous converter which is direct connected to a self starting synchronous motor or booster. The stator of the booster is arranged so that it can be shifted angularly thereby varying the direct-current voltage of the converter from zero to plus or minus full voltage. The complete outfit is of small enough dimensions to be mounted in the crane cab.

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Induction Disk Phonograph Motor

Further applications of induction disk motors have recently been made to low-power, low-speed equipment. These motors operate under the same principles as used in the customary induction-type alternating-current watthour-meter. The rotor consists of a conductive disk, through which a shifting flux is produced by one or more split phase electromagnetic elements. Eddy currents are generated in the disk and the reaction between the eddy currents and the flux produces the driving torque.

The chief applications of induction disk motors heretofore have been as timing devices in demand meters, time switches, etc. However, a larger motor has now been perfected for phonograph drive and has been adopted by two of the most prominent phonograph producers. The chief advantages of this motor are silence, constant speed, lack of vibration and reliability. The rotor runs on a vertical shaft, the upper end of which also carries the phonograph turn table. No speed reducing gears are therefore necessary, the rotor turning at slow speed and driving the turn table directly. The motor has high starting torque, giving it rapid acceleration. The speed is controlled by a very sensitive fly-ball governor, operating through friction. The normal speed is 78 to 80 revolutions per minute, at which a torque of 6 inch ounces is produced, this being sufficient to drive any standard phonograph. The input to the motor is approximately 35 watts.

An important advantage of this electric phonograph motor over the spring motor lies in the fact that the former supplies a constant driving torque regardless of the length of time it is operated, whereas the spring motor delivers a varying torque. The torque of the spring motor starts at a rather high value just after it has been fully wound and tapers down to a low value as the spring unwinds.

The induction disk motor is desirable, of course, only for low power applications having a low efficiency. It is very reliable and silent, however, owing to its relatively slow speed and simple construction.

Induction Voltage Regulators

A new development in connection with induction voltage regulators has been the combination of a series transformer and a transfer switch with the regulator and so arranged that the polarity of the series transformer may be reversed thereby doubling the range of the regulator. The cycle of operation of the combination produces the same results as would be obtained by a regulator of twice the capacity. The switch is geared to the regulator which may be automatically operated. An outdoor type of regulator has been developed with all the auxiliaries including current and potential transformers mounted within the auxiliary casing. Induction regulators have been developed for use on 12,000-volt single-phase circuits. The noise of single-phase regulators has been materially reduced by the use of a cushion support for the regulator in its tank and a similar cushion between stator and rotor. An indicator has been developed to show the boosting or lowering position of the regulator rotor.

Mercury-Arc Rectifier

During the past year the mercury-arc rectifier has been further developed and notable improvements have been made particularly with regard to the automatic upkeep of the vacuum and to simplifying the control and auxiliary apparatus. This piece of apparatus would appear to approach the ideal for the rectification of alternating current in that the function is performed without transforming the energy into magnetic and mechanical energy with the attendant losses. The loss affecting the efficiency of the rectifier is the arc drop within the tank and since the arc drop is approximately constant the rectifier does not show as high efficiency at rated load as does the rotary converter for large low voltage capacities. For heavy duty traction purposes involving voltages above 600 volts

the rectifier has better efficiency characteristics. American manufacturers are now offering rectifier equipments for railway substations and industrial power uses that may operate in parallel with rotary converter or motor generator equipments and arranged for complete automatic operation. Rectifiers are usually supplied with a slightly dropping characteristic, which may be adjusted to match the characteristics of shunt wound rotary converters operating in parallel. Rectifiers may also be compounded in order to obtain voltage control; however, it must be appreciated that this control will slightly lower the over-all efficiency and power factor of the rectifier unit. Equipment has been developed to include the application of automatic voltage regulators for maintaining constant d-c. voltages. A peculiar advantage of the rectifier over other types of converters from a commercial point of view is that the rating of a unit is independent of the frequency of the alternating current and within certain limits a given rectifier is suitable for operation at various voltages, the kilowatt capacity being greater the greater the d-c. voltage. While rectifiers have been extensively used in Europe for more than one decade, there are only two commercial installations in America which have been in commercial service for more than one year. A few more were added during the past year, and a large number of equipments are on the books of American manufacturers and will go into service this year.

The voltage limitations of the rectifier are much higher than those of synchronous converters and motor-generator sets, for they are built in capacities as large as 3000 kw. at 4000 volts d-c. One 4000-volt plant has been in successful operation for more than two years on a standard gage railroad in Europe. These capacities are characterized by very high efficiencies. Since the loss is due only to the resistance drop of the arc the efficiency is inherently higher for the higher voltage ratings. Other advantages which have been claimed are that there is no synchronizing operation and there are no moving parts. The absence of noise and vibration makes the rectifier peculiarly desirable for substations in congested and residential districts where quiet operation is necessary. The successful operation of a rectifier depends upon maintaining almost a perfect vacuum and equipment is available which will accomplish this automatically. The operation of this equipment is based upon the principal that the transfer of heat from one body to another is accomplished by radiation and conduction but the conduction is dependent upon the gas pressure and is zero in an absolute vacuum. This device is called a hot wire vacuum gage.

The operation of rectifiers of this type is liable to be interrupted by an occasional arc-back which is a short-circuit between anodes and occurs when one or more anodes function temporarily as a cathode. Since this occurrence causes no damage to the equipment except in very rare cases, the rectifiers may immediately be restarted by reclosing the breakers either manually or automatically. The cause of arcing back is being studied and it is hoped that this difficulty will be overcome.

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I wish in conclusion to express my appreciation of the assistance of Messrs. W. J. Foster, R. B. Williamson, V. Karapetoff, V. M. Mountsinger and others, in the preparation of this report.

STEAM POWER VS. WATER POWER

Is steam power to outdistance water power for generating electric current in the Pacific Coast country where "white coal" is king? This tendency is noted by the Journal of Electricity in an editorial declaring that cheapness of oil fuel and 300-per cent advances in the efficiencies of steam generating machinery during the past decade indicate that steam power may prove the more economical even in the water-powered state of California. Only one-third of the electric energy used in the state is generated by steam today, while hydroelectric plants produce the balance but engineers are prophesying the ratio may soon be reversed.

"A majority of the hydro power sites have been or are being developed," says the editorial, setting forth the facts of the case. "Efficiencies of 85 to 90 per cent of the theoretical have been obtained in waterwheels and there is little opportunity for improvement here. A cycle of comparatively dry years has placed added emphasis on steam plants.

"Many of the western states abound in low-grade coal which can be utilized either in pulverized form, as has been done successfully in Washington and Colorado, or can be subjected to low temperature distillation and burned in the form of coke and gas. Even California has extensive fields of lignite, and transportation facilities are such that cheap coal can be brought from Utah, Arizona, New Mexico or Washington. Whether steam will supplant hydro in supremacy is a debatable subject but certainly conditions point to a decided swing of the pendulum toward steam."

Notes on the Vibration of Transmission-Line Conductors

BY THEODORE VARNEY[1]

Associate, A. I. E. E.

Synopsis.—*This paper describes tests made with a graphic recorder to show the vibration of transmission-line conductors under various conditions of wind velocity, conductor tension and span length. The method of taking the records is discussed. Formulas are given for determining the velocity of propagation of transverse waves along a conductor, the wave length of a vibration, and the frequency of vibrations caused by "eddies" formed at a conductor subjected to air currents.*

If a wire is suspended freely between supports and is struck near one of the supports, a wave will run along the wire to the other support, be reflected and return to the starting point. If the supports are rigid, that is, possessed of infinite mass, the wave will be entirely reflected and it will pass back and forth until the viscosity of the wire damps out the wave. With a decrease in the mass of the support, the amount of the wave energy reflected is lessened. Part of the energy passes into the support, either storing energy therein to be given back to the latter if the support is elastic, or becoming dissipated by the viscosity of the support.

Assuming that the tension in the wire is constant, the velocity of propagation of the transverse wave is:

$$v = \sqrt{\frac{P}{m}} = \sqrt{\frac{P\,g}{w}} \qquad (1)$$

When

v = Velocity in feet per second
P = Total tension in the wire
m = Mass per ft. of wire
w = Weight per ft. of wire in pounds
g = Acceleration due to gravity

The time required for the wave to travel twice the length of the span is the fundamental time period. If at the instant the first impulse reaches the starting point the wire is struck again, the vibration will be sustained. If at the instant the impulse reaches the second support the cable is struck again, the two crests meet at the center, producing a node. If the frequency of the exciting force is increased, the span breaks up into a series of nodes and loops. If resonance occurs, there must be a whole number of loops between supports, provided the mass of the wire is uniform.

The velocity remaining the same, the product of wave length and frequency is a constant and is equal to the velocity; that is,

$$l\,f = v \qquad (2)$$

Where

l = Twice the distance between nodes
f = Frequency in cycles per second

In cases where resonant vibration of conductors has been observed, it was traceable usually to the wind blowing across the line and always at low velocities. A strong wind broke up the resonant conditions and merely swayed the span as a whole. The vibrations were in a vertical plane. Resonance appeared more frequently in the early morning or near sundown. Resonance also occurred over a wide range of cable tensions.

Resonance in a transmission cable is a very elusive thing; it begins without warning and ceases abruptly, and, while the conditions at the moment as regards temperature, wind velocity and direction may be noted, it is impossible to maintain or reproduce them at will.

It was at first thought that a span vibrating with fixed nodes and loops would not be affected by moving the point of support to the first node. If this were true, then the behavior of a single loop could be investigated on a small scale, experimentally, and would afford means of observing the behavior of a full sized span. Accordingly, an attempt was made with several sizes of stranded cables to produce resonant vibration by mounting the cable transversely in an aviation wind tunnel. The tunnel used was 8 ft. square and the wind could be varied from zero to 75 mi. per hour. The cables were supported at the sides of the tunnel and the tension in the cable was varied over a wide range.

No resonant vibrations could be produced. The cables vibrated rapidly with a very small amplitude, not over one one-hundredth or two one-hundredths of an inch. These small vibrations were noted by means of a reflecting mirror and a stroboscope and were found to agree fairly well with the eddy frequency.

The meaning of the expression "eddy frequency" will be explained later.

The probable reason why resonance and considerable amplitudes could not be obtained in the wind tunnel is that it is difficult to maintain constant wind velocities over the whole length of span. Moreover, upon further thought, it is more difficult to maintain approximately resonant conditions over a short span than it is over a long one. If, to assume an example, the wind velocity were adjusted so as to produce one loop in an 8-ft. span, it would require a change in wind velocity of 100 per cent to create the next larger whole number of loops, that is two, in the span. Any intermediate value of wind velocity would not produce resonance. If, on the other hand, the span were 80 ft., a 10 per cent change

1. Aluminum Company of America, Pittsburgh, Pa.

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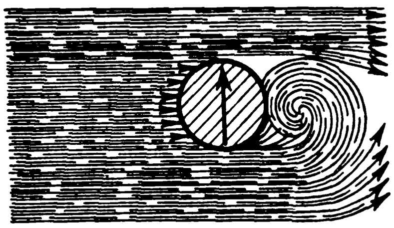
in velocity would be necessary to produce either nine or eleven loops in the span, while in a span 800 ft. long, only 1 per cent change would be necessary to produce 99 or 101 loops in the span.

In actual long spans of transmission lines, the nodes have been observed to shift back and forth in position with the slight changes in wind velocity, the vibrations, however, persisting with considerable amplitude for long periods of time.

In 1921 an investigation made by E. F. Relf and E.



Eddy Formation Produced by Wind Blowing on a Wire

Ower and covered by a report to the British Aeronautical Research Committee, showed that the singing note produced by wires moving rapidly through the air corresponded with the periodic eddies produced behind the wire.

When a fluid medium, such as air or water, flows past an obstruction in its path, eddies are produced behind the obstruction. If the obstruction is of symmetrical cross section such as a circle, the behavior of the eddies formed will be similar upon each side of the obstruction. As the fluid flows past the obstruction, the friction on the two sides is not exactly the same at any particular instant and this tends to slightly lower the velocity of the fluid passing on one side. The fluid on the other side, continuing in its normal velocity, creates a slight difference of pressure back of the obstruction, the lower pressure area being on the side where the higher velocity exists. This causes a flow of the fluid from the opposite side to fill this rarified area, and the action of the fluid takes the form of swirls or eddies. As this rarified area is restored to normal density by the inflow of the eddy, the velocity on that side of the wire is reduced and the inrush of the eddy accelerates the motion of the fluid on the other side and presently the eddy ceases on the first side and begins on the other, thereby repeating the cycle of events.

The result of this alternating-eddy formation is to produce an alternating force on the obstruction in a plane at right angles to the flow of the fluid. In aircraft work, the obvious means to prevent the formation of these eddies is to "stream-line" the section of the obstruction, thereby allowing the air to flow down both sides and join at the rear edge of the section without the formation of these eddies. The figure shown herewith illustrates this eddy phenomenon.

Experiments in both air and water were carried out from which the truth of the following general expression was established:

$$f = \frac{V}{D} \text{ function} \left(\frac{V\,D}{e} \right) \qquad (3)$$

Where

f = Frequency in cycles per sec.

V = Velocity of the medium with respect to the cylindrical wire

D = Diameter of the wire

e = Coefficient depending upon the medium, being 0.000159 for air and 0.0000122 for water

Further investigations gave the following data;

When

$$\frac{V\,D}{e} = 100, \text{ function} \left(\frac{V\,D}{e} \right) \text{ equals } 0.125$$

$$\frac{V\,D}{e} = 150, \text{ function} \left(\frac{V\,D}{e} \right) \text{ equals } 0.150$$

$$\frac{V\,D}{e} = 300, \text{ function} \left(\frac{V\,D}{e} \right) \text{ equals } 0.172$$

$$\frac{V\,D}{e} = 600, \text{ function} \left(\frac{V\,D}{e} \right) \text{ equals } 0.185$$

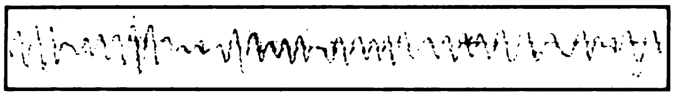
When

$\frac{V\,D}{e}$ is greater than 600, function $\left(\frac{V\,D}{e} \right)$ equals 0.185

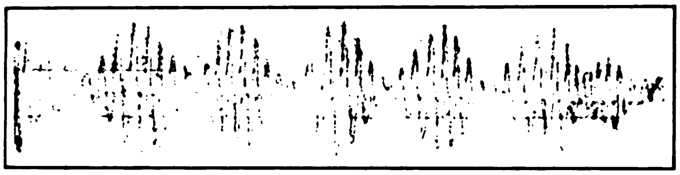
It will be noticed from the foregoing that function $\left(\frac{V\,D}{e} \right)$ is a constant for values of $\frac{V\,D}{e}$ of 600 or greater. For a wind velocity of one mile per hour, the minimum value of D would be 0.78 in. For two miles per hour the minimum value of D would be 0.39 in. Therefore for usual transmission line conditions, a constant value for the function $\left(\frac{V\,D}{e} \right)$ can be used. Curves of frequency plotted against wind velocity become, therefore, a series of straight lines—one for each diameter of conductor.

As a check upon the application of this theory, the following results tabulated from a long series of painstaking observations upon a certain transmission line are of interest. The cable in this case was 1 in. diameter, weighing 0.858 lb. per ft. and was supported upon steel towers.

The accompanying charts were obtained by attaching one end of a string to a transmission wire and the other end to a light wooden block arranged to slide in a slot in a vertical board which was fastened to a board resting on the ground. The lower end of this block had attached to it a light spring which served to keep the string taut and yet permitted the block, with the pencil attached, to move up and down in response to the



No. 1—Length: 4 seconds



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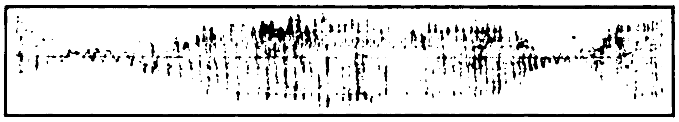

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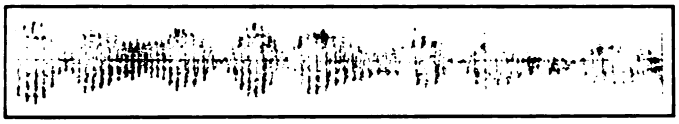
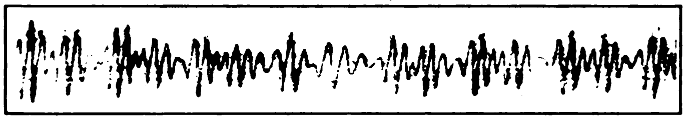


No. 4—Length: 4 seconds

No. 5—Length: 6 seconds



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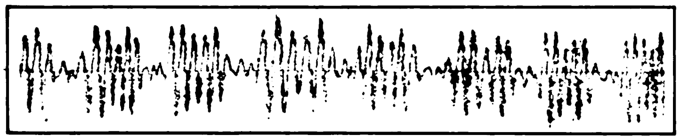

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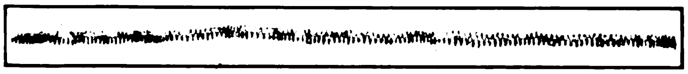

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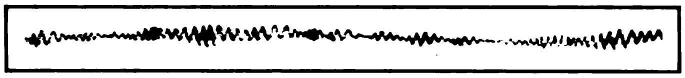


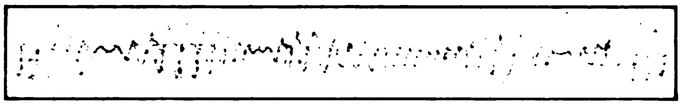
No. 9—Length: 7 seconds

No. 10—Length: 3 seconds

No. 11—Length: 7 seconds

No. 12—Length: 6 seconds

No. 13—Length: 4 seconds



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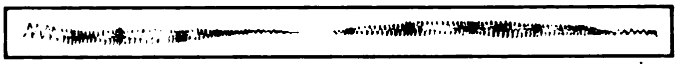

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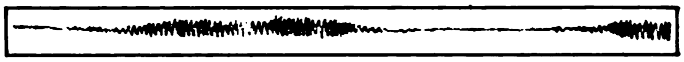
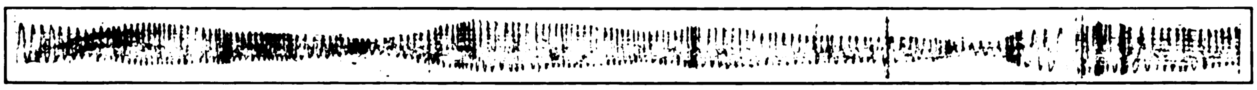
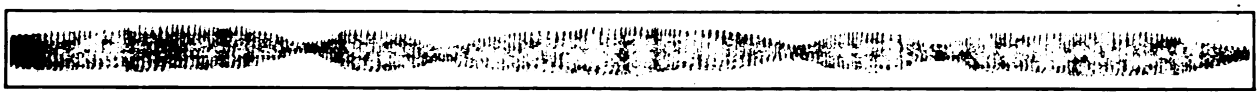


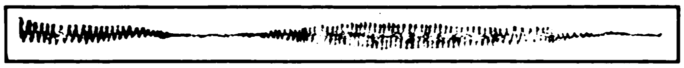
No. 16—Length: 6 seconds



No. 17—Length: 9 seconds

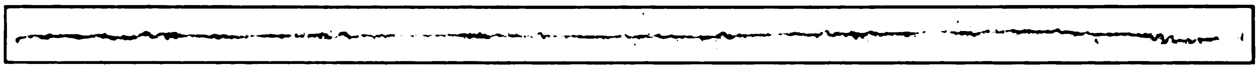


No. 18—Length: 11 seconds

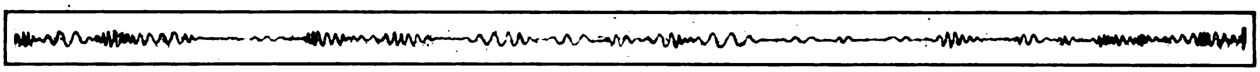


No. 19—Length: 6 seconds

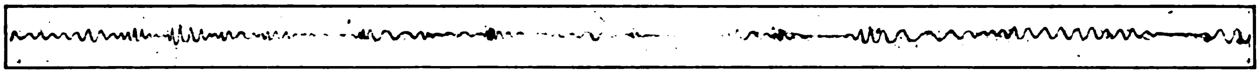
Records of Transmission-Line Vibrations
(See table for detailed information)



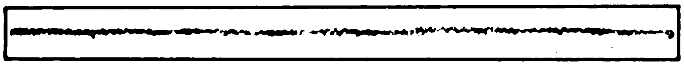
No. 20—Length: 8 seconds



No. 21—Length: 8 seconds



No. 22—Length: 8 seconds



No. 23—Length: 5 seconds

RECORDS OF VIBRATION OF TRANSMISSION-LINE CONDUCTORS
(See table for detailed information)

DATA RECORDED IN VIBRATION TESTS ON TRANSMISSION LINES

The conductor upon which the tests were made was 1 in. in diameter, weighed 0.858 lb. per ft. and was supported upon steel towers.

1	2	3	4	5	6	7	8	9
Chart No.	Span (ft.)	Tension (lb.)	Wave Velocity (ft. per sec. calculated)	Wind Velocity (M. P. H., Measured)	Eddy Frequency (cy. per sec. calculated)	Vibration Frequency Recorded on chart (cycle per sec.)	Amplitude of Vibrations Recorded on chart (1/32 inches)	Loop Length (ft.)
1	1200	8500	565	5.2	17.0	9.5	12	29.7
2	"	"	"	7.7	25.0	12.5	28	22.6
3	"	"	"	8.0	26.0	12.5	26	22.6
4	"	"	"	8.5	27.5	21.5	22	12.8
5	"	"	"	8.9	29.0	18.3	24	15.4
6	"	"	"	10.0	32.8	18.3	12	15.4
7	"	"	"	11.0	36.0	20.0	16	13.2
8	"	7930	545	10.0	32.8	33.0	4	8.3
9	"	7700	538	3.5	11.5	13.0	12	20.5
10	"	7530	532	3.9	12.8	14.0	24	19.2
11	"	"	"	4.8	16.0	11.3	18	23.4
12	"	"	"	5.2	17.2	10.5	14	25.7
13	"	"	"	5.6	18.7	12.0	20	22.5
14	"	"	"	7.8	25.5	22.0	12	12.2
15	"	"	"	8.0	26.0	22.0	6	12.1
16	"	"	"	19.1	62.5	23.0	6	11.6
17	"	"	"	21.3	69.5	22.0	18	12.3
18	"	"	"	21.3	69.5	22.0	20	12.3
19	"	"	"	22.5	73.0	22.5	8	11.8
20	984	5600	460	3.40	11.0	14.0	2	16.4
21	"	"	"	5.00	15.0	15.0	6	15.3
22	"	"	"	5.70	19.0	15.0	6	15.3
23	"	"	"	5.90	20.0	20.0	1	11.5

vibrations of the transmission-line wire. The spring was attached as nearly as possible at the middle point of the first node from the insulator clamp.

A wooden slide with a strip of paper attached to it was then moved in a direction at right angles to the movement of the pencil and was timed with a stop-watch. The device was crude but the charts afford a means of determining quite accurately the total number of vibrations produced in a certain time.

In the cases described herein the cable was quite large and the vibration had sufficient force so that the string could be pulled quite taut without damping the vibrations. This prevented, to a considerable extent, interference due to the fluttering of the string by the wind.

In other cases where the wire was smaller and the fluttering of the string interfered with proper results, a temporary platform was erected on the tower and by cutting off the current on the line, some charts have been obtained by attaching a pencil directly to the wire. The first described method has the advantage that it can be used on a live line and charts can be made on short notice, whenever the wind conditions are observed to be favorable, without taking time to cut the power off the line and arranging for a series of observations. However, as noted, it is very often difficult to

obtain satisfactory results by this means in the case of small line wire. The amplitudes of the vibrations are obtained by measuring the charts directly.

In the tabulations given herewith, the figures in column 1 refer to the number of the charts as appearing on the reproduction of the charts themselves. The second column gives the length of span where these particular charts and observations were made. In this case, the supports were practically level. It will be noted that the observations are made upon two-span lengths. The third column gives the total tension in pounds in the span at the time of the observations. These tensions were calculated from the observed sags. The fourth column gives the theoretical velocity of propagation of transverse waves in the cable as described in equation (**1**).

Column 5 gives the wind velocity in miles per hour as noted by a portable anemometer used during the experiments. Column 6 gives the theoretical eddy frequency calculated from the size of wire and observed wind velocity, using equation (**3**). In equation (**3**) the values of V and D must be in the same units; that is, V is feet per second and D is diameter in feet of the conductor. Also, these units might be used in terms of inches per second and inches of diameter.

Column 7 gives the frequency in cycles per second as taken directly from the charts. Column 8 gives the amplitude also measured directly from the chart. Column 9 is the calculated loop length using equation (**2**). The values of V in this equation are taken from column four and the values of F are taken from column 7. The values in column 9 obtained by this means are, therefore, theoretical but they check with a fair degree of accuracy with the actual observed distances between nodes at the time of the observations.

On account of the variable character of the wind under most conditions, however, these node points were observed to shift constantly back and forth. Usually, however, they corresponded to values sometimes smaller and sometimes greater than the loop length given in column 9. It is assumed, therefore, that the theoretical values given in column 9 are fair assumptions.

Chart 8 is particularly interesting because of the absence of "beats" and the exact agreement between the eddy and observed frequency. This is interpreted as indicating a practically uniform wind velocity throughout the entire span. It is likely also that the time period of oscillation of the tower supports acts to amplify or damp the line vibration.

A device at the support which has a period corresponding to a certain proportion of the natural period of the conductor will act as a damper. Such a damper having a period of about seven cycles per second would probably be effective in greatly reducing the amplitude of vibrations in the conductor throughout the range of wind velocities noted in the case described herein.

It is reported that the device recently described in the technical press[2] by Mr. G. H. Stockbridge, of Los Angeles, California, has been found effective. Further investigations on transmission lines in service are at present going on.

The writer is indebted for various courtesies and assistance in obtaining the data described in these notes from Capt. Wm. McEntee and Dr. A. F. Zahm of the United States Navy Yard, Washington, D. C.; Mr. H. A. Barre and Mr. H. Michener of the Southern California Edison Co., Los Angeles, Calif; Mr. A. E. Silver, Electrical Engineer, Electric Bond & Share Company, New York and to Messrs. M. E. Noyes, J. P. King, Walter Hays and C. B. Owen, Aluminum Company of America.

HYDROELECTRIC DEVELOPMENT IN FRANCE RETARDED

France has water-power resources which, under satisfactory conditions, are capable of producing the electric energy necessary for its economic advancement. A serious effort has been made to utilize these valuable natural resources, but unfavorable conditions for some years have impeded such efforts, and recent statistics on electric development show a marked decrease as compared with expected results. Although construction works begun during or subsequent to 1916 have been steadily continued and improvements have been made to the installations already in use, the carrying out of the greater part of new projects, for which plans were completed at the beginning of 1924, have been indefinitely postponed.

The average amount of current supplied by French hydroelectric plants during the period 1922 to 1924, inclusive, increased from 658,560 to 1,263,260 kilowatts, but the increase registered for 1925 was only about 50,000 kilowatts, and even this greatly slackened rate will probably not be maintained in 1926. This stagnation is not caused by decreased demand for additional current, for consumption of electric current steadily increases. During the past year there has been a tendency to meet this demand by the enlarging or erection of fuel power plants rather than by the installation of hydroelectric plants. The result is that three-fourths of the electric current furnished to consumers in France by the entire system of electric distributing stations is supplied by fuel power plants.

Lack of finance is the chief cause of this condition. The Government has made a careful survey of the electric power resources and has reached the conclusion that systematic construction and installation should be inaugurated and future development promoted. Special legislation and financial enactments are now pending which are intended to rectify the present situation by providing sources of revenue and foundations for loans.

2. *Electrical World*, December 26, 1925, p. 1304.

Some Notes on Electricity Transmission and Distribution Practise in Europe with Comments on High-Tension Substations and Switchgear

BY G. F. CHELLIS[1]

Member, A. I. E. E.

Synopsis.—*This paper describes some of the more recent overhead and underground electricity transmission developments in Europe and is intended to convey a general idea of the status of that art in some of the European countries.*

No attempt has been made to include all the recent high-tension lines in the countries touched upon, but those included are typical of the work being done and the voltages in use.

A most interesting part of the paper is a summary and analysis of the recent report of the Weir Commission of England recommending a policy with regard to superpower development in that country. This report covers a program extending to 1940 and proposes a plan of interconnection and base-load plant construction intended to tie together practically all parts of England.

* * * * *

GENERAL

A CONSIDERABLE amount of electrical plant construction has been going on in Europe during the last five years to meet increases in power demand, resulting principally from industrial growth.

Water-power has been developed wherever possible, but regardless of high fuel cost and uncertainty as to fuel supply, steam plants have been necessary in certain areas.

Recent statistics indicate that the electricity consumption per capita in some of the European countries is higher than in the United States, but such statistics are confusing and do not present a true picture of electrical progress, except where industrial and domestic consumption are separately shown. This point is clearly brought out by considering the total unit consumption in certain mining and industrial communities where it amounts to 50,000 watts or more per capita, but with relatively low domestic consumption.

A good deal of work must be done to educate the public to a greater use of electrical energy, and growth of domestic load in Europe should, therefore, be slower than in American communities which are being energetically exploited.

Although there are wide variations in climatic and topographical conditions, government regulations, and engineering points of view in Europe, there seems to have been produced in the different countries, types of line construction well suited to local conditions.

There is considerable diversity in the design of transmission line supports which, in general, are somewhat more flexible than the usual American designs; while spans are shorter, with relatively higher safety factors in conductors.

SWEDEN

As the distances over which power has to be transmitted in the European countries are relatively shorter, such extensive transmission line networks as those which have been developed in the United States, and Canada, are not found.

The Swedish State Lines, planned by the Royal Board of Water Falls, are perhaps an exception to this general statement, as these lines form the nucleus of an extensive future superpower system designed to work at

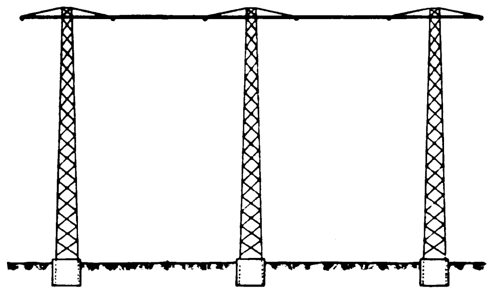


FIG. 1—TYPE OF STANDARD STEEL SUPPORT FOR TWO 200-KV., THREE-PHASE CIRCUITS

(TROLLHATTAN-VASTERAS LINE OF SWEDISH STATE POWER SYSTEM)

Height of support above ground	52.5 ft. (16 m.) approx.
Distance between mast centers	39.4 ft. (12 m.)
Conductor spacing	19.7 ft. (6 m.)

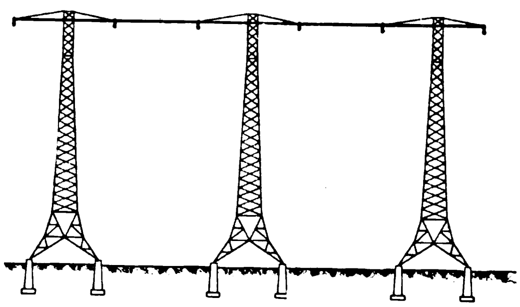


FIG. 2—TYPE OF STEEL ANCHOR STRUCTUREF OR TWO 220-KV., THREE-PHASE CIRCUITS

(TROLLHATTAN-VASTERAS LINE OF SWEDISH STATE POWER SYSTEM)

Height of support above ground	52.5 ft. (16 m.) approx.
Distance between mast centers	39.4 ft. (12 m.)
Conductor spacing	19.7 ft. (6 m.)

1. Whitehall Securities Corporation, Ltd., London, England.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

220 kv.; but those built to date will be operated at a reduced voltage until the higher voltage is required.

Two types of towers used in the construction of the Western Trunk Line of the Swedish State System between Trollhattan and Vasteras are shown in Figs. 1 and 2.

ITALY

Italy shares with Switzerland the run-off from the Swiss-Italian Alps, which provides an abundant source of water-power, and here, as well as in Switzerland, rapid progress has been made in hydroelectric development and transmission lines.

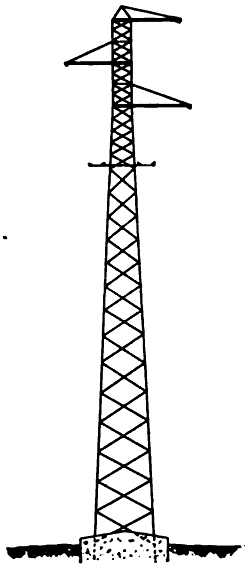


FIG. 3—TYPE OF STANDARD STEEL TOWER FOR ONE 125-KV., THREE-PHASE CIRCUIT

(TEMU-CEDEGOLO LINE OF THE SOC. GEN. ELLETTA DELL 'ADAMELLO)

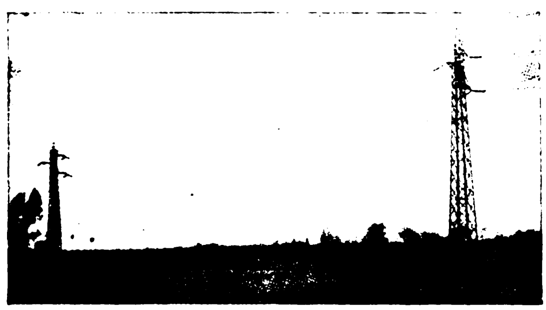


FIG. 4—TYPE OF STANDARD STEEL TOWER FOR ONE 130-KV., THREE-PHASE CIRCUIT

(REGGIO-EMILIA LINE OF THE SOC. ELETTA. INTERREGUIALE CISALPINA)

Height to lowest cross arm	69 ft. (21 m.)
Average span	820 ft. (250 m.)
Conductor spacing	17.5 ft. (5.3 m.)
Weight of tower	4800 lb. (2200 kilos)

Because of the rugged topography of Northern Italy, transmission lines must be largely confined to the narrow valleys, in some of which there are as many as ten parallel multicircuit lines of voltages ranging from 2-kv. to 130-kv.

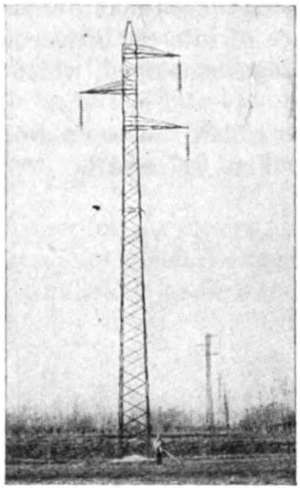


FIG. 5—TYPE OF STANDARD STEEL TOWER FOR ONE 140-KV., THREE-PHASE CIRCUIT

(OVESCA-ARQUATA LINE OF THE SOC. GEN. ITALIANA "EDISON DI ELETTA" MILAN)

Average span 656 ft. (200 m.)

The types of tower used on three of the more interesting lines recently built in Italy are shown in Figs. 3, 4, and 5.

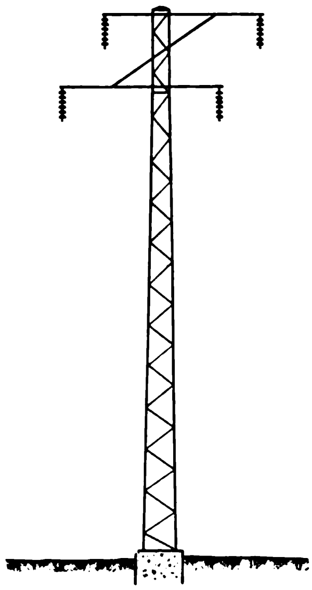


FIG. 6—TYPE OF STANDARD STEEL TOWER FOR ONE 135-KV., THREE-PHASE, 50-CYCLE CIRCUIT AND FOUR 66-KV., SINGLE-PHASE 16-2/3-CYCLE CIRCUITS

(AMSTEG-IMMENSEE LINE OF THE SWISS FEDERAL RAILWAYS)

Length of line 29 mi. (47 km.)
Average span 787 ft. (240 m.)
Maximum span 1610 ft. (490 m.) with 620 ft. (190 m.) difference in elevation of supports
Conductors aluminum steel reinforced except bronze on long spans
Ground wire galvanized steel

SWITZERLAND

The most important recently constructed transmission lines in Switzerland have been built by the

Swiss Federal Railways, in conjunction with the electrification of that system. Certain of these lines are jointly owned by the Federal Railways and the Swiss Power Transmission Co., Ltd., of Berne.

These lines are of interest on account of the high single-phase voltages employed, which are 66 kv. and 132 kv.

The types of standard tower used on three of these lines are shown in Figs. 6, 7, and 8.

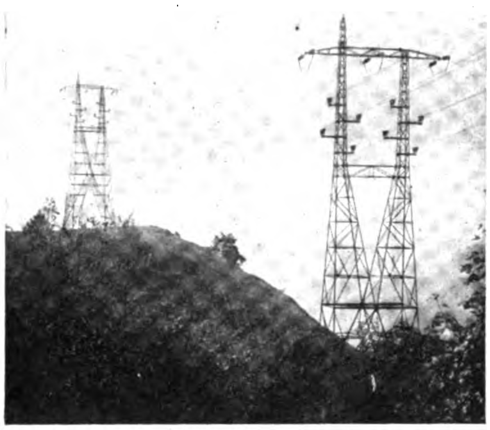


FIG. 7—TYPE OF STANDARD STEEL TOWER FOR TWO 132-KV., 16-2/3-CYCLE, SINGLE-PHASE CIRCUITS

Length of line	134 mi. (216 km.)
Height to lowest conductor	28 ft. (8.5 m.)
Average span	737 ft. (216 m.)

Conductors aluminum steel reinforced.
Insulators, suspension type, seven units.
Ground wire, copper clad steel.

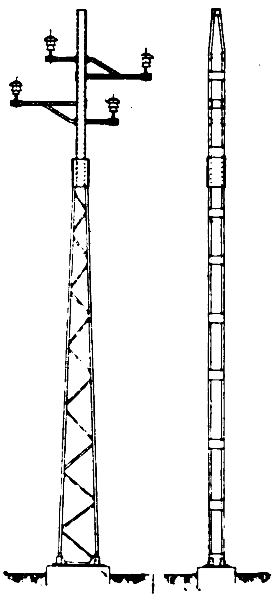


FIG. 8—TYPE OF STEEL TOWER USED ON STANDARD TRANSMISSION LINES FOR TWO 66-KV., SINGLE-PHASE, 16-2/3-CYCLE CIRCUITS

(SWISS FEDERAL RAILWAYS)

Length constructed. 155 mi. (250 km.)
Average span. 410 ft. (125 m.)
Conductors, stranded copper
Ground wire, galvanized steel

SPAIN

Concrete poles, Fig. 9, with concrete cross-arms cast integral are used on the 70-kv. lines of the Cia Anonima Mengemor, Spain.

A photograph of one of the anchor towers of the 130-kv.

FIG. 9—TYPE OF CONCRETE LINE SUPPORT ON 70-KV. LINES OF CIA ANONIMA MENGEMOR, SPAIN

Average span 328 ft. (100 m.)

Albaseta - Dos Aquas line of the Sociedad Anonima Hidroelectrica Espanola is shown in Fig. 10.

GERMANY

The 100-kv. Lauta-Trattendorf line in Germany is worthy of serious consideration as a precedent in the construction of high-tension lines on public highways.

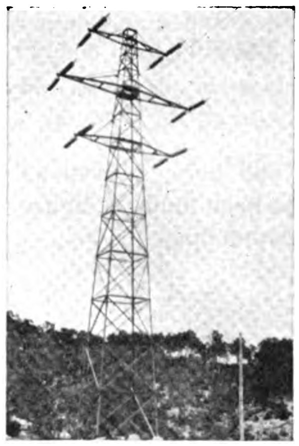


FIG. 10—TYPE OF STEEL ANCHOR TOWER ON 130-KV. ALBASETA-DOS AQUAS LINE OF THE SOCIEDAD ANONIMA HYDROELECTRICA ESPONOLA

Average span 656 ft. (200 m.)

While few municipal authorities would sanction the construction of lines of such voltages in the public street, the factor of safety is no doubt higher than that common to overhead contact wires for tramway systems.

A typical view of this line is shown in Fig. 11.

ENGLAND

In England, with the exception of one group of companies in the North, which operates about 1000 mi. of high-tension lines, extensive overhead transmission

systems have not been developed. This is perhaps due to the wide distribution of its coal deposits which renders transmission less effective than in places where power markets are widely separated from sources of fuel.

A further explanation of the relatively few overhead lines constructed in England is to be found in the well-established practise of placing power lines underground, which has to a large extent been forced by strict Government and Municipal regulations, and by the difficulty and delay experienced in securing suitable rights of way.

Numerous attempts have been made in England to establish a policy with regard to national superpower developments, beginning as early as 1914. The principal schemes have been included in reports made in 1918 by the Electric Power Supply Committee (known as "The Williamson Report") and the report of the Commission appointed by the Minister of Transport

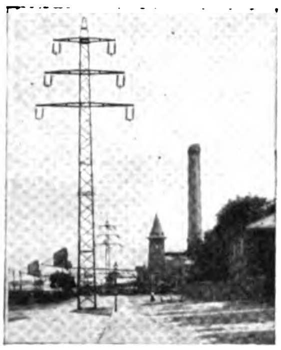


Fig. 11—Type of Steel Support on 100-Kv. Lauta-Trattendorf-Moabit Line in Germany

Height of tower, 92 ft. (28 m.)
Height to lowest crossarm 65 ft. (19.8 m.)
Conductor spacing (3.1 m.)
Conductors—copper
Insulators, two strings of six Kapp units
Minimum clearance between line and buildings (26 m.)

to review the national problem of the supply of electric energy (known as The Weir Report) which was published early in the year 1926.

The scope of the report covers a period to the year 1940 when the consumption in Great Britain, now growing at the rate of 19 per cent per annum, would be raised from the present figure of 110 units per capita to 500 units, the rate now obtaining in the United States; but it is expected that the 500-unit figure may be reached before that date.

The basic recommendations of the Committee are as follows:

a. To reduce to 58 in number 438 of the power stations in Great Britain, many of which are small and unsuited to generate power economically. The 58 stations, 28 of which would be of capital order and 30 of secondary order, would be designed to produce electrical energy at a minimum cost. (These 438 stations do not include 48 stations owned by railway companies, and operated particularly for railway electrification.)

b. To establish a gridiron (high-tension transmission network) for the purposes of interconnecting the 58 power stations.

c. Provision for the output of the 58 power stations to be turned into the gridiron at a predetermined price per unit with privilege of purchasing for local supply, at the price billed to the gridiron.

d. Provision for the closing down of nearly 400 generating plants which is expected to be brought about automatically as the companies operating them would be able to purchase power from the gridiron at a cost less than that of private generation.

e. Provision for the establishment in communities, not at present supplied with electricity, for local authorities, who would distribute power purchased from the gridiron in such areas.

f. Recommendations in favor of the standardization of frequency affecting a few of the larger suppliers. Subject to further investigations this may be undertaken at public expense at a total gross cost approximately £10,500,000, and a net cost of £8,000,000 after allowing for expenditure represented by useful additions to plant capacity.

It is estimated that the total expenditure to 1940 would extend upward to £250,000,000 and that with proper coordination and assistance from the Government, this figure is substantially less than would result if developments were allowed to continue under existing conditions.

It is further estimated that one-half of this amount of new money would be required in connection with the development of distribution systems, this portion of capital to be provided by local authorities, power or distribution companies, as at present.

It is stated that the remaining half of the capital can be conveniently divided into two sections:

First. The amount necessary to construct the high-tension network for bulk transmission, plus working capital, reserve, and interest capitalized for a period of five years, at which date the net earnings from the gridiron would be expected to be sufficient to cover all obligations.

It is estimated that the sum of £25,000,000 would be required for gridiron expenditure at the end of five years from the date the scheme might be put into operation.

Second. The amount necessary to provide local authorities, or other authorized persons with capital required for the erection of new capital generating stations, or additions to present stations. Within certain limits capital and interest would be guaranteed by the Government.

The report points out the following conditions obtaining in Great Britain at the time of its issue.

Average price charged to consumers for all purposes	2.047d. (pence)
Gross revenue	£34,256,000
Revenue per £100 invested	£21.2
Plant installed	3,096,535 kw.
Maximum load	1,844,000 kw.
Spare plant	68 per cent of maximum load
Units sold per annum	4,016,000,000
Units sold per head of population	110
Annual load factor	24.9 per cent
Capital invested per kw. for Generation	£23.8
Capital invested per kw. for distribution	£28.5
Total capital investment per kw. for generation and distribution	£52.3

It is estimated that as a result of economies to be effected by the recommendations of the committee, the position in the year 1940, or whenever the national consumption has been raised to 500 units per head, would approximate the following:

Units sold per capita	500
Maximum load	8,135,000 kw.
Kw. installed	10,000,000 kw.
Spare plant	25 per cent
Units sold	21,385,000,000 (kw-hr.)
Annual load factor	30 per cent
Total capital invested for generation	£127,000,000
Capital invested for "Grid Iron" transmission	£29,000,000
Capital invested for distribution	£243,500,000
Total revenue	£88,100,000
Average price per unit	1 d. (pence) or under
Number of capital stations	28
Number of secondary stations	30
Total number of stations	58

In the annex to Appendix I of the report there appears an interesting estimate of the cost of power stations of 133,000-kw. installed capacity, capable of meeting maximum load conditions of 100,000 kw., which is said to be based on contracts for the Barking Station of the County of London Electric Supply Co., Ltd., one of the principal superpower stations constructed in England to date.

	£ per kw.
308 acres of ground at Barking	0.733
Civil engineering works, piling, wharfs, railway sidings, water culverts, screens and foundations	1.880
Buildings and cranes	1.722
Turbo alternators and accessories	3.950
Boilers and accessories, and ash-removal plant	3.464
Switchgear and cables	0.683
Step-up transformers and station auxiliaries	0.593
Piping	0.465
Coal-storage equipment, consisting of cranes, locomotives, and cars	0.148
Sundries, including batteries and charging sets, oil coolers and pumps, oil filter plant, auxiliary sets and wiring and fittings	0.301
	£13.939
Engineering supervision, legal and incidental expenditure (5 per cent)	0.697
	£14.636

It is estimated that the average total cost of generation per kw. on the basis of coal at 16s. (shilling) per ton would be 0.3456d. (pence) with an additional capital and operating charge on main transmission lines of 0.0291d. (pence) or a total of 0.3747d. (pence) per unit sold over the gridiron.

Local distribution expenditure, including capital charges, local management and taxes, is further taken at 0.5000d. or 0.8747d. per unit at the distribution system, which is raised to 1.029d. on the basis of 85 per cent distribution efficiency.

It is understood that the assumed efficiency of 85 per cent has caused some amount of criticism.

According to the report the average cost of 1d. per unit would not be a uniform price maintained throughout Great Britain, but would vary according to local generating conditions, the amount of transmission network involved, and the distribution expense.

The estimated figure for Scotland is given as 1.038d. per unit, and that for Central England as 1.029d. per unit.

A striking feature of the report is a recommendation that the transmission network be owned and controlled by a new body created by Act of Parliament, termed the Central Electricity Board, which would purchase and dispose of energy from all of the interconnected stations, or alternatively charge for the use of the transmission network, or a further alternative according to which all generating stations would be purchased and the less efficient ones closed down, leaving the best stations to be operated by the Board, thus bringing all generation and transmission under the control of a single body.

Objection has been raised in some quarters on the ground that acceptance of the latter recommendations might be a step toward government ownership. On this account an opposition movement is on foot to prevent the bill being passed by Parliament.

The report is noteworthy as constituting the largest scheme ever proposed for the unification and extension of electric service for the definite purpose of reducing the cost of electric energy to a community.

In general, the measure seems to be popular, and there is every indication that some such Bill will be authorized by Parliament in the near future as it appears to be agreed that only through the intervention of Government interest can such a system be brought into being on account of the great diversity of interests involved.

The report shows typical curves of load and load factor, but no maps or other data are included to show details of the interconnecting network.

A transmission voltage of 33 kv. seems to be considered sufficiently high for average English conditions, at present, and has been more or less standardized for both overhead and underground lines. Some 66-kv. lines have been built and still higher voltages will no doubt be employed if extensive electrification plans are adopted.

Typical views of some of the high-tension trans-

mission lines recently constructed in England are shown in Figs. 12, 13 and 14.

Fig. 15 shows the dead-end structure of a 66-kv. line and its junction with 66-kv., single-conductor cables leading to the transformers.

Fig. 12—Semi-Anchor Tower, 66-Kv. Dunstan-Bedlington Line Northeast Coast Power Co., Newcastle-on-Tyne, England

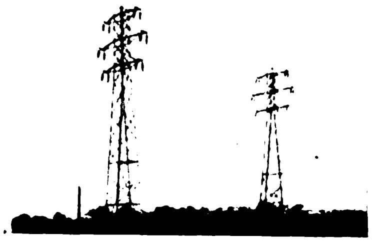


Fig. 13—Straight Line Railway Crossing 66-Kv. Dunstan, Bedlington Line, Northeast Coast Power Co., Newcastle-on-Tyne, England

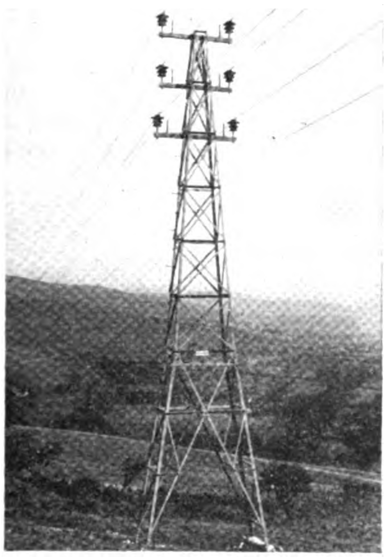


Fig. 14—Type of Standard Steel Tower on 33-Kv. Glen Valley Line of North Wales Power Company

A type of steel line support which works out somewhat cheaper than the usual type of steel tower is shown in Fig. 16.

This structure consists of steel-tubular members mounted in steel-socket pieces, and held rigidly in place by means of high grade steel guys of large diameter.

High-Tension Caples

Among the European power companies operating

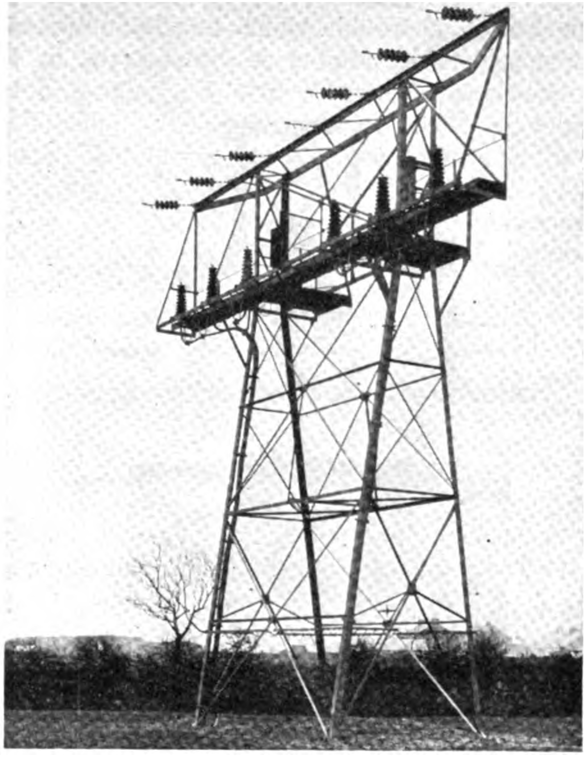


Fig. 15—Dead-End Structure of Double Circuit 66-Kv. Line Showing Junction with 66-Kv. Single Conductor Cables Leading to Transformers. Northeast Coast Power Co., Newcastle-on-Tyne, England

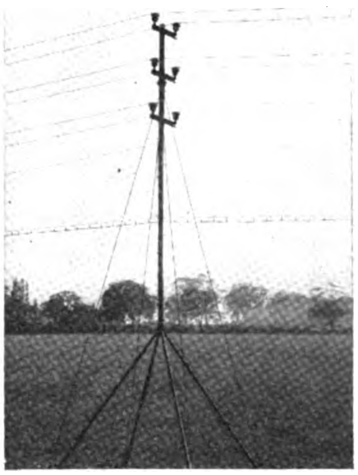


Fig. 16—Straight Line Kay Pole for Two 11-Kv., Three-Phase Circuits

Note telephone cable carried on messenger wire.
Average span 330 ft. (100 m.)

cable transmissions of relatively high voltage are the North East Coast Power Co., Newcastle-on-Tyne, England, 66 kv., Union D'Electricité Paris, France,

60 kv., and Provincial Electricity Works Bloemendaal Holland, 55 kv.

There is also a considerable amount of 33-kv. cable in operation in England.

In Italy a 130-kv. experimental cable of the Pirelli type has been in operation for something over a year with promising results.

One source of trouble which has been responsible for a considerable number of breakdowns in high-

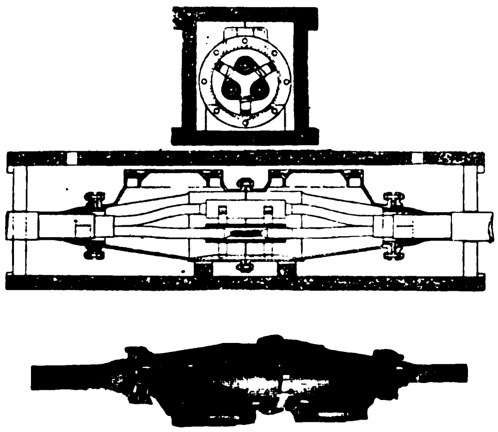


FIG. 17—THREE-CONDUCTOR, 50-KV. CABLE JOINT OF BRITISH MANUFACTURE

tension cable installations is the result of pressure differences within the sealed cable, where considerable difference in elevation exists throughout a part or whole of its length.

Pressure differences are created if there is any movement of compound used in the cable or its joints and

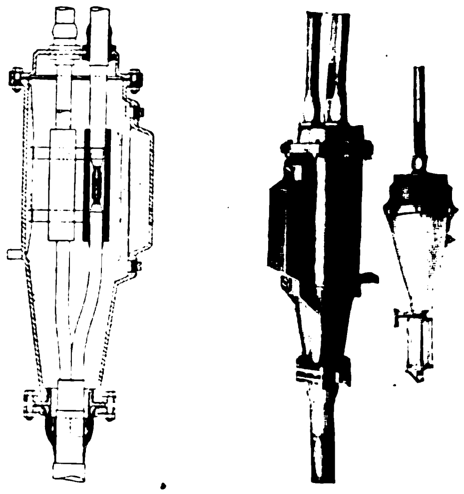


FIG. 18—THREE-CONDUCTOR, 50-KV. TRIFURCATING BOX WITH SINGLE-CONDUCTOR TAILS AND SEALING END, OF BRITISH MANUFACTURE

any voids caused by such movement of the insulating compound must necessarily weaken the insulation, resulting in failure.

This has led to the development of a type of joint design for filling under pressure, which is expected to ensure complete filling and to prevent voids, but the writer is not able to say whether or not this method has been successful.

Investigations are in progress to determine the feasibility of constructing supertension cables in which a uniform potential gradient would be maintained by means of metallic sheathes, placed between layers of insulation and connected to taps in the transformer winding.[2]

Cables so constructed would be expected to run high in cost, and the splicing and sealing of the ends would seem to present unusual difficulties. However, it is not improbable that continued investigation may develop a cable with solid insulation for supertension voltages at a cost no greater than that of a steel tower line, particularly if there is a saving in cost of right of way, as might be expected in congested districts.

A three-conductor, 50-kv. cable joint of British manufacture is shown in Fig. 17 and in Fig. 18 and a

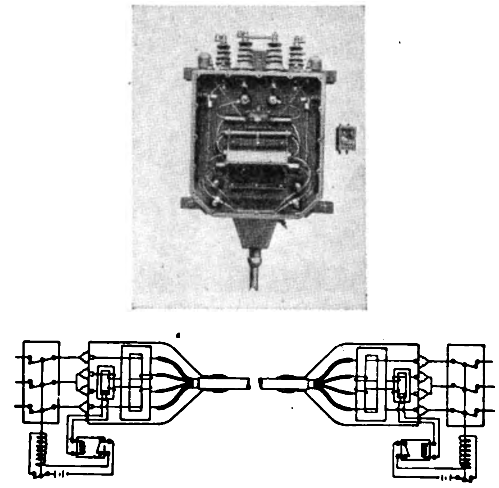


FIG. 19—CONNECTION DIAGRAM OF CALENDER HUNTER FOUR-CONDUCTOR SYSTEM OF CURRENT BALANCED CABLE PROTECTION AND INTERIOR VIEW OF A SEALING END SHOWING PHYSICAL ARRANGEMENT OF BALANCING TRANSFORMER

50-kv. trifurcating box with its single-conductor tails and sealing end.

Practically all distribution in England is accomplished by means of underground cables.

The principal distribution problem is to be found in the London area which is served by about 80 power plants.

A frequency of 50 cycles predominates, but there is considerable diversity as regards phase and voltage.

Low-tension distribution is direct current, two- and three-wire, and alternating current with various systems of connections. Lighting voltages vary from 100 to 240 volts, while power service voltages extend to something over 500 volts. Bulk supply is sold at high-tension voltage.

The main feeder cables of power systems are fre-

2. See paper by A. M. Taylor in *Journ. I. E. E.*, London, England, No. 315, February, 1923.

quently protected by means of current balance, this being accomplished in various ways. In the case of two parallel feeders, the current in one is balanced against the current in the other by means of differential relays which open the circuit-breakers upon a very slight difference in current value.

Cables are in use with six conductors, three of which in a three-phase system are similarly balanced against the remaining three.

A new form of cable specially designed for balanced

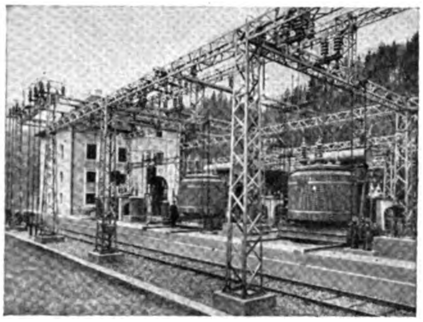


Fig. 20—Shilbrugg Substation of the Swiss Federal Railways, Showing 66-Kv., Single-Phase Construction

protection, and which costs somewhat less than six-core cable, has recently been brought out. This system utilizes a special form of four-conductor cable in which two conductors have one-half of the cross-section of the remaining two, and current transformers of special design contained in the sealing ends at each end of the cable. These transformers function to cause a current to flow in a separate winding when the current in the different phases becomes unbalanced. The

Fig. 21—12,000-Kv-a. Outdoor Transformer Installation of the Northeast Coast Power Co. at Dunstan, England

resultant current is employed to operate a relay arranged to open the circuit breakers.

A diagram showing the connections of the special balancing transformers and relay and the interior of one of the sealing ends is shown in Fig. 19.

High-Tension Equipment

Until quite recently European engineers have conformed to a universal practise of placing high-tension equipment indoors, but with the use of larger units and higher voltages, the outdoor substation is beginnnig to make its appearance.

The recently constructed substations of the Swiss Federal Railways are outdoor type and are relatively simple because of the use of the single-phase system of power transmission and distribution to track circuits.

A photograph of the Shilbrugg substation of the Swiss Federal Railways near Zurich is shown in Fig. 20.

Fig. 21 shows a recent outdoor transformer installation in England with its 66-kv., single-core cable connection. The sealing end for the 66-kv. cable may be seen in the foreground, bolted directly to the transformer tank.

The more prominent electrical manufacturers in England and on the Continent have developed complete lines of equipment for voltages up to 130 kv., while some are prepared to offer equipment for higher voltages.

Lightning protection seems to have received considerable attention on the Continent. The predominat-

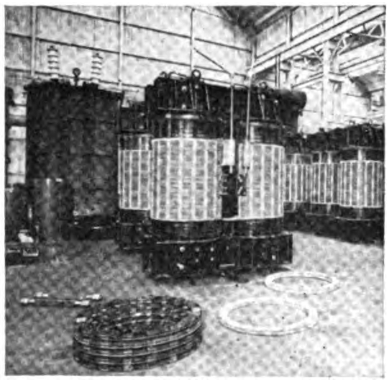


Fig. 22—12,500-Kv-a., 110-12-Kv., Single-Phase, Water-Cooled Transformer Units of British Manufacture

ing type of arrester has horn gaps in series with water co.umns contained in vertical porcelain receptacles, which are mounted on high-tension insulators. In some cases arresters of the electrolytic and oxide film types of American manufacture are used.

Lightning protection seems to have caused very little concern in England. A length of cable at the end of a high-voltage line is considered by many British engineers to be an excellent method of lightning protection.

On the Continent there seems to have been some fear regarding the solid grounding of high-tension neutrals, although the advantages of grounding are recognized. In some instances a compromise is resorted to, by placing a horn gap in series with the neutral-ground connection. The horn gap is set sufficiently close to break down if a ground occurs.

It is almost universal practise on the Continent to design transformers for forced oil cooling, as this type of transformer costs somewhat less than the water-cooled type. Water-cooled transformers are, however, built in considerable quantities, both on the

Continent and in England, as they are sometimes to be preferred.

Fig. 22 shows part of a group of 12—110-kv:, 12,500-kv-a. single-phase water-cooled transformers recently built in England for shipment to India.

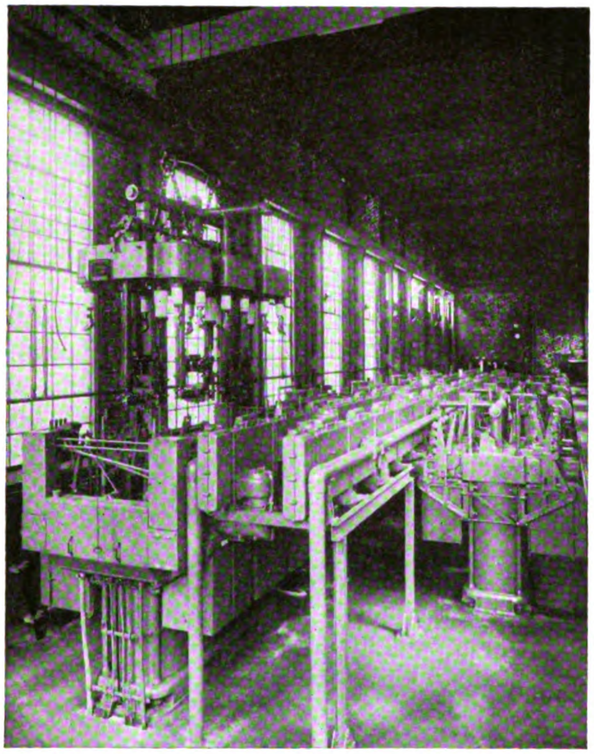


Fig. 23—Portion of 33-Kv., Iron-Clad Switchgear Installed at Barking Station of the County of London Electricity Supply Co.

(On back of Photo)

Showing one-quarter of the ultimate switchgear. In the foreground is seen the sealing off of the end of the busbars and the tail end of the vent pipe leading down through the floor to the outside of the building, but in this case the drawout portion of the main oil circuit breaker is shown removed and suspended above its panel. The operation is interlocked with the crane to ensure that all conductors are dead before it commences.

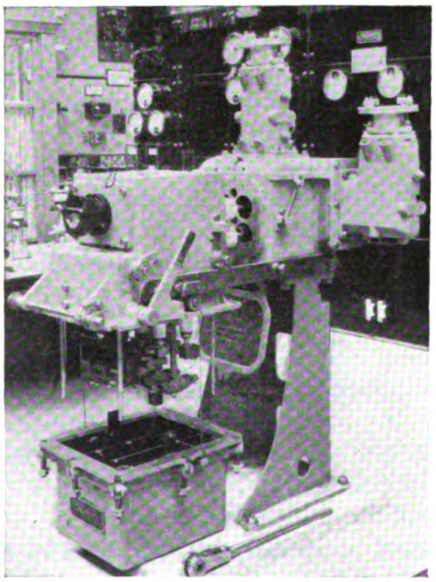


Fig. 24—Hand-Operated, Armor-Clad, Flame-Proof, Draw-Out Type Feeder Pillar for Industrial and Mining Service

Circuit breaker tank opened for inspection

There have been developed in England very complete designs of fully enclosed, or co-called "Armour clad" switchgear, for voltages as high as 33 kv.

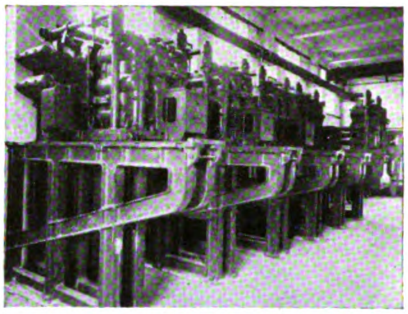


Fig. 25—Electrically-Operated, Armour-Clad Switch-Gear of Draw-Out Type for Power Station Service, 500,000 Arc Kv-a. Rupturing Capacity

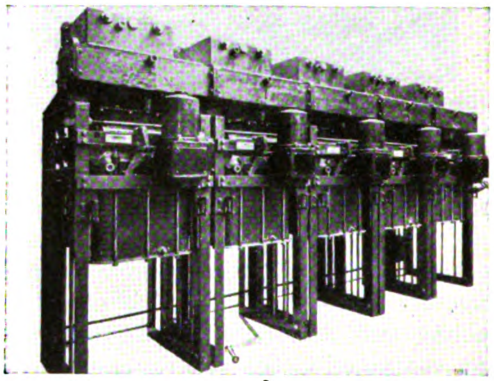


Fig. 26—Electrically-Operated, Armour-Clad Switch-gear of the Drop Tank Type of 250,000 Arc Kv-a. Rupturing Capacity Installed at Talbot Road Power Station, Nottingham, England

When circuit breaker is open tank may be lowered for inspection by means of the crank shown in the foreground. During the lowering process all leads are disconnected and live parts protected automatically.

Fig. 27—Self-Contained, Armour-Clad Distribution Substation of British Manufacture

The recent switchgear installation at the Barking Station of the County of London Electricity Supply Co. introduces one of the most modern developments of this type of gear, which is designed for an operating voltage of 33 kv. and rupturing capacity of 1,500,000 arc-kv-a.

Fig. 23 shows one quarter of this gear in place, with one of the circuit breakers withdrawn. In the foreground may be seen the sealing ends of the compound-filled busbar components and the gas-vent pipes leading through the floor to the outside of the building.

One of the features of the Barking Station gear is the very complete system of interlocks, which has been developed to such a point that it is practically impossible to perform any switching operation in the wrong sequence. To make the system fully complete each section is interlocked with the crane so that no circuit-breaker mechanism can be removed from its position until all connections have been made dead.

This type of gear has been extensively developed to cover all classes of power, mining and industrial requirements.

Three examples of anchor-clad switchgear are shown in Figs. 24, 25 and 26.

A complete armour-clad substation containing high-tension switches, distribution transformer and low-tension fuses is shown in Fig. 27.

Conclusion

The writer wishes to express his appreciation to all who furnished or assisted in securing information or illustrations contained in this paper.

Automatic and Supervisory Control of Hydroelectric Generating Stations

BY FRANK V. SMITH[1]

Associate, A. I. E. E.

Synopsis.—*The paper describes the application of automatic equipment and supervisory control to a number of interesting hydroelectric installations.*

A brief description is first given of the operation of standard equipment, the function performed by it and the protective measures provided. Then several typical stations involving single units, multiple units, self-synchronizing and automatic synchronizing are described, together with some test results of the current surges occurring during the starting operations. The paper closes with some comments on the high-speed, synchronous relay type of supervisory control and remote metering.

* * * * *

General

THE installation of hydroelectric stations equipped with automatic or supervisory control has become so widespread that it may not be out of place, at this time, to review some of the more interesting applications in order to show the variety of problems confronting the switchboard engineer and the methods of handling them. A brief description will be given of the scheme of control that has become more or less standardized for this type of station and then an analysis of several installations.

In general, the equipment is either entirely automatic or operated by means of supervisory control from a remote point, the latter scheme becoming more and more popular because of its greater flexibility.

The simplest kind of supervisory control, known as the Audible Type, is used because of the limited number of operations that have to be performed and the call of economy. Only two wires are necessary for this type. A standard telephone, together with a box containing a number of line keys and a dial, similar to that used in automatic telephone equipment, is required at the dispatching point and a relay cabinet at the generator end. Any number of stations up to ten can be controlled with the same pair of wires looping through them. If separate lines are run out radially from the dispatcher, a key is required for each line to connect it to the supervisory equipment.

Every number dialed sends a train of impulses over the line which, by means of rotary selector switches, perform a certain operation in the distant station and an answer back is received through the telephone (or loud speaker) in the form of a number of busses of different tones, the indication being repeated until another number is dialed or the line disconnected. Fig. 1 shows the complete equipment with the exception of the telephone. At the right is the dispatcher's box with dial and on the left the relay cabinet installed in the remote station. The microphone with low- and high-tone buzzers can be clearly seen while at the extreme left are the rotary switches. A battery of 16 volts is required at the generating station while 110 volts is generally used at the dispatcher's end.

The first operation is to connect the correct station to the supervisory control. This is done by throwing the line key and dialing the number of the station desired—perhaps No. 3. A selector switch then operates in each station stepping to Point 3. This is so arranged that when it stops on any point other than the number of its own station, it sets up a lock-out which prevents further action; but at No. 3 it operates another rotary switch that completes a circuit to a buzzer three times every revolution giving three buzzes in the telephone

1. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

which are repeated until the circuit is interrupted from the dispatching station by further dialing.

The next operation may be to determine the head of water in the forebay. The maximum variation in head is divided into 10 parts with a float switch making contact as it moves over the range and these points are connected to a similar rotary switch so that on checking water head a number of buzzes are heard indicating the point on the scale at which the float stands.

The dialing of another number will set the master

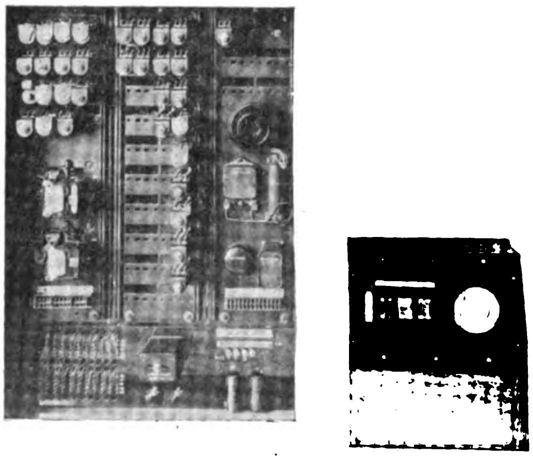


Fig. 1—Audible Type Supervisory Control

relay in the station in operation and the unit will start up and put itself on the line. In stations which are entirely automatic, this master element is energized by such a device as a time clock, frequency relay, float switch or something of the kind which starts the machine when certain predetermined conditions exist.

In general the automatic equipment is arranged to perform the following functions:

a. Start the unit, provided normal conditions exist, upon the operation of the master-starting element

b. Stop the unit by means of the master element

c. Protect against generator overvoltage

d. Protect against motoring of the generator

e. Prevent the opening of the line circuit breaker on short time periods of low a-c. voltage

f. Protect against discharge of the battery. Battery control with automatic means for charging is the most reliable method available because of its complete independence from the a-c. system with its occasional voltage dips.

g. Shut-down the unit temporarily if:

1. The line is short-circuited or overloaded to a point that the machine voltage drops below 80 per cent of normal for several seconds
2. The machine windings tend to overheat
3. The unit overspeeds
4. The unit is caused to operate on a reverse, single or badly unbalanced phase line.

h. Shut-down and lock-out the unit if:

1. A bearing overheats
2. The generator field fails
3. The oil pressure in the governor falls below a safe value
4. The differential relays operate

i. On normal shut-down, the oil circuit breaker and field contactor are prevented from opening until the gates reach the no-load running position. This gradually transfers load to other units on the system and prevents sudden dropping of load on the automatic generator.

j. Prevent the generator from starting if:

1. The unit has been locked out by any function under *h*
2. Conditions as listed under *g* have not been righted

The unit may be provided with a periodic relay so arranged that in event of its being shut-down temporarily as under *g* it will attempt to start only a predetermined number of times and then lock itself out.

The items listed under *h* represent serious troubles in the machine and operate an annunciator lock-out relay which has a series of targets, one for each device, and tells at a glance the cause of the shut-down.

Where supervisory control is used, a warning signal is sounded in the dispatching station whereupon the cause of the trouble can be checked and the station started again if it is of a minor nature.

Single Unit Stations

One of the most interesting cases of the application of this type of control is to be found on a property of the Interstate Public Service Company in the Middle West. Here there is an old barge canal on which are located five hydroelectric stations each containing one vertical

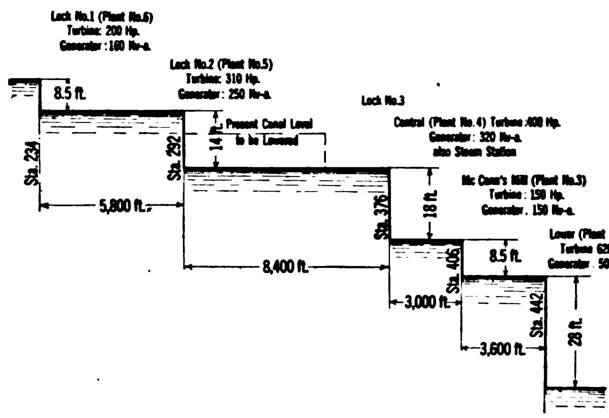


Fig. 2—Interstate Public Service Company Canal Profile

generator. These are known as plants No. 2, 3, 4, 5 and 6 stretched over a canal length of about four miles with machines rated at 500, 150, 312, 250 and 150 kv-a. respectively. Plant No. 4 is the Central Plant and is used as the dispatching point, as a steam station is also located close to the canal and operators are therefore nearby. All machines generate at 2400 volts and are tied together and to the rest of the system with a transmission line at this voltage. Each machine has a direct-connected exciter of ample capacity. Fig. 2 shows the lay-out of the canal.

The four automatic stations are controlled from Plant No. 4, out of which one pair of lines runs to Plants No. 5 and No. 6 and another pair to No. 2 and No. 3. Plant No. 4, itself, is manually operated.

When starting up a station, the key to connect the East or West line to the supervisory is thrown at the control desk and the number of the desired station is dialed. On receiving assurance that the correct plant is connected to the line a check is made of the water-level. If this is suitable the station is started by dialing the proper number. A solenoid on the governor is then energized and the gates begin to open till a point is reached to give approximately normal speed at no load. As the wheel comes up, the exciter, which is not yet connected to the a-c. generator field but has most of its own rheostat short-circuited, builds up its voltage and closes the main line breaker at approximately synchronous speed. As the generator is provided with damper windings it pulls rapidly into step, assisted by the field excitation which is thrown on by an auxiliary switch on the main breaker. The generator then operates in the usual manner under the control of a standard vibrating regulator. This self-synchronizing method of putting a machine on the line is the simplest scheme that is available and even eliminates the necessity of a speed switch to determine the point at which the breaker is closed—this point being set by exciter voltage. As the system is very large compared with the size of the units, no appreciable shock is felt on the line when the machine is closed.

In order to utilize all the water available, the three smaller units at Dams Nos. 3, 5, and 6 operate under float type of load control; the gate opening depending entirely on the head of water available. On the larger units the usual type of speed governor is used with the addition of a float attachment for limiting the load on low head.

The supervisory control performs the usual functions of starting and stopping the units and reading the head of water, power output (determined from the gate opening) and breaker position. In addition, a point is furnished for voltage control; this is provided by means of a contactor which short-circuits a section of the voltage regulating rheostat on the generator and, in effect, recalibrates it for a different voltage. Two trouble horns are furnished in the dispatching station, one for the east and one for the west line. When any machine locks out due to operation of its protective equipment, the horn sounds until the station in trouble is located by means of the supervisory system.

On another part of this system there are now being installed two generators rated at 300 kv-a. and 400 kv-a., 2300 volts in different stations a few miles apart. These are to be entirely automatic, starting and stopping by means of a combination of float switch and time-clock so arranged that the machines will operate according to a predetermined time schedule providing the water-level is within the proper limits.

Multiple-Unit Stations

In these cases there has been but one generator per station. However, installations of two or three machines in the same plant are quite common and give rise to no particular problem. When supervisory control is used, the separate units are handled almost independently as if they were in different stations; the load and breaker positions, etc., of each unit are read separately, although, of course, one water-level indicator is sufficient for the station. When under complete automatic control one machine is given preference so that it will always start first and the others will follow in order as conditions demand. A simple knife switch is generally supplied so that the No. 1 machine can be changed at stated intervals and thus distribute the service over the various units. Sometimes, in order to

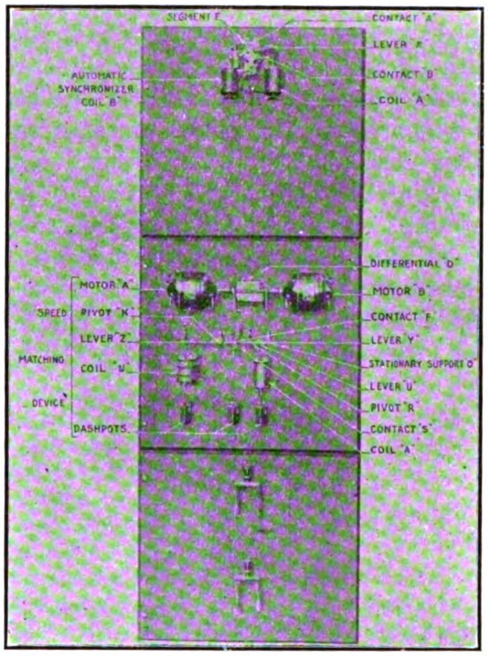


Fig. 3—Automatic Synchronizer

obtain the maximum output from the station, arrangements are made so that as many machines as possible will operate at their maximum points of efficiency rather than distribute the load equally over all units.

One of the most interesting applications in the country is to be found on the property of the Wisconsin Public Service Company on the Peshitgo River. Here, there is a string of four plants at Caldron Falls, High Falls, Johnson Falls and Sandstone Rapids, connected by a 66,000-volt line which runs south to Green Bay. High Falls is a manually operated station of 8750-kv-a. from which the other three are controlled.

Automatic Synchronizing and Self-Synchronizing

The first automatic to be installed was Johnson Falls which contains two 2200-kv-a., 2400-volt, 150-rev. per min. vertical machines with direct-connected exciters and is located three and one-half miles down

the river from High Falls. Since High Falls would be the only station in operation when the machines at Johnson Falls were started up it was felt that if the usual self-synchronizing scheme of throwing the generator on the line without field at approximately synchronous speed were utilized, the bump on the system might be objectionable, and it was decided to make use of the automatic synchronizer. In any case in which the incoming generator capacity is an appreciable percentage of the system kv-a. the use of the automatic synchronizer is essential if smooth operation is to be secured, in fact, in some cases where the machine is on the end of a long line with limited capacity an attempt to throw it on without synchronizing might well produce such a drop in voltage as to allow any synchronous motors on the system to drop out of step.

The automatic synchronizer shown in Fig. 3 is composed of two parts—the speed matcher and the synchronizer proper. The generator is brought up to speed with its field excited from the direct-connected exciter under the control of its voltage regulator and as it nears synchronism the speed matcher comes into play. This consists of a pair of small single-phase motors working through a differential to a contact-making device. One motor is connected to the leads of the incoming machine and the other to the bus. Depending on whether the machine is below or above synchronism, contact is made through the differential to raise or lower the speed of the water-wheel through

Fig. 4—Control Panel for Rheostatic Regulator

the electrically operated governor so that it is held at synchronous speed. An anti-hunting device prevents oscillations. The automatic synchronizer then functions to close the breaker when exactly in phase. This consists of two solenoids working through a lever mechanism and an oscillating segmental contact. It can be seen mounted on the top of the panel. One solenoid is arranged with coils excited from a potential transformer connected in such a way as to have a maximum pull when the voltage of the machine is in phase with the bus and zero pull when directly out of phase. The other solenoid is connected in the reverse manner so that as the machine approaches synchro-

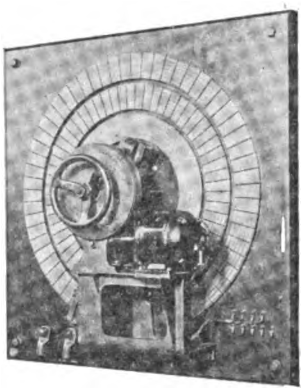


Fig. 5—High Speed Face Plate for Rheostatic Regulator

nism, the pull of the two solenoids reaches a maximum alternately and oscillation takes place in the lever mechanism. The frequency of these oscillations falls as the machine approaches synchronism and when it reaches that corresponding to a complete revolution of a synchroscope needle in approximately five seconds the oscillating segment makes contact long enough to complete a circuit to the control relay and close the machine breaker connecting it to the line. The machine then continues to operate when under the control of its voltage regulator. Synchronizing by this means is much more rapid and more accurate than could be done by hand.

An interesting point in connection with the installation is the use on the generator of the high speed face-plate rheostatic voltage regulator rather than the vibrating type. This regulator is coming into very common use in hydro stations—particularly automatic stations—because of its extreme simplicity and very satisfactory operation. The exciter voltage is maintained constant and regulation takes place entirely on the main field rheostat. A typical control panel is shown in Fig. 4 and the motor-operated face plate in Fig. 5. The forward and reversing contactors of the motor are shown on the top of the panel while the control element proper is below. Variation in bus voltage, working through the lower mechanism, results in rapid cutting in or out of resistance with suitable anti-hunting devices to prevent over-travel of the motor. In this regulator the time element of the exciter field is eliminated so that its speed of operation is quite comparable with the vibrating type and is particularly applicable where heavy field currents necessitate a large number of relays on the vibrating regulator.

The second station to be installed on this system was

Caldron Falls about seven mi. up the river from High Falls where there are two 4000-kv-a., 2300-volt vertical machines. It was decided in this case to use the more usual scheme of self-synchronizing to put the machines on the line. For this reason they were provided with damper windings (these being unnecessary, of course, in the case of Johnson Falls) and a speed switch which operates to close the machine breaker at 95 per cent speed connecting it to the line without field, the field being applied by means of an auxiliary switch on the breaker. Another departure from the practise at Johnson Falls was the use of a vibrating regulator for each machine rather than a rheostatic regulator.

A very interesting picture of the characteristics of the two schemes of starting can be obtained from oscillographs taken at the time of closing the generator breaker. Fig. 6 shows the self-synchronizing generator.

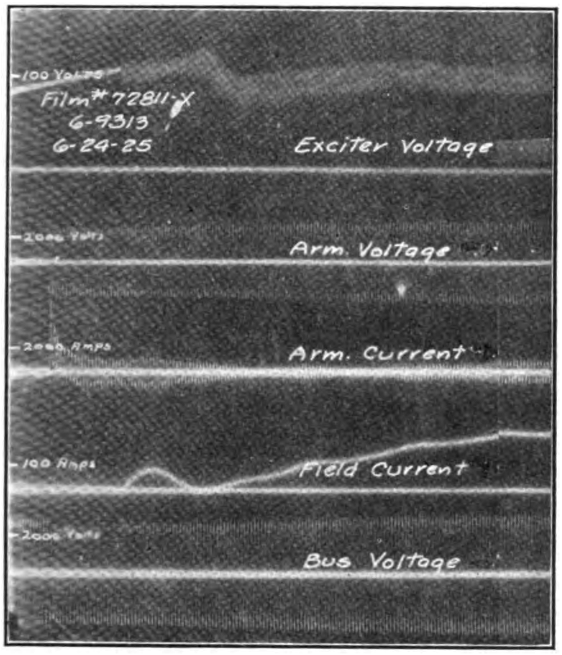


Fig. 6—Oscillograph of Self-Synchronizing Generator

It will be seen that as there is only the reactance of the winding to limit the current, it rises to seven and one-half times full-load current. Several seconds elapse before it has dropped to full load. When the breaker closes, the voltage falls to 75 per cent of normal for a few cycles. Fig. 7 shows the action with an automatic synchronizer. The armature current reaches only 35 per cent of full load and oscillates for a few seconds.

In deciding on the type of control to be used in the latest plant at Sandstone Rapids, experience obtained from the other two pointed to the use of an automatic synchronizer and the face plate rheostatic regulator. Here there are two 2400-kv-a., 6600-volt, 150-rev. per min. machines with direct-connected exciters. In general, the equipment will be very similar to Johnson Falls.

An interesting point in connection with these stations is that they are arranged for starting, not only from the supervisory control, but also from a low-frequency relay. This relay will energize the master element if the frequency drops to 57 cycles; a delay of a few seconds being provided to take care of momentary dips. Only one relay per station is necessary and after it starts machine No. 1, it is transferred to No. 2 to be ready to start it when required. The machines close down when a predetermined underload exists for a stated time, variable up to 30 min.; shutting-down takes place in the reverse order from starting up.

In order to show the extreme flexibility of this type of supervisory control it might be well to enumerate the number of different operations that can be performed by its means in the Sandstone Rapids Plant.

1. Start machine No. 1
2. Stop machine No. 1
3. Release lock out on machine No. 1. This is to allow the machine to operate as a complete automatic station starting by means of its frequency relay if conditions demand.
4. Supervise water-level machine No. 1
5. Supervise gate-opening machine No. 1
6. Increase load on machine No. 1
7. Decrease load on machine No. 1
8. Raise upper limit of gate-opening machine No. 1
9. Lower upper limit of gate-opening machine No. 1
10. Close breaker No. 1. This is a high-tension oil circuit breaker connecting to one of the 66,000-volt feeders.
11. Open breaker No. 1
12. Supervise breaker No. 1
13. Start machine No. 2
14. Stop machine No. 2
15. Release lock out on machine No. 2
16. Supervise water-level machine No. 2
17. Supervise gate opening machine No. 2
18. Increase load on machine No. 2
19. Decrease load on machine No. 2
20. Raise upper limit of gate-opening machine No. 2
21. Lower upper limit of gate-opening machine No. 2
22. Close breaker No. 2
23. Open breaker No. 2
24. Supervise breaker No. 2

Application to Old Stations

Automatic operation shows such economy that it is not only applied to new stations, but also many old ones are being changed over by the addition of the necessary equipment. In one station just put in operation under supervisory control, there is one 1000-kw., 100-rev. per min., 2300-volts, waterwheel generator and one 500-kw., 120-rev. per min., 2300-volt generator both excited from a 50-kw., 125-volt, 500-rev. per min. waterwheel-driven exciter. In general a direct-connected exciter is by far the more desirable for automatic control but, of course, in an old station it cannot always be provided.

Since the machines had no damper windings, they could not be expected to pull into step by the usual self synchronizing method and an automatic synchronizer was, therefore, provided. The station is operated by

supervisory control from a point two miles away. No voltage regulator is used as the machines operate with fixed excitation. The first operation is to start up the exciter and when it is up to voltage machine No. 1 or No. 2 is brought up to speed and field applied. As it nears synchronism, the automatic synchronizer is connected in circuit and the machine synchronized to the line. Only one synchronizer is provided for the two machines and it is automatically connected to the incoming machine as it speeds up.

In addition to the control and supervision of the generators proper, there are 9-feeder circuit breakers in the station which are operated over the supervisory equipment.

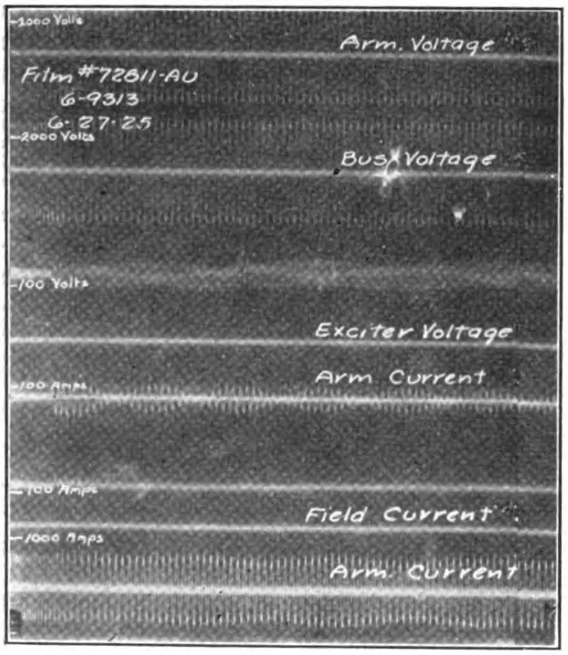


Fig. 7—Oscillograph of Generator Automatic Synchronizing

Large Automatic Unit

One of the largest automatic generators to be put in service will be that of the New England Power Company rated at 9000-kv-a., 2300-volts, three-phase, 60-cycle, 180-rev. per min. with direct connected exciter. The equipment is entirely automatic and in general follows along the usual lines. The machine is started by a combination of time clock and the energizing of the high-tension line from the neighboring station of Davis Bridge, three mi. away. The generator will come into service when the high line is energized providing the time clock has completed contact. The latter can also be arranged to take the generator off and put it on again over the noon hour.

The machine is provided with damper windings and comes on the line by the self-synchronizing method. Remote control is provided from Davis Bridge for adjusting the load on the governor motor when desired but there is nothing further in the way of supervision. As the automatic unit will be on the stub end of a line, the output can be measured at Davis Bridge by the incoming meters.

The voltage is stepped up from 2300- to 110,000-volts through three 2000-kv-a. transformers to tie in with the power system. An emergency motor generator set is provided for excitation in case of trouble with the direct-connected exciter.

Synchronous Visual Type Supervisory Control

In all these installations, the same kind of supervisory control has been used—the audible type—because it is quite sufficient to take care of all requirements. It is possible, however, that what is known as the Synchronous Relay Type of control will find application where remote synchronizing is desirable or where there are such a large number of stations to be controlled that a constant visual indication is required of the status of the equipment in each one.

This apparatus is extremely flexible in its application and there is practically no limit to the number or kinds of operations that can be performed. It does not operate on the impulse or code principle but really sets up a complete circuit from the dispatchers board key over two line wires to the control relay of the apparatus to be operated. This can be a circuit breaker or any indicating device such as a float switch, ammeter or voltmeter which can be arranged to reproduce its indication at the dispatching point.

The apparatus consists of batteries of relays at both ends of the line; these operate in synchronism and are kept together over a two-wire drive circuit with interlocks so arranged that the relays must operate in a predetermined order and corresponding relays at both ends of the line must operate together otherwise the whole equipment comes to rest and refuses to function. Each pair of relays corresponds to some particular operation in the automatic station and as they operate they step another two wire signal line from point to point so that at any particular instant a complete circuit is provided over these signal wires from the control key in the dispatcher's office to the proper apparatus in the automatic station.

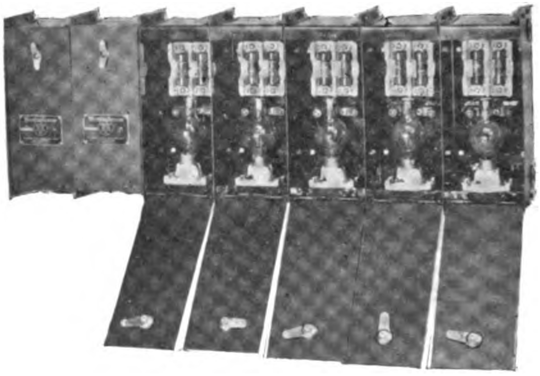


Fig. 8—Supervisory Control Protective Tubes

When it is desired to perform any particular opera-

tion, the corresponding key is depressed and then the drive circuit set in operation. The relays operate in synchronism until the signal circuit reaches the key that has been operated and thus a complete circuit has been completed through to the apparatus and the operation takes place. In the case of remote synchronizing, voltage transformers are connected to points in the substation cabinet and a synchroscope to corresponding points at the dispatcher's end. The circuit breaker to be closed is arranged to be the next point in sequence so that, the moment synchronism is reached, the dispatcher operates a key which instantly transfers the signal line from the synchroscope point to the breaker point and closes the breaker.

Continuous lamp indication is given of the position of all equipment and telltale lights are provided to show any automatic operation.

Supervisory Protective Equipment

It might be well to mention here the necessity for some kind of apparatus to protect the supervisory control equipment from line disturbances. It is very common to find the telephone wires used for the supervisory run underneath the high-tension transmission lines where they will be subject to induced voltages from the high-tension line as well as the possibility of direct contact. In order to prevent such over-voltages getting into the control equipment vacuum tubes to provide a path to ground are connected to the supervisory line at both ends. Fig. 8 shows a battery of such tubes. Each tube contains four electrodes. In the case of a two-wire line, an electrode is connected to each line and the other two are connected together and to ground. The four are spaced so that they will discharge at a difference of potential of about 250 volts between pairs, thus preventing any higher voltage than this remaining on the control wires. Small fuses are furnished for connection between the tubes and the supervisory and in the case of overhead wires paralleling high-tension lines, fuses of the transmission line voltage rating are also used on the line side. These vacuum tube protectors have been known to take care of the most severe conditions without difficulty.

D-C. Hydro Station. Although the great majority of installations are for a-c. generators there are some cases where vertical d-c. machines have been used. These are provided with the necessary WR^2 and overspeed capacity and use Kingsbury thrust bearings. The commutator is placed below the rotor to prevent carbon and copper falling in the windings.

The machines are entirely automatic in operation, being controlled by a float switch. As the water-level rises the float makes contact and starts the governor oil pump motor and when the proper operating pressure has been reached, an electric solenoid puts the governor in operation, the gates open and the machine comes up to speed. The automatic voltage regulator then comes into operation and balances the voltage of the machine with the bus by working on a motor-operated field rheostat. The main d-c. breakers are closed and the load taken by the generator is regulated by the water-level; the float switch operates over a rheostat which is inserted in the voltage regulator circuit thus recalibrating it and allowing it to regulate for higher or lower voltage and therefore larger or smaller output. The units are shut down at a predetermined minimum head.

In addition to balancing the voltage at start and regulating it for load the regulator has a third element which limits the output of the generator in case of trouble. In event of overload, the voltage is cut down thus limiting the output and if the overload continues the thermal relays lock the machine out.

Conclusion

While no attempt has been made to go into the equipment supplied for any of these plants in very great detail, it is hoped that sufficient has been described to show the variety of applications confronting the automatic engineer, the types of problems that are encountered, and the extreme flexibility of the equipment in its capacity to take care of practically any conditions that can arise.

ELECTRICAL HOUSEHOLD APPLIANCES IN THE NETHERLANDS

A large demand for modern electrical household appliances has recently been created in the Netherlands as a result of the activities of the municipal electric works at Amsterdam where American products are generally favored.

The general application of electrical appliances has been restricted by the comparatively high rates, consequently the number of electric household appliances used has been small. Special rates are now being quoted for electricity used during the daytime, and the municipal electric works at Amsterdam has announced that it will supply electric energy at a lower "night tariff" from 11 p. m. to 7.30 a. m.

The municipal enterprise is demonstrating devices in a special showroom. Among the articles shown is an electric stove which stores heat during the night hours for use the next day. When the stove, which weighs about 330 lbs. is fully charged, the inside temperature is 275 deg. cent., while the outside is 70 deg. cent.

Various types of electrically operated refrigerators are also on exhibition. Water tanks with a capacity of 1½, 6, 10, 40, and 60 gallons are available. The water is heated to 85 deg. cent. Radiation is at the rate of three-quarters of a degree per hour, so that hot water will be available all day.

The municipal works are supplying purified, dry air in cylinders which can be placed in bedrooms of people suffering from asthma.

Abridgment of

Synchronous Machines

I—An Extension of Blondel's Two-Reaction Theory

BY R. E. DOHERTY[1] and C. A. NICKLE[1]

Associate, A. I. E. E. Associate, A. I. E. E.

***Synopsis.**—Blondel treated salient pole machines by resolving the fundamental space component of m. m. f. along the two axes of symmetry—the direct axis of the pole, and the quadrature axis between poles. Using this idea and applying harmonic analysis, Blondel's theory has been extended in the present paper to a comprehensive system of treatment in which the effect of harmonic m. m. fs., as well as the fundamental and also of field m. m. f. in the quadrature axis, as well as in the direct have been taken into account.*

It is shown that the "armature leakage flux" which causes reactance voltage drop in synchronous operation comprises all fluxes due to armature currents which generate fundamental voltage except the space fundamental component, the latter constituting the total flux of "armature reaction."

Impressing upon the variable air-gap permeance those space harmonics of m. m. f. which are due to the fundamental time component of current and which therefore rotate at various fractional speeds produces odd space harmonics of flux rotating at many different speeds and in opposite directions. Some of these listed in Table I produce fundamental voltage, but most of them generate time harmonics. The former, which are reactive voltages, are only those of the nth space order rotating at one nth speed—that is, those which correspond in space order and speed to the harmonic m. m. fs. The corresponding reactances are definitely defined in Appendix C in terms of permeance coefficients, and means are outlined for quantitative determination of such coefficients from graphically constructed field plots. Although, strictly, there are as many field plots required as there are significant m. m. f. harmonics, an approximation, developed in Appendix B, is given in which only one plot is necessary, other permeance waves being derived therefrom.

It is shown that only the average term and the second space harmonic of the permeance series affect the fundamental voltage. Hence, unless it is required to calculate the harmonic voltages, only those two terms of the permeance series need to be determined.

In the application of the results, the fundamental voltages thus produced by the armature currents are superposed upon that due to current in the field winding, which latter has been previously treated. This gives the vector diagram, Fig. 19, from which the steady state relations are set down in equations.

In Part II, the steady-state angle-power relations are developed, including an interpretation of the "reluctance term" in the power or torque equation.

In Appendix D, the vector diagram for salient pole machines is interpreted in terms of the well-known Potier diagram for cylindrical rotor machines. Also the effect of saturation both on angle-power relation and on the value of excitation required under load, is discussed.

Subsequent papers in the near future will present results which have been obtained from the application of the method and point of view here outlined to the solution of problems relating to abnormal operating conditions of synchronous machines.

* * * * *

INTRODUCTORY

THE ever widening application of synchronous machines and their great importance as a factor in the operation of power systems have created the occasion for an extended study of their behavior under the various normal and abnormal conditions. The results of the investigation comprise not only the determination of such operating characteristics, but also extensions in fundamental theory and in mathematical facilities for applying it. It is the authors' purpose to present the results of the investigation in a series of papers, the present one dealing with the theory relating to steady-state, polyphase operation.

The present work is essentially an extension of Blondel's[2] treatment, and an application of the results to definite problems. His fundamental conception of resolving the armature m. m. fs. and fluxes in salient pole machines into two space components—one in line with the pole axis, the other in quadrature thereto—is the basis of the present study. The fundamental premises are extended, and new constants which are necessary to characterize the performance are defined and incorporated in the equations. As in any engineering analysis, this has involved certain assumptions, carefully defined, which would simplify the equations to a practical degree, but which would not throw the calculated results beyond the limit of reasonable accuracy. That is, the predominating factors which practically determine the characteristics have been included, and those have been omitted which complicate the equations without significantly affecting the calculated result. The final equations are thus relatively simple, considering the nature of the phenomena related.

Lyon[3] has treated the *flux* distribution, voltage and power of a synchronous machine by an interesting application of harmonic analysis to the flux waves which must exist. He starts with a general equation for the complicated resultant flux wave; hence, the resulting series contain coefficients which it would be very difficult to determine. However, it is true, as Prof. Lyons says, that it is "useful to know what harmonics may be present even when their magnitudes can not be calculated." The present paper, while applying the same general method of attack, *i. e.*, harmonic analysis, nevertheless starts with the resolution of *m. m. f.* waves, instead of *flux* waves, and takes advantage of the symmetry embodied in salient pole

1. Both of the General Electric Co., Schenectady, N. Y.
2. Bibliography 11.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

3. Bibliography 7.

machines, by making the resolutions along the two axes of symmetry,—*i. e.*, applies Blondel's idea. This treatment gives m. m. f. waves spread over definite permeance distributions, thus making it possible to determine the coefficients of the significant harmonics of the flux waves.

Thus several aspects of the problem have been treated during the investigation; an extension in fundamental theory, comprising an harmonic analysis of the phenomena in the air-gap, and the inclusion of exciting field ampere-turns in the quadrature axis, the definition of characteristic constants, and thus, to this extent, a basis for their determination; the formulation of characteristic equations; the excitation-voltage-load characteristic; angle-power relations under steady and transient states; short-circuit phenomena under steady and transient states, single phase and polyphase; and mechanical forces and torques due to electromagnetic reactions under various conditions.

The present paper is in two parts. The first interprets and extends the theory relating to steady-state conditions, including definitions of the essential constants; constructs the excitation-voltage-load diagram, and shows the relation of this to the corresponding familiar diagram for cylindrical rotor construction. Part II treats the steady-state power-angle relations.

I. General Theory

Percentage Representation of Quantities. It is convenient to express the quantities involved in percentage (as a fraction) of their normal values. While the base of the fraction for each quantity has definite dimensions, the fraction is, of course, a numeric, and its use avoids cumbersome conversion factors in the equations. Nevertheless, the results thus expressed by fewer symbols are none the less definite. It is believed that many mathematical treatments of engineering problems could be immensely simplified in this way.

On this basis:

Unit voltage is normal rated voltage.

Unit armature current is normal rated current.

Unit power is normal three-phase power.

Unit impedance is that impedance through which normal voltage at normal frequency causes normal current to flow.

Unit field current is that field current which induces normal fundamental, open circuit voltage at normal speed.

Unit space fundamental flux is the flux which rotating at normal speed induces unit voltage.

Unit flux density is the maximum density of the unit fundamental flux wave.

Unit space fundamental magnetomotive force is the resultant fundamental magnetomotive force produced by normal three-phase armature current.

Unit permeance coefficient is that coefficient which, multiplied by unit m. m. f., gives unit flux density.

Unit time is the time required for one cycle of fundamental frequency.

Unit angle is 2π.

Unit speed is normal synchronous speed.

All armature voltages and currents are per phase.

Armature Current Phenomena. It has been shown by Arnold and others[4] that in a synchronous machine, the *space* distribution of *m. m. f.* due to each armature coil can, under certain reasonable assumptions[5], be resolved into rotating space harmonics. The superposition of these m. m. f. distributions due to all coils produces an interesting and highly convenient result—namely, a number of space sinusoids of m. m. f. of different pole spans, rotating at different speeds, some forward, some backward. Thus, for instance, in a balanced three-phase system, the fundamental sinusoid alone rotates at synchronous speed with respect to the armature, *i. e.*, with the field poles; the third harmonic, vanishes; the fifth, with a pole span of one-fifth, rotates backward at one-fifth of synchronous speed; the seventh, with a one-seventh span, forward at one-seventh speed; the ninth vanishes; the 11th, backward, and so on. Stated in other words, for balanced current (sine wave in time) in a three-phase armature, there are a number of different, independent, *space* sinusoids of *m. m. f.*, each rotating at a different speed; and they exist as sinusoids, of course, regardless of the salient-pole character of the magnetic circuit of the rotor, so long as the poles are symmetrical. Fig. 1 shows the fundamental and fifth of such a system at one instant of time.

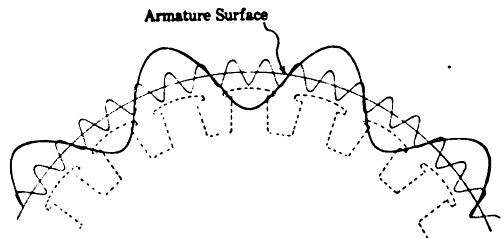


FIG. 1—TRAVELING SPACE SINUSOIDS OF M. M. F.

While the method is here discussed in terms of a three-phase machine, the general theory obviously applies to any polyphase system. In two-phase, the only difference is in the number of harmonics dealt with. For this case, the space harmonics of m. m. f. are as follows; the fundamental, forward at synchronous speed, the 3rd backward at $1/3$ speed, 5th forward at $1/5$ speed, etc.—all of which may be treated in the foregoing manner. In single-phase, the method of analysis is the same, but the results involve some additional

4. Bibliography 2; and 4, chapter VII.

5. The particular assumptions involved in order that m. m. f. with respect to the rotor may be definite at each point of the armature surface are infinite permeability of the armature iron, no slots, armature current concentrated at points along the armature surface, and symmetrical field structure.

Subject to these assumptions, the armature m. m. f. becomes equivalent to a distribution of magnetic potential along the armature surface.

constants which enter the problems of transient state; hence this case will be treated in a later paper.

If there are time harmonics in the current, each one of them will produce its own system of space sinusoids of m. m. f., which will be like that produced by the fundamental term in all respects except that the speed of rotation of each sinusoid will be increased by the order of the time harmonic of current. For instance, if the current in each phase comprises a fundamental and a fifth harmonic, there will be two systems of space sinusoids: one due to the fundamental, as described in the foregoing paragraph; and another in which the sinusoids of full pole span (*i. e.*, fundamental in space) rotates at five times synchronous speed, the third vanishes, the fifth (one-fifth pole span) at five-fifths speed, and so on.

It is possible to superpose the armature m. m. fs.[6] as in the foregoing, because they are all assumed[7] to be distributed along the armature surface. However, the field pole m. m. f. is not. It is distributed radially and at some distance from the armature currents. Hence, the superposition of the armature and field m. m. fs. is not permissible. But all of the *fluxes* at any point on the armature surface, produced by all of these m. m. fs., can be superposed; likewise, the corresponding voltages.

So the problem is to determine all of the space harmonics of flux which are produced by all currents of both the field and armature, and which generate voltage in the armature conductors; then to superpose such of them as are significant, in order to determine the resultant voltage. In addition, there are voltages due to those fluxes which do not appear in the air-gap—namely, slot leakage and end-winding leakage. These fluxes are practically proportional to, and in phase with, the armature current, and thus produce corresponding reactive voltages. The resultant of all of the foregoing voltages is, of course, the terminal voltage.

Turn now to the flux waves produced by the rotating sinusoids of m. m. f. Under steady-state operation the fundamental space wave of the armature m. m. f. rotates at synchronous speed with the field poles, at some definite angle of displacement. Hence whatever may be the shape of the flux wave thus produced, it is nevertheless steady in value and fixed with respect to the poles. All of the space harmonics of m. m. f., on the contrary, rotate at speeds different from synchronous speed, and therefore travel over magnetic paths of varying permeance, each wave of m. m. f. producing a pulsating, tufting, rotating flux—rotating, as it were, at a non-uniform velocity with respect to the poles, yet, at the same time, pulsating in magnitude.

6. Neglecting the magnetic reluctance of the armature.

7. The assumption is that the m. m. f. wave of each coil is approximately a square wave, and hence that the total current in each slot is concentrated in a conductor in the center line of the slot, at the surface of the armature, as illustrated for a particular case in Fig. 2.

This is, of course, a complicated phenomenon, but it can be handled analytically as follows:

1. Resolve each rotating space harmonic of m. m. f. into two stationary pulsating waves with respect to the poles.
2. Determine the two corresponding stationary (with respect to the poles), pulsating *flux* waves produced by (1).
3. Combine the flux waves of (2) into *rotating* space harmonics of flux.
4. Determine the component voltages which the space harmonics of flux in (3) generate.

The same method of analysis, of course, applies to the space fundamental of m. m. f. as well as to the space harmonics of m. m. f., the essential difference in result being that the speed of the space harmonics of *flux* due to the space fundamental of m. m. f. is zero with respect to the poles.

Before proceeding to such analysis, it is necessary to resolve the system of three-phase, balanced, sine-wave (in time) currents into two component three-phase systems: one in which the current in each individual phase reaches maximum at the instant the axis of the field pole coincides with the axis of magnetization of the

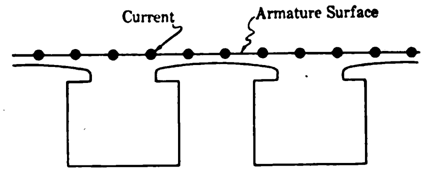


FIG. 2—ASSUMED CURRENT DISTRIBUTION ALONG THE ARMATURE SURFACE

phase under consideration—this is called the *direct* component because it produces the direct component of armature reaction; and another in which the current in each individual phase reaches maximum at the instant its axis of magnetization is in line with the axis midway between poles, that is, one-quarter cycle later—this is the *quadrature* component. Each of these complementary, three-phase systems has its own set of rotating space sinusoids of m. m. f. as described in the foregoing.

While the general case is treated in Appendix A, the physical significance is necessarily somewhat obscured in such a treatment. Hence it appears desirable to illustrate by carrying through the analysis of some particular harmonic,—say the fifth. The procedure is the same for any harmonic, including the fundamental.

The first step is to define the references clearly. Since the resolution of m. m. fs. is to be made with respect to the poles, the space reference will be taken as the axis of a field pole, and time will be reckoned from the instant the axis of magnetization of some particular phase, say phase 1, lines up with the pole axis. Thus, referring to Fig. 3A, the electrical angle α is measured from the axis of pole a in the direction of rotation. The position of the axis of phase 1 with reference to pole a is shown for the instant $t = 0$. In

Fig. 3B, the position of phase 1 with respect to pole a is shown for

$$t = 0.25, \text{ for which } \alpha = -0.25$$

Now consider the time-space relations of the m. m. f. waves. By hypothesis the *direct* component of current is maximum at the instant for which the space relations of the m. m. fs. are shown in Fig. 3A, that is at $t = 0$. That is, the instantaneous value of this current is

$$i_d \cos t \qquad (1)$$

Thus at that moment, the fundamental[8] A_{1d} and the fifth A_{5d} space harmonics of m. m. f. have the space relations with respect to the poles as shown. Be it remembered that the fundamental is fixed in magnitude and position with respect to the pole, whereas the 5th, like the other harmonics, is rotating with respect to the pole.

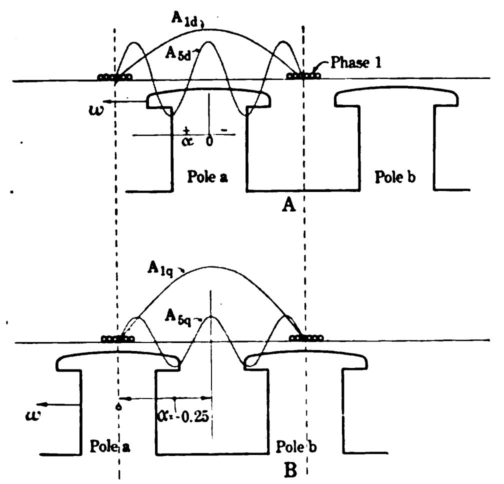


FIG. 3—SPACE AND TIME RELATIONS BETWEEN THE FUNDAMENTAL AND 5TH SPACE HARMONIC OF M. M. F.

A—For direct component of armature current
B—For quadrature component of armature current

The *quadrature* component of current, on the other hand, is a maximum at a *later* time, that is at $t = 0.25$. Thus the instantaneous value is

$$i_q \sin t \qquad (2)$$

and the space relations of its corresponding m. m. f. waves *at that instant* are shown in Fig. 3B. But obviously this position is *not the space position which the 5th had at* $t = 0$, since the wave is rotating with respect to the poles. The *quadrature* fundamental, like the *direct* fundamental, is of course stationary with respect to the pole, and of constant magnitude.

To analyze the 5th, it is necessary to obtain an expression for each of the two components of the rotating 5th space sinusoid of m. m. f., namely a_{5d} and a_{5q}. The known characteristics are (a) the amplitude, (b) the space distribution, or position of the rotating wave at one instant, and (c) the speed and direction of rotation. Take the *direct* component first:

(a) amplitude, A_{5d}

(b) maximum value of wave coincides with pole axis at $t = 0$

(c) rotates backward with respect to the armature at $^1/_5$ speed, and with respect to the poles at $^6/_5$ speed, thus at an electrical angular velocity (referred to its own wave length) of six times normal.

The equation for such a rotating wave is

$$a_{5d} = A_{5d} \cos \{ 5 (\alpha + \psi) + 6 t \} \qquad (3)$$

at $t = 0$, it is,

$$A_{5d} \cos 5 (\alpha + \psi)$$

But from the assumed boundary condition in Fig. 3A, the space distribution at $t = 0$ is

$$A_{5d} \cos 5 \alpha$$

Hence $\psi = 0$. Thus the wave is

$$a_{5d} = A_{5d} \cos (5 \alpha + 6 t) \qquad (4)$$

Likewise, the 5th rotating m. m. f. wave due to the *quadrature* component of current is

$$a_{5q} = A_{5q} \cos \{ 5 (\alpha + \psi') + 6 t \} \qquad (5)$$

At $t = 0.25$, it is

$$A_{5q} \cos \{ 5 (\alpha + \psi') + 1.5 \}$$

which must represent the wave in the particular position shown in Fig. 3B, that is

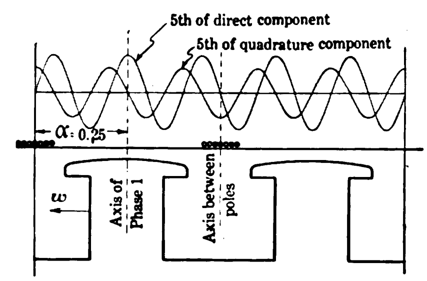


FIG. 4—THE DIRECT AND QUADRATURE COMPONENTS OF THE 5TH SPACE HARMONIC OF M. M. F. AT $t = 0$. EQS. (2) AND (4) RESPECTIVELY

$$- A_{5q} \sin 5 \alpha$$

Thus

$$\cos \{ 5 (\alpha + \psi') + 1.5 \} = - \sin 5 \alpha$$

Hence

$$\psi' = - .05$$

and the equation of the wave is, by (5)

$$a_{5q} = A_{5q} \cos \{ 5 (\alpha - .05) + 6 t \}$$

or

$$a_{5q} = A_{5q} \sin (5 \alpha + 6 t) \qquad (6)$$

The waves represented by (4) and (6) are shown in Fig. 4 for the instant $t = 0$.

The stated plan is to resolve each of the two waves (4) and (6) in two pulsating components, stationary with respect to the poles, and then determine the corresponding stationary, pulsating flux waves. Thus, by direct trigonometric transformation, (4) becomes,

$$a_{5d} = A_{5d} (\cos 5 \alpha \cos 6 t - \sin 5 \alpha\, 6 t)$$

8. The waves as shown are due not only to current in phase 1, but also to currents in the other two phases, the resultant waves of all the currents having, *at that instant*, the same space distribution as the corresponding harmonics produced by phase 1 alone. The magnitudes are different, of course.

which comprises the two stationary pulsating waves

$$a'_{5d} = A_{5d} \cos 5\,\alpha \cos 6\,t \quad (7)$$

and

$$a''_{5d} = -\,A_{5d} \sin 5\,\alpha \sin 6\,t \quad (8)$$

Similarly, (6) becomes,

$$a'_{5q} = A_{5q} \sin 5\,\alpha \cos 6\,t \quad (9)$$

and

$$a''_{5q} = A_{5q} \cos 5\,\alpha \sin 6\,t \quad (10)$$

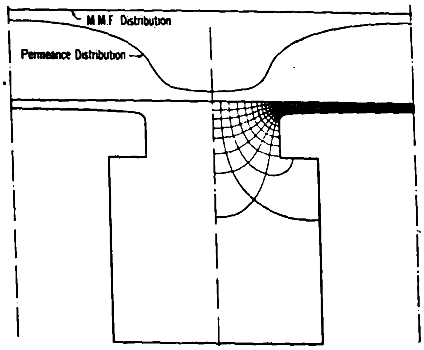
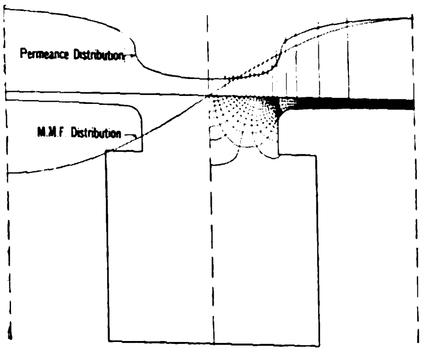
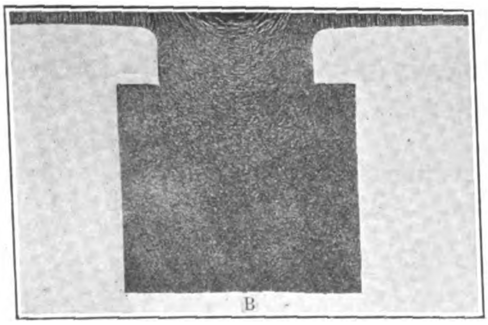


FIG. 5—A—FLUX AND PERMEANCE DISTRIBUTION FOR THE ZERO HARMONIC (CONSTANT M. M. F.), GRAPHICALLY DETERMINED



A

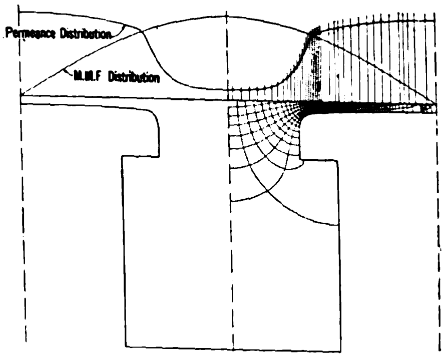
FIG. 6—A—FLUX AND PERMEANCE DISTRIBUTION FOR FUNDAMENTAL, COS α DISTRIBUTION OF M. M. F., GRAPHICALLY DETERMINED



B—FLUX DISTRIBUTION BY TEST

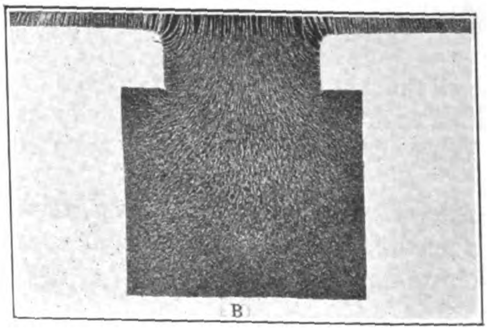
The next step is to obtain the flux waves produced by these stationary, pulsating waves of m. m. f. The product of the m. m. f. at any point along the armature, by the permeance coefficient applying to the magnetic path at that point, gives the flux density at that point. But the permeance[9] coefficient, as well as the m. m. f., is a function of the space angle α. Although it is different for each harmonic and is in any case a somewhat complicated function of α, it is at least a function which is symmetrical about both the direct and quadrature axes, in all cases of symmetrical salient poles, and can therefore be represented by a Fourier series of even cosines.[10] Fig. 5 shows the distribution of m. m. f., permeance coefficient and resultant flux for the zero harmonic; Fig. 6, the same for the fundamental, cos α distribution of m. m. f.; Fig. 7, for fundamental, sin α distribution of m. m. f.; Fig. 8, for the 5th harmonic, cos $5\,\alpha$ distribution of m. m. f.

These flux distributions were determined in one case



A

FIG. 7—A—SAME AS FIG. 6, EXCEPT FOR SIN α DISTRIBUTION OF M. M. F.



B—FLUX DISTRIBUTION BY TEST

by graphic method, and in the other by test. Also the permeance distributions were determined in one case from the field plot, and in the other, from the curve in

9. Question may be raised whether it is proper to consider the m. m. f. and permeance thus distributed, since the air-gap, in the case of salient poles, is extremely variable, and hence the total m. m. f. indicated at any point may not be entirely consumed in the corresponding permeance; that is, the return path from pole to armature may consume more or less than the path from armature to pole. It is permissible because, over a pole pitch, the distributions are symmetrical, thus giving a corresponding return path in a similar position somewhere within the pole pitch.

10. Even cosines, because a cycle of the resultant permeance wave is of one-pole pitch, thus one-half cycle of fundamental space angle.

Fig. 10, derived in Appendix B. It will be noted that there is a very reasonable agreement. By appropriate modification of the result for uniform air-gap, the permeance distribution for salient poles may be plotted, as in Figs. 11 and 12, and analyzed.

The two permeance coefficient series, one for the

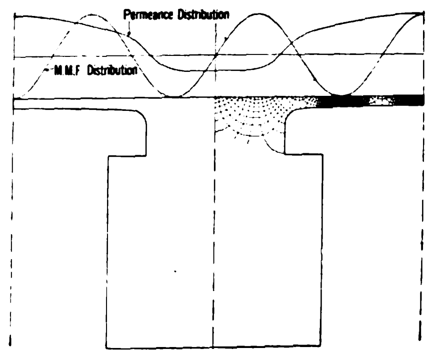


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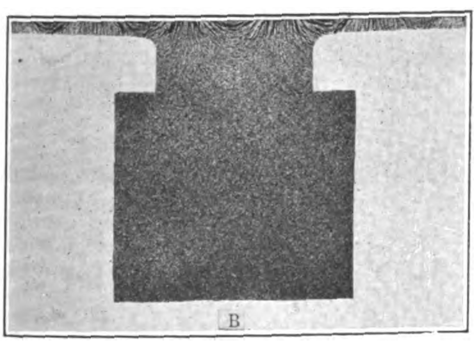
FIG. 8—A—FLUX AND PERMEANCE DISTRIBUTION FOR THE 5TH HARMONIC OF M. M. F. COS α DISTRIBUTION, GRAPHICALLY DETERMINED



B—FLUX DISTRIBUTION BY TEST

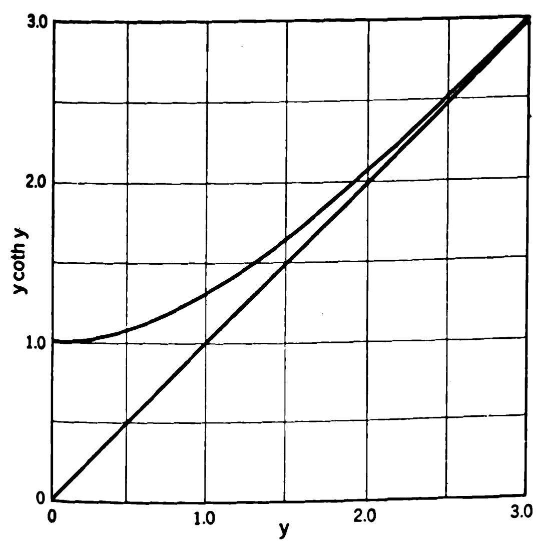


FIG. 10

cosine, the other for the sine distribution of the 5th harmonic m. m. f., are respectively,

$$p^{\mathrm{V}}_{c} = p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{2c} \cos 2\,\alpha + p^{\mathrm{V}}_{4c} \cos 4\,\alpha + \ldots \quad (11)$$

and

$$p^{\mathrm{V}}_{s} = p^{\mathrm{V}}_{0s} + p^{\mathrm{V}}_{2s} \cos 2\,\alpha + p^{\mathrm{V}}_{4s} \cos 4\,\alpha + \ldots \quad (12)$$

the subscript c and s indicating cosine and sine respectively, and the numerally (thus avoiding the appearance

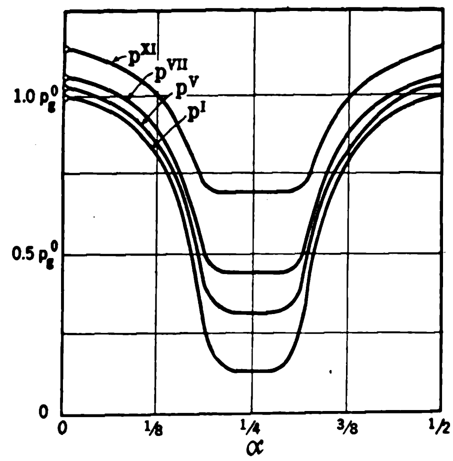


FIG. 11—PERMEANCE DISTRIBUTIONS DETERMINED FROM FIGS 21 AND 22

ANALYSIS OF THESE WAVES GIVES:

$p_0^{\mathrm{I}} = 0.66\ p_g^0$	$p_2^{\mathrm{I}} = 0.44\ p_g^0$
$p_0^{\mathrm{V}} = 0.73\ p_g^0$	$p_2^{\mathrm{V}} = 0.37\ p_g^0$
$p_0^{\mathrm{VII}} = 0.79\ p_g^0$	$p_2^{\mathrm{VII}} = 0.33\ p_g^0$
$p_0^{\mathrm{XI}} = 0.94\ p_g^0$	$p_2^{\mathrm{XI}} = 0.25\ p_g^0$

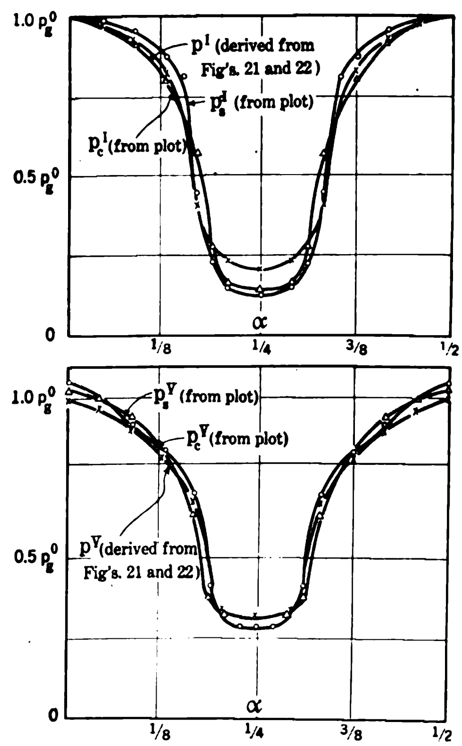


FIG. 12—COMPARISON OF DERIVED AND PLOTTED PERMEANCES FOR 1ST AND 5TH HARMONICS

of an exponent) indicating that the series is for the 5th space harmonic of m. m. f.

The flux waves are, therefore, obtained by multiplying (7) and (10) by (11), and (8) and (9) by (12).

Thus,

$$\beta'_{5d} = \frac{1}{2} A_{5d}[(p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c}) \cos \alpha + (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c}) \cos \overset{3}{2} \alpha$$
$$+ (2\, p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{10c}) \cos 5\alpha$$
$$+ (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{12c}) \cos 7\alpha + \ldots] \cos 6t \qquad (17)$$

$$\beta''_{5d} = -\frac{1}{2} A_{5d}[(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) \sin \alpha + (p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) \sin 3\alpha$$
$$+ (2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s}) \sin 5\alpha$$
$$+ (p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{12s}) \sin 7\alpha + \ldots] \sin 6t \qquad (18)$$

$$\beta'_{5q} = \frac{1}{2} A_{5q}[(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) \sin \alpha + (p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) \sin 3\alpha$$
$$+ (2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s}) \sin 5\alpha$$
$$+ (p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{12s}) \sin 7\alpha + \ldots] \cos 6t \qquad (19)$$

$$\beta''_{5q} = \frac{1}{2} A_{5q}[(p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c}) \cos \alpha + (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c}) \cos 3\alpha$$
$$+ (2\, p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{10c}) \cos 5\alpha$$
$$+ (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{12c}) \cos 7\alpha + \ldots] \sin 6t \qquad (20)$$

Thus the stationary pulsating 5th space harmonic of m. m. f. a'_{5d}, impressed on the variable (in space) permeance, produces space waves of *flux* of *all* odd harmonics, including the fundamental, there being a definite progression in the subscripts of the permeance constants for the increasing order of the odd space harmonic.

It will be noted that if the corresponding harmonics of (**17**) and (**18**), and of (**19**) and (**20**) be paired, the result will be that for each space harmonic of the series, there will be two flux waves in space and time quadrature, *but of different amplitude.* Now just as the rotating 5th harmonic m. m. f. wave was resolved into two equal stationary pulsating waves in space and time quadrature, so in the present case the equal components (*i. e.*, two amplitudes equal to the smaller) can be composed into one main rotating wave; and the difference between the amplitudes constitutes a residual, single, stationary, pulsating wave, which can be resolved, according to the well-known scheme, into two equal waves of one-half amplitude, rotating in opposite directions. Thus one of these must rotate with the foregoing main wave, and in space phase with it, and the other alone in the opposite direction.

Thus equations (**17**) and (**18**) together contain two rotating *flux* waves for each odd harmonic of space distribution, the speeds of rotation being different for all harmonics; hence a corresponding difference also in the magnitude and order of the harmonic voltages thus generated; likewise, (**19**) and (**20**). These flux waves are obtained by pairing the corresponding space harmonics of (**17**) and (**18**), and of (**19**) and (**20**), and expanding them.[11]

11. They could be obtained also by the scheme used to illustrate the physical meaning of the waves, as in Fig. 7.

Eqs. (**17**) and (**18**) therefore give:

$$\beta_{5d1} = \frac{1}{4} A_{5d}[(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) + (p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c})] \cos(\alpha + 6t)$$
$$+ \frac{1}{4} A_{5d}[-(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) + (p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c})] \cos(\alpha - 6t) \qquad (21)$$

$$\beta_{5d3} = \frac{1}{4} A_{5d}[(p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) + (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c})] \cos(3\alpha + 6t)$$
$$+ \frac{1}{4} A_{5d}[-(p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) + (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c})] \cos(3\alpha - 6t) \qquad (22)$$

$$\beta_{5d5} = \frac{1}{4} A_{5d}[(2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s})$$
$$+ (2\, p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{10c})] \cos(5\alpha + 6t)$$
$$+ \frac{1}{4} A_{5d}[-(2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s})$$
$$+ (2\, p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{10c})] \cos(5\alpha - 6t) \text{ etc.} \qquad (23)$$

And (**19**) and (**20**) give:

$$\beta_{5q1} = \frac{1}{4} A_{5q}[(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) + (p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c})] \sin(\alpha + 6t)$$
$$+ \frac{1}{4} A_{5q}[(p^{\mathrm{V}}_{4s} - p^{\mathrm{V}}_{6s}) - (p^{\mathrm{V}}_{4c} + p^{\mathrm{V}}_{6c})] \sin(\alpha - 6t) \qquad (25)$$

$$\beta_{5q3} = \frac{1}{4} A_{5q}[(p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) + (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c})] \sin(3\alpha + 6t)$$
$$+ \frac{1}{4} A_{5}[(p^{\mathrm{V}}_{2s} - p^{\mathrm{V}}_{8s}) - (p^{\mathrm{V}}_{2c} + p^{\mathrm{V}}_{8c})] \sin(3\alpha - 6t) \qquad (26)$$

$$\beta_{5q5} = \frac{1}{4} A_{5q}[(2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s})$$
$$+ (2\, p^{\mathrm{V}}_{0c} + p^{\mathrm{V}}_{10c})] \sin(5\alpha + 6t)$$
$$+ \frac{1}{4} A_{5q}[(2\, p^{\mathrm{V}}_{0s} - p^{\mathrm{V}}_{10s})$$
$$- (2\, p^{\mathrm{V}}_{0c} + p_{\cdot 10c})] \sin(5\alpha - 6t) \text{ etc.} \qquad (27)$$

The third subscript is the order of the space harmonic *flux* wave. Thus, β_{5q3} is the 3rd harmonic space flux produced by the 5th space m. m. f. due to i_q.

Consider the meaning of these waves. Each one has an electrical angular velocity of six times normal (referred to its own wave length) with respect to the pole. The wave moves forward if the sign of t is minus, and backward if it is plus[12]. Thus, (**25**) comprises two waves,

12. For instance, in a rotating wave, say (**25**), $\sin(\alpha + 6t)$ must equal a constant. That is, $\alpha + 6t = C$, and $\frac{d\alpha}{dt} = -6$. Thus velocity is backward at 6 times normal speed.

one (the first term) rotating backward at six times synchronous speed with respect to the poles, five times speed with respect to the armature; the other, rotating forward at six times speed with respect to the poles, thus seven times with respect to the armature. These waves are of full pole span; hence the former generates a 5th harmonic, the latter a 7th harmonic voltage in the armature conductors. Eq. (**26**) likewise comprises two 3rd harmonic space waves, one forward, one backward, with respect to the pole at 6/3 or two times speed, thus generating in the conductors a 9th and a 3rd harmonic voltage. Similarly, (**27**) comprises two 5th harmonic space waves which generate a fundamental and 11th. Similarly the waves due to the *direct* component 5th, in eqs. (**21**), (**22**) and (**23**) produce corresponding harmonic voltages. It will be noted that the only fundamental voltages resulting from the 5th space harmonic of m. m. f. are those due to the backward rotating 5th and the forward rotating 7th space flux waves it produces. All other space fluxes which it produces give higher harmonic voltages.

It is shown in Appendix B that for the 5th and higher space harmonics of m. m. f., the permeance series for the cosine distribution is approximately—almost exactly—the same as that for the sine distribution. Thus, making the approximation that

$$p^{\mathrm{V}}{}_{ms} = p^{\mathrm{V}}{}_{mc}$$

then all of the waves due to the 5th m. m. f. which produce fundamental voltage are,

$$\beta_{5d5} = A_{5d}\, p^{\mathrm{V}}{}_0 \cos (5\,\alpha + 6\,t) \qquad \textbf{(29)}$$

$$\beta_{5q5} = A_{5q}\, p^{\mathrm{V}}{}_0 \sin (5\,\alpha + 6\,t) \qquad \textbf{(30)}$$

$$\beta_{5d7} = \frac{1}{2}\, A_{5d}\, p^{\mathrm{V}}{}_2 \cos (7\,\alpha + 6\,t) \qquad \textbf{(31)}$$

$$\beta_{5q7} = \frac{1}{2}\, A_{5q}\, p^{\mathrm{V}}{}_2 \sin (7\,\alpha + 6\,t) \qquad \textbf{(32)}$$

What will be the magnitude and phase of the voltages generated by these waves of flux? In general, voltage is, by definition, *minus* the rate of change of magnetic linkages.[13] Thus

$$e = -\,\frac{d\,\Omega}{d\,t} \qquad \textbf{(33)}$$

The plan is to change the reference of the rotating flux waves from the poles to the armature; then to resolve each wave into two stationary, pulsating components, involving cosine and sine space distributions. The former will produce linkages with phase 1; the latter will not. The linkages thus obtained may then be applied in (**33**).

For illustration, take (**29**). This 5th harmonic wave moves backward at $^6/_5$ speed with respect to the poles, hence at $^1/_5$ speed with respect to the armature thus giving an angular speed, on its own wave length, equal to normal. Let γ be the space angle measured along the armature surface, and reckoned from the axis of phase 1, Fig. 14. Since at $t = 0$ the armature reference (axis of phase 1) and the pole reference (axis of the pole) coincide, the space distribution with reference to the armature will, at that instant, be the space distribution with respect to the pole. Thus the rotating wave expressed with respect to the armature is,

$$\beta_{5d5} = A_{5d}\, p^{\mathrm{V}}{}_0 \cos (5\,\gamma + t) \qquad \textbf{(34)}$$

Resolve this by expansion into

$$\beta'_{5d5} = A_{5d}\, p^{\mathrm{V}}{}_0 \cos 5\,\gamma \cos t \qquad \textbf{(35)}$$

and

$$\beta''_{5d5} = -\,A_{5d}\, p^{\mathrm{V}}{}_0 \sin 5\,\gamma \sin t \qquad \textbf{(36)}$$

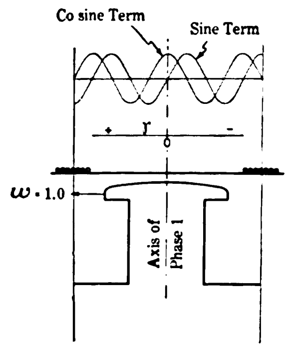


Fig. 14—Space Reference on the Armature, Showing the Position of the Pole and Flux Waves at $t = 0$

These are shown in Fig. 14. The flux expressed in (**35**) produces linkages with phase 1, but (**36**) does not. The linkages are

$$\Omega_{5d5} = C_5\, \phi_{5d5} = \frac{A_{5d}\, C_5\, p^{\mathrm{V}}{}_0}{5} \cos t \qquad \textbf{(38)}$$

where C_5 is the reduction factor[14] due to pitch, distribution and connection of the coils. The instantaneous voltage, expressed as a fraction of normal voltage, is by (**33**) and (**38**)

$$e_{5d5} = \frac{A_{5d}\, C_5\, p^{\mathrm{V}}{}_0}{5} \sin t \qquad \textbf{(39)}$$

But,

$$A_{5d} = \frac{C_5}{5}\, A_{1d}$$

Hence

$$e_{5d5} = \frac{A_{1d}\, C^2{}_5\, p^{\mathrm{V}}{}_0}{25} \sin t \qquad \textbf{(40)}$$

Similarly[15]

13. Linkages of a circuit are understood to be positive when they agree in sign with those produced by a positive current in the circuit.

14. C. A. Adams, bibliography (10).

15. Or these equations may be obtained from the general equations (**58a**) and (**59a**).

$$e_{5q5} = \frac{A_{1q}\, C^2{}_5\, p^V{}_0}{25} \cos t \tag{41}$$

$$e_{5d7} = -\frac{1}{2} A_{1d}\, p^V{}_2 \frac{C_5}{5} \frac{C_7}{7} \sin t \tag{42}$$

$$e_{5q7} = -\frac{1}{2} A_{1q}\, p^V{}_2 \frac{C_5}{5} \frac{C_7}{7} \cos t \tag{43}$$

Consider the phase of these voltages. From eqs. (**1**) and (**2**) i_d is a cosine function of time, and i_q a sine function. But e_{5d5}, produced by i_d, is a *plus* sine

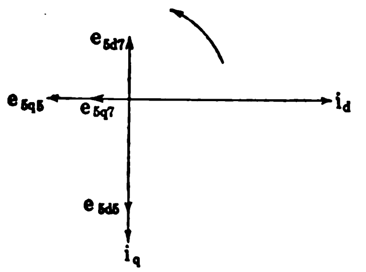


FIG. 15—VECTOR DIAGRAM OF VOLTAGES PRODUCED BY THE 5TH HARMONIC M. M. F.

function. Hence it *lags* a quarter period behind i_d. Similarly, e_{5q5} lags a quarter period behind i_q, which produces it; e_{5d7} leads i_d by a quarter period; and e_{5q7} lags behind i_q by a quarter period. These relations are shown in Fig. 15. It will be noted that e_{qd7} (fundamental) voltage produced by 7th space harmonics of flux (itself produced by the 5th space harmonic of m. m. f.) is a reactive voltage of the same phase relation to the current producing it, as the reactive voltage across a condenser, whereas e_{5d5}, e_{5q5} and e_{5q7} (produced by 5th space harmonics of flux) are of the same nature as the reactive voltage across an inductance. By taking the vector sum of the fundamental voltages due to *all* harmonics[16] (including the fundamental), produced by i_d, and, in addition, the reactive voltages due to the slot and end-winding leakages, the result will be the total reactive voltage produced by i_d, and will thus determine the synchronous reactance x_d for the *direct* component of current. Similarly, x_q is determined for the quadrature component.

The general equations for all harmonics due to the total sine wave (in time) current are given in Appendix A as eqs. (**58a**) and (**59a**).

From these equations the various fundamental voltages[17] have been computed, and are tabulated in Table I, and are shown in Fig. 16 as vectors in relation to the other voltages due to armature current. From these results, the expressions for the reactances are derived in Appendix C.

16. The voltages in Fig. 15 are produced by the 5th space harmonic of m. m. f. alone. There is a similar set of voltages for the 7th, 11th, 13th, 17th, 19th, etc., harmonics of m. m. f.

17. While only the fundamental voltages are derived in detail, equations (**58a**) and (**59a**) contain the harmonics.

It will be helpful to sum up the points thus far established. The general plan, it will be remembered, is to determine, first, all of the component voltages produced by armature currents, such voltages comprising (a) all of those generated by flux emanating from the armature surface, *i. e.*, the air-gap flux, (b) that due to flux crossing the slots, (*i. e.*, slot leakage) and (c) that due to end winding leakage; and, second, all voltages due to current in the field winding; then, by superposition of all significant components, to determine the resultant, which is the terminal voltage. In the foregoing, the voltages due to the air-gap fluxes which are produced by armature current have been determined.

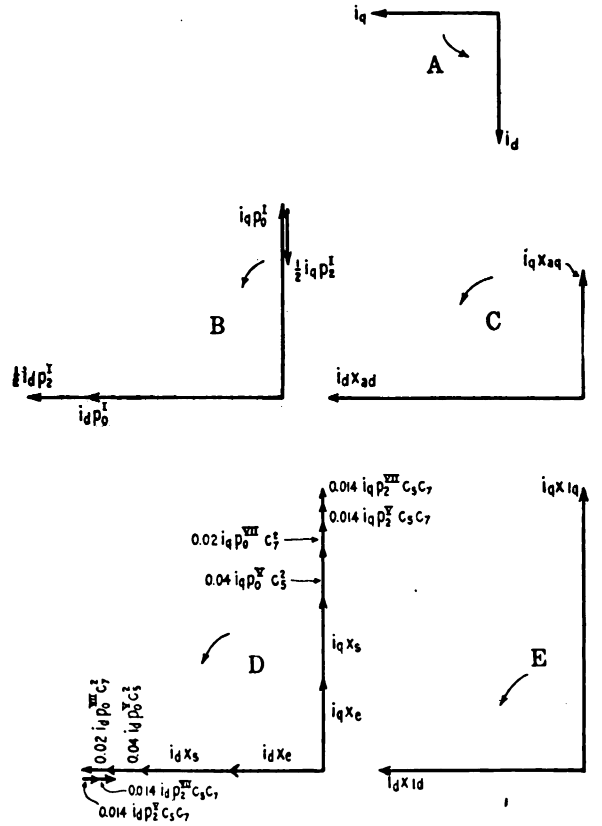


FIG. 16—FUNDAMENTAL VOLTAGES DUE TO ARMATURE CURRENTS

A—Components of armature current
B—Component armature reaction voltages
C—Resultant armature reaction voltages
D—Component leakage reactance voltages
E—Resultant leakage reactance voltages (D and E magnified in scale, compared with B and C)

The voltages due to slot and end winding leakage have been previously determined.[18] Hence all voltages due to armature current are accounted for. In Appendix C the important ones of these are assembled in expressions for reactance.

Field Current Phenomena. The other source of flux is the field current. This current is due to the exciter voltage, assumed to be constant, and to such harmonic

18. Bibliography 8.

voltages as are short-circuited by the field winding. The rotating space harmonic m. m. fs. produced by the armature current are of odd order, and rotate at odd fractions or multiples of synchronous speed with respect to the armature. Hence their electrical angular speed (on the harmonic base) with respect to the field pole and field winding must be of even order; because one times speed is always added to or subtracted from the odd term. For instance, the 5th rotates backward at 1/5th speed with respect to the armature, thus 6/5th with respect to the pole. Hence it generates a 6th harmonic. The 7th rotates forward at 1/7th speed with respect to the armature, hence 6/7th with respect to the poles. Hence it also generates a 6th harmonic in the field winding.

Therefore, the general form of the field current will be a Fourier Series of even harmonic terms, thus

$$I = I_0 \cos 2t + I_4 \cos 4t + \ldots . + I'_2 \sin 2t + I'_4 t + \ldots . \quad (44)$$

But inasmuch as, in a three-phase machine, the 5th is the lowest order[19] of rotating harmonic m. m. f. (excepting the fundamental), the 6th harmonic must be the lowest order harmonic in the field current. Moreover, since the 7th m. m. f. harmonic also produces only a 6th in the field current, and since the next existing space harmonics are the 11th and 13th, both of which generate a 12th harmonic in the field winding, and next the 17th and 19th, which generate an 18th, it follows that the only harmonics in the field winding are multiples of the 6th.

But these are all of practically negligible magnitudes. While the 6th harmonic ripple may, in rare cases, be detected in the field current under the condition of balanced three-phase currents, and although it does very slightly affect the fundamental voltage, its influence is practically insignificant. Hence only the effects of the average term I_0, which is sustained by the constant exciter voltage, are considered.

The voltage due to the flux produced by I_0 has been adequately treated before.[20] The flux wave thus produced is of the general shape indicated in Fig. 17, and hence contains a fundamental and odd harmonics. The component harmonic waves are, of course, stationary with respect to the poles and therefore generate replica voltage waves in the individual armature conductors. The flux wave is determined, as in Figs. 5, 6, 7 and 8, by graphic field plot from a scale drawing of the armature and field pole.

If there should be a field m. m. f. in the *quadrature* axis, there would be another flux wave produced, symmetrical about that axis, hence containing only odd terms—fundamental and odd harmonics.

Significance of Various Voltages. Consider now some aspects of the various fluxes and voltages. Which of them are important? Which of the fluxes determine the leakage reactance; which, the armature reaction?

Take the harmonic voltages first. These are due, as already explained, to (a) a set of rotating flux waves produced by a sine wave (in time) current; (b) an additional set of rotating waves for each time harmonic in the armature current. In the various sets, the speed of rotation of the respective *space* harmonics (*i. e.*, of the same pole span) is proportional to the order of the time harmonic producing it, and the amplitude is proportional to the amplitude of the time harmonic current; (c) the space harmonics of the field flux; and (d) the effects of permeance waves due to slots.[21]

How important are these harmonic voltages? Some are of no importance because they are of negligible magnitude. This may be due either to small amplitude of the flux harmonic, or to reduction by the connection and space phase of armature conductors. It is well known, for instance, that either a Y connection or $2/3$ coil pitch eliminates the third harmonic; $4/5$ pitch, the 5th; $6/7$ pitch, the 7th, etc.; and the distribution of coils greatly reduces any which may remain.[22] So in many cases the harmonics may be neglected because they are not appreciable.

Therefore, since the harmonics do not significantly influence the regulation and power relations, principally to be considered here, they will be neglected. If their evaluation, for other purposes, is ever required, the foregoing treatment, particularly eqs. (**58a**) and (**59a**), constitutes a basis for their determination.

Consider the fundamental voltages. They are due to

(a) fundamental space component of flux due to the *direct* component of armature m. m. f., *i. e.*, *direct* armature reaction.

(b) fundamental space component of flux due to the *quadrature* component of armature reaction.

(c) 5th space harmonic flux,[23] rotating backward at $1/5$ speed, and due to the *direct* component of armature current.

(d) 5th space harmonic,[23] rotating backward, and due to the *quadrature* component of current.

(e) two corresponding components, (*i. e.*, *direct* and *quadrature*) of the 7th space harmonics, rotating forward at $1/7$ speed.

19. There is an exception to this in the case of a delta-connected machine in which the circulating currents (third harmonic and its multiples) produce space third harmonics of m. m. f. and odd multiples thereof. However, these m. m. fs. rotate at such a speed as to induce in the field winding 6th, 12th, 18th, etc., time harmonics of current.

20. Bibliography 7, and Appendix of 8.

21. This is neglected in the present treatment. It is a different factor from the ripples due to current concentration, the latter being taken into account. The former have been treated by Lyon. See bibliography 7.

22. In most modern alternators the harmonics are practically all thus screened out, leaving the terminal generated voltage almost a true sine wave. Bibliography 10.

23. Each of these, *i. e.*, (c), (d) and (e), comprises two flux components: one due to the 5th space harmonic of m. m. f.; the other, to the 7th. See Table I.

(f) two components of the 11th rotating backward at $^1/_{11}$ speed;[24] and so on.

(g) slot leakage flux produced by both components (*direct and quadrature*).

(h) end-winding leakage flux produced by both components.

(i) fundamental space components of flux due to field m. m. f. in the *direct* axis.

(j) fundamental space component of flux due to field m. m. f. in the *quadrature* axis.

Consider these in detail. The terms (a) and (b)

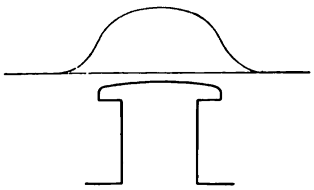


FIG. 17

are the usual vectors of voltage produced by the flux of armature reaction; these are $i_q\, x_{aq}$ and $i_d\, x_{ad}$ in diagram, Fig. 18. (i) corresponds to the *nominal* voltage e_d. (j) is an added similar term e_q, Fig. 19,

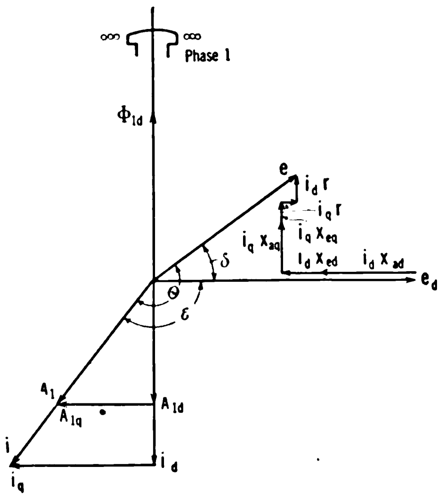


FIG. 18—VECTOR DIAGRAM FROM EQUATIONS. NEGLECTS SATURATION

for the quadrature axis. (g) is the usual slot leakage $i_q\, x_s$, and $i_d\, x_s$, Fig. 16D, which is independent of currents in any other slot, and is therefore the same for single or polyphase currents for full pitch coils. They are, however, different for fractional pitch. It may therefore be treated as external reactance,[25] provided the slot contains current of one phase only. Slot reactance is obviously the same for the *direct* and *quadrature* components of current. (h) corresponds to the usual end winding leakage reactance $i_q\, x_e$ and $i_d\, x_e$, Fig. 16D. There is some mutual reactance between phases, and hence it is not the same for single-phase and polyphase currents, and hence can not be considered as external reactance. It is here assumed to be the same for the *direct* as for the *quadrature* component of current.

In Appendix C, expressions for the various reactances are derived.

VECTOR DIAGRAMS

From the foregoing, and the results in Appendix C, the vector diagram, neglecting saturation, can be constructed. The diagram, of course, will contain the same quantities as the well-known Blondel diagram, with the rather trifling exception discussed above, regarding the leakage reactance voltages.[26]

From Table I, the voltages due to armature reaction, *i. e.*, to the space fundamentals of flux, are

$$-j\, A_{1d}\left(p_0{}^{\mathrm{I}} + \frac{1}{2}\, p_2{}^{\mathrm{I}}\right) = -j\, \dot{i}_d\, x_{ad}$$

and

$$-j\, A_{1q}\left(p_0{}^{\mathrm{I}} - \frac{1}{2}\, p_2{}^{\mathrm{I}}\right) = -j\, \dot{i}_q\, x_{aq}$$

The voltages due to leakage reactance, derived in Appendix C, are

$$-j\, \dot{i}_d\, x_{ld}$$

and

$$-j\, \dot{i}_q\, x_{lq}$$

Taking the fundamental flux ϕ_{1d}, *direct* axis, as the time reference vector, the vector diagram in Fig. 18 is constructed. By the convention adopted in the equations, $\dot{i}_q$ was taken as lagging with respect to $\dot{i}_d$. This corresponds to a *motor* load; hence in Fig. 18, according to the definition, the power-factor angle θ is greater than 90 deg., *i.e.*, $>$ .25. Redrawing Fig. 18 in Fig. 20, the conventional relations are shown, in which i_q is reversed, thus a generator load. Also the reactances are combined, since saturation is in this particular case neglected.

$$x_d = x_{ad} + x_{ld}$$
$$x_q = x_{aq} + x_{lq}$$

The vectors in Fig. 20 are the *induced*, not the consumed, voltages.

Introducing an excitation current in a field winding around the quadrature axis, brings in an additional voltage e_q as shown in Fig. 19. The general power-angle relations are derived in Part II from this diagram. An approximate method, due to Blondel, for taking

24. When irregular armature windings are used, for instance, fractional slots per pole and then additional harmonics occur. These are important since they may create serious vibration in the stator frame; and, in the case of induction motors, may significantly increase the leakage reactance. Their computation is beyond the scope of this paper.

25. The effect of currents of different phases in the same slot, as in fractional coil pitch, is accounted for by appropriate factors in the calculation of slot leakage.

26. In the present treatment these comprise all fundamental voltages except those produced by the two space fundamental flux waves.

saturation into account will be referred to in Part II and also in Appendix D, in which Fig. 20 will be interpreted in terms of the familiar Potier diagram for cylindrical rotor machines.

An idea of relative phase and magnitude of voltages may be obtained from an inspection of Table I. Referring to Fig. 16D, in which the phase relation of the various vector voltages of Table I is shown,[27] it will be noted that the only ones which do not have the same phase relation with respect to the current which causes them, are those which involve products $C_5\,C_7$, $C_{11}\,C_{13}$, etc.—that is, those terms in which a flux of one space order is produced by m. m. f. of another space order.

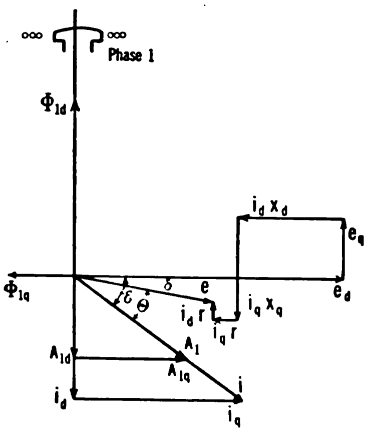


FIG. 19

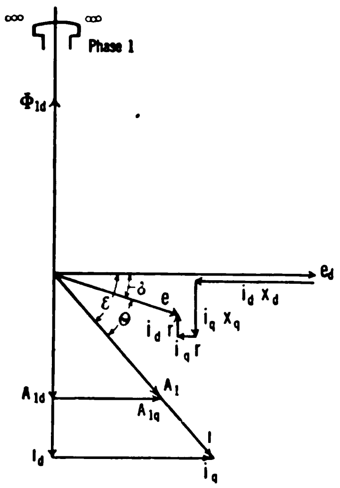


FIG. 20—VECTOR DIAGRAM—USUAL CONVENTIONS

The diagrams show nothing above the 7th, since the next term involves the 11th and 13th, and is entirely negligible. They are, in other words, only those terms which involve second harmonic permeance coefficients for m. m. f. space orders > 1.0, such as p_2^{V}, p_2^{VII}, etc. They are given in eq. (7c) Appendix C. It will be observed in Fig. 16D that the only such terms are

$$0.014\, i_d\, p_2^{V}\, C_5\, C_7$$
$$0.014\, i_d\, p_2^{VII}\, C_5\, C_7$$

27. In the diagram, currents are substituted for corresponding armature reactions.

TABLE I

FUNDAMENTAL VOLTAGES

A. Due to Direct Component of Armature Current.

n	m	k_n	Order of Flux Wave	Amplitude and Phase of Fundamental Voltages
1	0	1	1	$-j\,A_{1d}\;p_0^{I}$
1	2	1	1	$-j\,\dfrac{A_{1d}\,p_2^{I}}{2}$
5	0	−1	5	$-j\,\dfrac{A_{1d}\,C_5^2\,p_0^{V}}{25}$
5	2	−1	7	$+j\,\dfrac{A_{1d}\,C_5\,C_7\,p_2^{V}}{70}$
7	0	1	7	$-j\,\dfrac{A_{1d}\,C_7^2\,p_0^{VII}}{49}$
7	2	1	5	$+j\,\dfrac{A_{1d}\,C_7\,C_5\,p_2^{VII}}{70}$
11	0	−1	11	$-j\,\dfrac{A_{1d}\,C_{11}^2\,p_0^{XI}}{121}$
11	2	−1	13	$+j\,\dfrac{A_{1d}\,C_{11}\,C_{13}\,p_2^{XI}}{286}$
13	0	1	13	$-j\,\dfrac{A_{1d}\,C_{13}^2\,p_0^{XIII}}{169}$
13	2	1	11	$+j\,\dfrac{A_{1d}\,C_{13}\,C_{11}\,p_2^{XIII}}{286}$

B. Due to Quadrature Component of Armature Current

n	m	k_n	Order of Flux Wave	Amplitude and Phase of Fundamental Voltages
1	0	1	1	$-j\,A_{1q}\,p_0^{I}$
1	2	1	1	$+j\,\dfrac{A_{1q}\,p_2^{I}}{2}$
5	0	−1	5	$-j\,\dfrac{A_{1q}\,C_5^2\,p_0^{V}}{25}$
5	2	−1	7	$-j\,\dfrac{A_{1q}\,C_5\,C_7\,p_2^{V}}{70}$
7	0	1	7	$-j\,\dfrac{A_{1q}\,C_7^2\,p_0^{VII}}{49}$
7	2	1	5	$-j\,\dfrac{A_{1q}\,C_5\,C_7\,p_2^{VII}}{70}$
11	0	−1	11	$-j\,\dfrac{A_{1q}\,C_{11}^2\,p_0^{XI}}{121}$
11	2	−1	13	$-j\,\dfrac{A_{1q}\,C_{11}\,C_{13}\,p_2^{XI}}{286}$
13	0	1	13	$-j\,\dfrac{A_{1q}\,C_{13}^2\,p_0^{XIII}}{169}$
13	2	1	11	$-j\,\dfrac{A_{1q}\,C_{13}\,C_{11}\,p_2^{XIII}}{286}$

In the above terms, $A_{1d} = i_d$ and $A_{1q} = i_q$. See "notation."

These are *reversed* with respect to the other voltages produced by i_d. The corresponding terms produced by i_q are,

$$0.014\, i_q\, p^{V}{}_2\, C_5\, C_7$$
$$0.014\, i_q\, p_2{}^{II}\, C_5\, C_7$$

which *add on* to corresponding voltages produced by i_q.

What about the magnitude? The product $C_5 C_7$ may be of any value between zero and a maximum value = 1.0 for a three-phase machine. It is zero if the coil pitch is either $^4/_5$ or $^6/_7$, and greatly reduced for other pitches.[28] It is greatly reduced also by coil distribution.[29] The permeance coefficients $p_2{}^V$ and

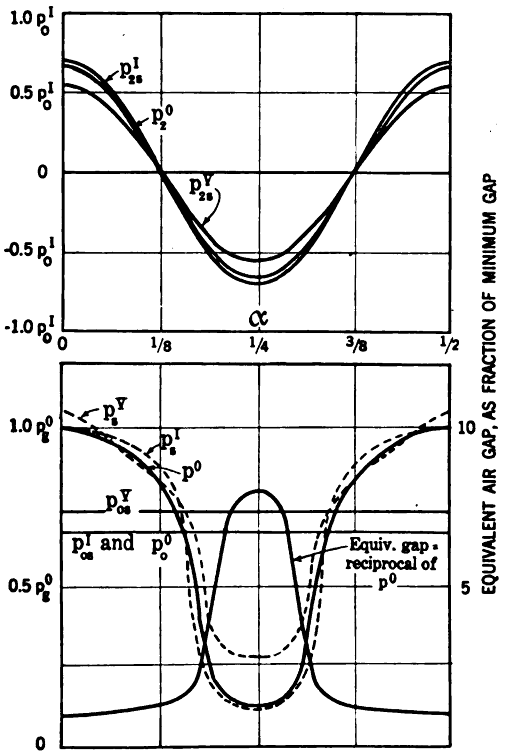


FIG. 21—PERMEANCE DISTRIBUTION DETERMINED FROM FIELD PLOTS. ALSO EQUIVALENT AIR-GAP

$p_2{}^{VII}$ are of the order of 50 per cent of $p_0{}^I$. Thus the maximum possible value of each term is of the order of ½ of one per cent of the armature reaction voltage due to i_q or to i_d. This would give a maximum variation in leakage reactance voltage with pole position, of the order of ± 1 per cent of the armature reaction voltage; and in many cases, on account of fractional pitch, etc., it would be practically zero. Therefore the conclusion is that in many salient pole machines the variation in leakage reactance with pole position is entirely negligible, and is of small magnitude in any case approaching the usual design practise.

PRACTICAL APPLICATION OF RESULTS

The application of the method given here requires numerical data for the zero and second space harmonic of permeance for each significant harmonic m. m. f. The harmonic m. m. fs. are easily computed, and are all expressed in Table I in terms of the fundamental m. m. f. component. But the permeance coefficients must be determined from field plots[30] such as shown in Figs. 5, 6, 7, 8 and 9. From such plots, the permeance curves are determined and analyzed to obtain the required value of the average and the second harmonic coefficients. Partial analysis of these particular plots is shown in Fig. 21.

In order to avoid having to plot, as above, the flux distribution for each significant harmonic, including the fundamental, an approximation is made as follows: A plot is made for the zero harmonic, as in Fig. 5, which results are shown also on Fig. 21. In addition the latter shows a curve of "equivalent air-gap," taken as the reciprocal of the permeance for the zero harmonic. From this and the curve in Fig. 10, derived in Appendix B, the permeance curves for any harmonic can be obtained, as in Fig. 11. These are then analyzed for the zero and second harmonic. The results thus obtained for the particular case here illustrated are compared in Table II with those obtained directly from the plots and are also compared in complete curves in Fig. 12. It will be noted that the agreement is very satisfactory. The only discrepancy worth noting is between $p_{2c}{}^I$ and $p_{2s}{}^I$, which are, from plots, respectively 0.43 and 0.47. The value derived from Figs. 10 and 21 is 0.44.

TABLE II

COMPARISON OF PERMEANCES OBTAINED DIRECTLY FROM FIELD PLOTS, AND DERIVED FROM FIGS. 10 AND 21.

	Values from plots	Values Derived from Figs. 10 and 21
$p_{0c}{}^I$	$0.67\ p^0{}_g$	$0.66\ p^0{}_g$
$p_{0s}{}^I$	$0.67\ p^0{}_g$	
$p_{2c}{}^I$	$0.43\ p^0{}_g$	$0.44\ p^0{}_g$
$p_{2s}{}^I$	$0.47\ p^0{}_g$	
$p_{0c}{}^V$	$0.74\ p^0{}_g$	$0.73\ p^0{}_g$
$p_{0s}{}^V$	$0.73\ p^0{}_g$	
$p_{2c}{}^V$	$0.38\ p^0{}_g$	$0.37\ p^0{}_g$
$p_{2s}{}^V$	$0.37\ p^0{}_g$	

$$\frac{\text{min. gap}}{\text{pole pitch}} = 0.02 \qquad \frac{\text{pole arc}}{\text{pole pitch}} = \frac{2}{3}$$

$$\frac{\text{max.}}{\text{min.}}\ \text{gap} = 1.5 \qquad p_g{}^0 = 1.5\ p_0{}^I$$

28. Of course it would be zero also for a pitch of either $^2/_5$ or $^4/_7$, etc.

29. C. A. Adams, Bibliography 10.

30. Comprehensive treatments of flux plotting are being prepared by engineers of the General Electric Company, for presentation at an early date.

The above simplifying assumptions are fully discussed in Appendix B.

The general plan, therefore, is to obtain a permeance curve for the zero harmonic for the machine under consideration, and from that, the "equivalent air gap" curve. Then with the aid of Fig. 10, plot a group of curves as in Fig. 11. An analysis of these will give the required $p_0{}^n$ and $p_2{}^n$.

Research Relations Between Engineering Colleges and Industry

BY W. E. WICKENDEN[1]

Member, A. I. E. E.

IN our present easy-going attitude toward language, we are tempted to use the word "research" to mean so many things that we have no word left to mean research. The effort to sell a research program to industry has induced us to translate the word into such unmistakably practical terms as "in a word it is invention," to quote a recent official pamphlet.

In the present discussion it is probably safe to assume that we are dealing only incidentally with disinterested pioneer work in the realm of pure knowledge, which is the scientist's calling. Engineering is always utilitarian and concrete, and most engineers abandoned the alternative of becoming physicists, chemists or mathematicians in order to become engineers. This observation holds for professors as well as practitioners. Every professor of engineering worthy of the title, however, is qualified to investigate engineering problems involving elements of novelty which call for extended observation, refined technique, and a resort to fundamental principles. The indications are that both the men and facilities available for these purposes in the engineering colleges are now being utilized very inadequately, to the detriment of both industry and education.

A fairly complete survey of the engineering colleges in the United States shows that not less than 58 have organized arrangements for research, at least on paper. Included in this number are 41 institutions which have organized plans through which the services of the engineering staff are made available in consulting capacities to industries, public service utilities and others. If we include those institutions in which research is fostered on a purely individual basis, the total rises to 110.

The total expenditures of the organized research departments are not less than $1,250,000 per annum and may reach as high as $1,500,000. Of such expenditures in the academic year 1924-'25, approximately 11 per cent represented direct appropriations for research by the several states, 40 per cent funds allotted by the colleges from their general funds, and 49 per cent funds derived from outside sources, principally from public, professional and industrial organizations.

At least 34 institutions have full-time research staffs, with between 250 and 300 men so engaged. To this number may be added about 350 more who render part-time research service for definite compensation and about 200 who give part-time service in organized departments without special compensation. The number engaged on a purely individual basis is difficult to estimate.

Impressive as these totals are, it must be remembered that there are two corporations in the electrical industry which spend on research more than double the total outlay of the engineering colleges and that at least two in other fields exceed the total of the colleges. Organizations at this end of the industrial scale are unlikely to turn to the engineering colleges to get their problems solved. Big business can probably be induced to give support to organized investigation in engineering colleges only on the plea that such activity is necessary in order to maintain the proper setting and staff for the training of the grade of engineers big business requires. Pure research rather than engineering investigation seems likely to get the bulk of the financial assistance from this source, and it seems probable that it will be disbursed through some intermediary or clearing house, instead of passing directly to individual colleges or professors. The present campaign of the National Academy of Sciences for a national research endowment, under the leadership of Mr. Herbert Hoover, is working successfully on this principle.

At the other end of the scale are innumerable, small units of industry which live from balance sheet to balance sheet, with no consciousness of research needs and little margin for the support of research activities. Such organizations occasionally meet acute problems outside the scope of their normal routine and staff. When these emergencies call for investigation, a college professor or laboratory staff may fit the need admirably, but is this not first aid rather than research?

Many of these smaller units of industry are concerned with the traditional arts rather than with the applications of modern science. They are likely to remain deaf to any appeal to support research for the sake of repay-

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ing their debt to science or for the sake of maintaining a wide margin between pure knowledge and practical invention. It is just these industries, however, which are most apt to be handicapped by the decline of sporadic invention and likely to profit most relatively, from an adequate program of research. Support for such investigation is not to be expected from the single units of such industries, but their state and national trade associations are the natural agencies to foster such activities. There are attractive possibilities of dividends in the form of better methods, economies and more exact control in the present state of the art. Research, looking in advance of the present art, is a form of mutual insurance covering the risks of supersession or revolutionary changes in the art.

A recent report of the Babson Statistical Organization announced that an English factory was testing out the production of a flexible, colorless, resilient, non-inflammable glass of organic origin. It went on to say:

> "The point of this letter, however, is not only about glass. This is but one of numerous far-reaching discoveries which have recently been reported. We believe that business is entering an era of the most rapid and revolutionary changes in the chemistry and physics of manufacturing. To those who are quickest in taking advantage of such discoveries, they present unlimited opportunities, but the manufacturer, merchant or investor who is asleep to these changes will be hurt.
>
> "The time has passed when advertising alone will get sales. The two best salesmen today are 'a better product' and 'a cheaper way of making it.' Research opens the way to both. Furthermore, since the most deadly competition is not between concerns, but between industries, we urge clients to combine their energies with others in the same line of business. This saves duplication of efforts, leads to maximum results and keeps one best informed about all impending developments. Make use of the help which the United States Bureau of Standards at Washington stands ready to give you, and also that of other technical organizations of high standing. Cease worrying about gaining the temporary advantage of exclusive patents, and combine your resources in the way that will do most to permanently help your industry."

It is significant that the occasion which brought the above report to the writer's desk was a request from its authors for a complete list of the engineering colleges with facilities for organized research in cooperation with industry. The writer is strongly of the opinion that trade and industrial associations offer by far the most promising agencies through which to promote industrial cooperation with the colleges in engineering research. The support of such activities by individual corporations is apt to be sporadic while trade associations can effectively maintain a continuing relation. The results of work supported by individual corporations are apt not to be widely disseminated or used. A good deal of such support is frankly on a courtesy basis, without a vital interest in its effectiveness or utilization, and with little genuine collaboration between the college and the industry.

A trade association, administering its funds in trust for its constituency and genuinely concerned to show a good return for the investment, provides an excellent medium for the joint shaping of research projects and a widely ramified channel through which to disseminate results. It would seem that the most fruitful result may be expected when a trade association concentrates its cooperative program at a single college, or at a small group of institutions at most. Such work ought not to be located on a courtesy basis or split up on a political basis, but should seek to capitalize distinctive advantages of men, plant and environment. There is a definite loss when such resources are spread over many institutions as a fairly ineffectual mist, when they might be concentrated into a fairly powerful stream. In this respect the European situation is far better ordered than our own. The policy of concentrating resources abroad has led to the upbuilding of a group of notable and distinctive research centers which are the principal factor in attracting and holding to educational and research work the outstanding authorities in the several fields. The result has been to give the several institutions an individuality quite unknown among us.

The writer does not feel that the colleges can rest their case for industrial backing for their research programs on the needs of the colleges or on an assumed sense of obligation on the part of industry to see that the colleges obtain the men, money and facilities needed to do their best work. The industries recognize these obligations rather vaguely, and when confronted by the competing pleas of 100 to 150 institutions are justified in feeling rather helpless. The Babson report, however, speaks in the tongue which industry understands and to which it responds.

The work being done at Cincinnati in cooperation with the Tanners' and the Lithographers' national organizations, the power brake studies at Purdue in cooperation with the American Railway Association, the studies in warm air heating and ventilating at Illinois, and the great project of the Portland Cement Association in association with Lewis Institute are worthy examples of adequately supported, nationally backed and effectively concentrated research programs, involving real collaboration between colleges and industries and leading to results of great significance and value.

A 7,500,000-c. p., 900-watt searchlight is being installed on the Broadmoor Hotel's Summit House on Cheyenne Mountain, overlooking Colorado Springs and Manitou, Colorado. The highest beacon in the world is said to be the 5,000,000-c. p. aviation light on Sherman Hill, Wyoming, 8600 ft. above sea level.

A Flux Voltmeter for Magnetic-Tests

BY G. CAMILLI[1]

Associate, A. I. E. E.

Synopsis.—*A voltmeter is described for a-c. circuits the voltage indications of which are directly proportional to the maximum flux density, regardless of the wave shape of the voltage. While the instrument is suitable for many varieties of magnetic tests, its most important application is to the reduction of transformer core-loss measurements to sine-wave basis. Test data indicate excellent accuracy for the meter in this application in comparison with other schemes or outfits used at the present time for that purpose. Losses determined by this new meter are, in general, appreciably larger than those determined by the older methods.*

The new meter makes it unnecessary to use, for reliable results, large generators to reduce the wave distortion caused by transformer excitation loads, and permits the use of any generator that will carry the load thermally.

Introduction

This paper describes a voltmeter for a-c. measurements designed so that its indications are directly proportional to the maximum value of a-c. magnetic flux regardless of wave shape. It is graduated in terms of equivalent effective sine-wave voltage, so that at any wave shape the maximum magnetic flux is the same as the maximum value of sine-wave flux generating a sine-wave voltage of the same effective value as the indication of this voltmeter. The instrument is particularly useful in core-loss measurement and for exploring alternating-flux magnetic networks. It is useful also for the determination of the form factor of a-c. voltages, and, with slight modifications, the form factor of alternating currents.

It is recognized that certain circuit characteristics are functions of the maximum value of the alternating wave. For instance, hysteresis loss and also magnetizing current to a large extent are functions of the maximum flux density, not functions of r. m. s. values of current, voltage or flux. The problem of measuring this maximum flux has not been satisfactorily solved by other methods though ballistic galvanometers and core-loss voltmeters or correction outfits have been developed and used for the purpose. The ballistic galvanometer is not well suited to a-c. measurements, and core-loss voltmeters have serious limitations as will be pointed out later.

The instrument developed by the writer for this purpose, called a flux voltmeter, consists essentially of a rectifier in series with a d-c. voltmeter. Across these two in series is impressed the voltage which is generated in a coil surrounding the core under test in which the alternating flux exists. Under this condition, the voltmeter indications, as will be proved later, are proportional to the maximum magnetic flux in the core.

Theory of the Instrument

The principles underlying the functioning of the flux voltmeter are two:

First, in an a-c. circuit, the maximum alternating flux density is proportional to the arithmetic average value of the reactive voltage drop regardless of the wave shape of the voltage, provided the wave does not cross the zero line more than twice per cycle.

Second, if an alternating voltage is rectified without changing the wave shape, and is impressed on a d-c. voltmeter, the meter indication is proportional to the arithmetic average value of the rectified wave which is the same as the arithmetic average value of the unrectified a-c. wave.

The proof of the first theorem is as follows:

Let e be the instantaneous voltage consumed in the inductance of a circuit, and ϕ the flux associated with that circuit. By elementary theory,

$$e = K \frac{d\,\phi}{d\,t} \tag{1}$$

where K is constant of the circuit. It follows from (1) that

$$e\,d\,t = K\,d\,\phi$$
$$\int e\,d\,t = K \int d\,\phi$$

The integral of $d\,\phi$ is obviously the change in the flux; and its maximum value, that is, the maximum change in flux, is obtained by finding the maximum change in the integral of $e\,d\,t$. Referring to Fig. 6, the integral of $e\,d\,t$ is the area of the voltage wave (alternately positive and negative, plus a constant of integration), and the maximum change in $\int e\,d\,t$ is the area of half a cycle of the voltage wave. Thus,

$$\int_{t_1}^{t_2} e\,d\,t = K \int_{\phi\ \text{lower limit}}^{\phi\ \text{upper limit}} d\,\phi$$

$= K$ times the maximum change in flux.

The area of one-half cycle of the voltage wave may be also determined, however, if we know the average voltage, by the equation,

$$\int_{t_1}^{t_2} e\,d\,t = \text{area of half-cycle}$$
$$= e_{avg}\,(t_2 - t_1)$$

The maximum change in flux is therefore proportional to e_{avg} since $(t_2 - t_1)$ is a constant, being the duration of half a cycle dependent only on the frequency of the circuit. Since, also, the flux density is proportional to the total flux, the maximum a-c. flux

1. Transformer Engineering Department, Pittsfield Works, General Electric Company.

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density, B_{max}, must be proportional to the maximum total a-c. flux, ϕ_{max}, and thus we have,

$$B_{max} \text{ is proportional to } e_{avg}.$$

The factor of proportionality is taken care of as follows: the meter scale being graduated in terms of effective sine-wave voltage, it follows that the alternating flux density in the circuit under test corresponds to an effective sine-wave voltage of the same equivalent value as the indication of the flux voltmeter. In other words, for any given wave shape of voltage, the flux voltmeter indicates its equivalent sine-wave value, which would cause the same maximum flux or

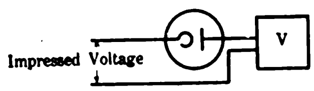

FIG. 1

flux density. On pure sine-wave voltage, the indications of the flux voltmeter are naturally identically the same as those of an ordinary r. m. s., a-c. voltmeter. In fact, the meter is calibrated in this way.

The reason for the limit to wave distortion mentioned above, namely, that the wave must not cross the zero

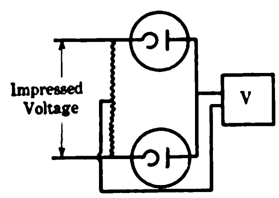

FIG. 2

more than twice per cycle, may be understood as follows.

Considering the positive half cycle of the voltage wave, assume that this dips through the zero and has a negative portion. The positive portions of the half-cycle will add to the flux in accordance with the integral of $e\,d\,t$, and the negative portion will subtract by the

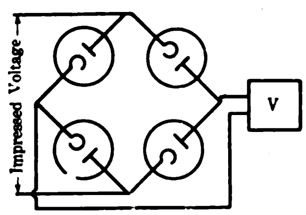

FIG. 3

same integral. Since the flux voltmeter rectifies the entire wave, this small negative portion will also be rectified and instead of reducing the voltmeter reading will increase it. The reading of the voltmeter, therefore, even though it still represents the arithmetic average of the voltage wave, will not truly represent the maximum of the flux wave. This limitation, however, is hardly a handicap because it is almost inconceivable that a commercial voltage wave could be so distorted as to cross the zero more than twice per cycle.

Description of the Instrument. The practical construction of an instrument to meet these requirements is quite simple. Vacuum tubes are used for rectification, and a high-resistance, d-c. voltmeter to read the arithmetic average value of the rectified wave.

A diagrammatic sketch of the simplest possible con-

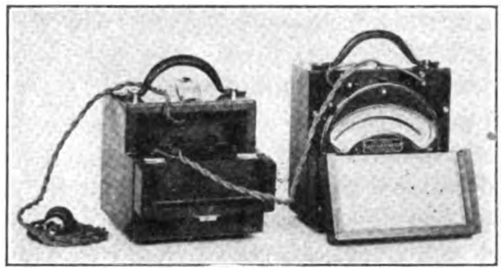

FIG. 4

struction is shown in Fig. 1 which shows a single rectifier tube in series with a d-c. voltmeter. The voltage to be measured is impressed across the voltmeter and rectifier in series; and the meter indication is then proportional to the integral of the impressed voltage.

Although the scheme of Fig. 1 is extremely simple, it suffers from two disadvantages: first, due to half-wave rectification the frequency of the pulsations of the rectified wave is one-half of that of the completely rectified wave, and it was observed that with 25-cycle impressed voltage, the needles of some voltmeters would vibrate like a frequency-meter reed. The second disadvantage is that with half-wave rectification the deflection of the meter is reduced to one-half. To increase the deflection would require a reduction in the resistance of the meter to one-half, double the current, all double the losses,—all of which would be undesirable.

The scheme shown in Fig. 2 using two tubes and an auto-transformer for rectifier yields full-wave rectification and better characteristics in general, except that the exciting current drawn by the shunt auto-

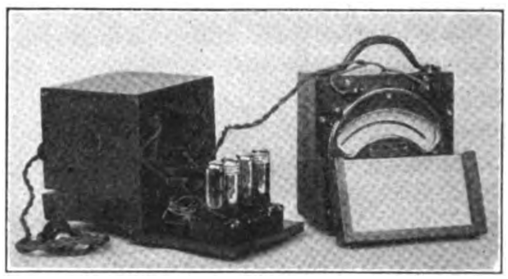

FIG. 5

transformer might be objectionable, especially when instrument transformers are used.

The connection found most satisfactory is shown diagrammatically in Fig. 3, consisting of a four-tube, full-wave rectifier in combination with a d-c. voltmeter.

The instrument used for the investigations described below was constructed in accordance with the scheme of Fig. 3. Fig. 4 is a reproduction of a photograph of the outfit, showing the rectifier and voltmeter in separate cases, although some units now under construction incorporate the rectifier and voltmeter in one case. Fig. 5 shows the contents of the rectifier unit,—four vacuum tubes and one filament-current transformer. The purpose of the filament-current transformer is to obtain the necessary filament current from the lighting circuit instead of from the circuit under test. To draw this current from the circuit under test would be doubly objectionable: it would load the potential transformers in the circuit unnecessarily and reduce their accuracy, and it would change the calibration of the instrument with varying load voltage. Supplying the filament excitation from a lighting circuit eliminates both these difficulties, especially the latter, inasmuch as variations of the voltage of the lighting circuit, within the range of 110 to 125 volts, have no sensible effect on the calibration of the instrument.

The voltmeter is graduated in terms of equivalent effective r. m. s. sine-wave voltage, so that the maximum flux density in the core under test is the same as the maximum flux density for an r. m. s. sine-wave voltage of the same value as that indicated by the flux-voltmeter.

The constants of the tubes, meter and transformer are as follows:

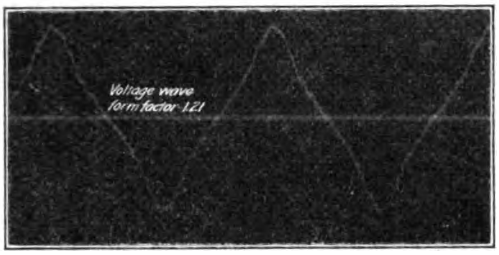

Fig. 6

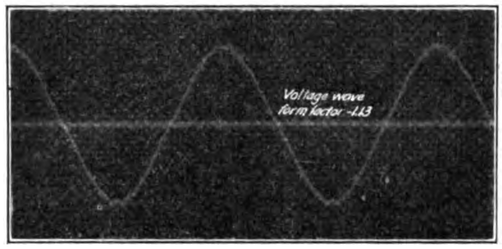

Fig. 7

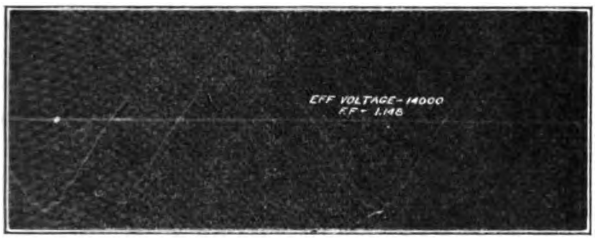

Fig. 8

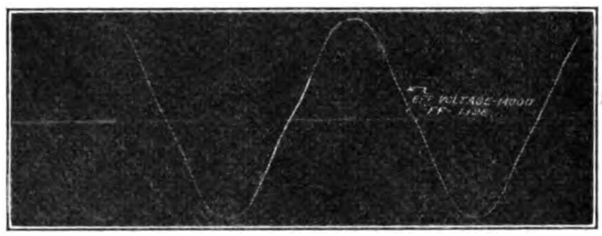

Fig. 9

Fig. 10

Fig. 11

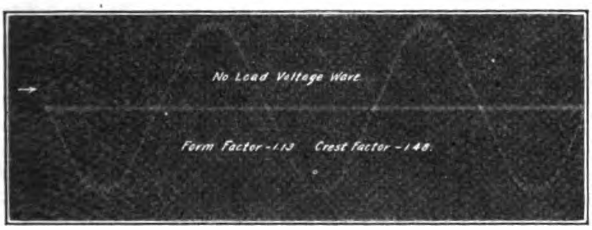

Fig. 12

Tubes: Radio Corporation of America type, *U X*-120 tubes, well known to the radio public. Although this tube is of the three-element type, its grid and plate are connected together so as to act as a single electrode for rectification. The resistance of the tube in this connection is of the order of 5000 ohms. Rated filament voltage three volts, filament current 0.125 amperes.

Transformer: primary rated 110—125 volts, 25—60 cycles; four secondary windings, one for each tube, each rated 3—3.75 volts.

Voltmeter: d'Arsonval type, d-c. voltmeter, resistance 178,000 ohms. Scale 150 volts, equivalent sine-wave voltage.

Effect of Tube Resistance

A voltmeter circuit always has a large series resistance incorporated within the voltmeter box. Tube

resistance, therefore, not only is not a handicap but is a useful element, furnishing some of the desired resistance to the voltmeter circuit. In fact, were it not for the variability of tube resistance, it would have been desirable to use sufficiently high-resistance tubes to replace and eliminate all other series resistance. It is known that tube resistance varies with plate voltage, however, and therefore the tubes were chosen so as to make their resistance a small fraction of the total resistance of the voltmeter circuit. In the outfit described above, the tube resistance is only about five per cent of the total resistance, and therefore any little variations in the tube resistance are imperceptible in the total resistance.

Accuracy of the Flux-Voltmeter

The accuracy of the flux voltmeter in measuring the average value of any given voltage was tested both by the writer and by the Bureau of Standards and in both instances was found to be very satisfactory. Our tests consisted of (a) form-factor tests checked by oscillographic analyses, and (b) tests of application to core loss measurements.

Form-Factor Measurements

The form factor of a wave is defined as the ratio of the r. m. s. value of the wave to its arithmetical average value. Since ordinary a-c. voltmeters give the r. m. s. value, and the flux voltmeter the arithmetical average value, the form factor of a given voltage wave may be obtained by means of these instruments. The value so obtained may be checked oscillographically by computing from an oscillographic record of the wave both its effective and its average values in accordance with well-known methods. Since the flux voltmeter is graduated in terms of equivalent effective sine-wave volts, and since the form factor of a sine wave is 1.11, it follows that the form factor of a distorted wave is:

$$\text{form factor} = 1.11 \times \frac{\text{a-c. voltmeter reading}}{\text{flux-voltmeter reading}}$$

The foregoing method of test and checking was applied to seven different wave shapes obtained on different generators under different conditions of loading, with results as follows:

Items	Exciting Current Load on the Generator	Form Factor: By Oscill.	Form Factor: By Flux Voltmeter	Figures
	Per Cent			
1	20	1.21	1.231	6
2	7	1.13	1.128	7
3	30	1.148	1.149	8
4	6	1.128	1.122	9
5	55	1.18	1.18	10
6	18	1.14	1.15	11
7	2.2	1.13	1.115	12

Those who are familiar with oscillographic analyses will appreciate the great difficulty of obtaining precise results. In view of this fact, and also in view of the possible small errors of the a-c. voltmeter used, the foregoing tests may be considered excellent commercial checks on the commercial accuracy of the flux voltmeter The instrument is really much more precise than these tests seem to indicate, as the Bureau of Standards tests show.

The analyses of the oscillograms were made by a different person who had no knowledge of the form factor obtained by the flux voltmeter, in order that the observations might be unbiased.

Measurement of Transformer Core Loss

The Institute rules provide that the efficiency rating of transformer shall be based on sine-wave operation. Although certain classes of transformer losses, such as the ohmic loss of the conductor, are not affected appreciably by ordinary variations in wave shape, it is known that core loss is seriously affected by the wave shape of the impressed voltage. Since it is difficult to obtain sine-wave voltage on a commercial scale for the testing of transformers, particularly for the condition of exciting current loads which tend to distort the generator voltage, some scheme that will reduce core-loss tests to a sine-wave basis is a necessity. The flux voltmeter was developed primarily for this purpose. The graduation of the scale in terms of equivalent effective sine-wave voltage is particularly useful for this purpose.

The principle of the application of the flux voltmeter to core-loss measurement is based on the fact that if the rated excitation voltage is set by the flux voltmeter at the rated frequency, the maximum flux density in the core corresponds to the rated sine-wave voltage excitation, even though the actual impressed voltage may be badly distorted.

The maintenance of the correct rated maximum flux density in the core by this means assures that the hysteresis loss of the core will correspond to the rated sine-wave voltage, because hysteresis depends on the maximum flux density.

Aside from the hysteresis loss, a core has also eddy-current losses.

Comparing the two types of losses we find that, in general,

(a) The eddy-current loss in laminated transformer cores is much smaller than the hysteresis loss, the eddy-current loss being of the order of one-quarter of the hysteresis loss. This difference in magnitude emphasizes the much greater importance of obtaining the hysteresis loss correctly than of obtaining the eddy-current loss correctly.

(b) While hysteresis loss varies as a complicated function of the density, the eddy-current loss varies substantially as the square of the effective r. m. s. voltage. So by means of the flux voltmeter we obtain the hysteresis loss correctly, and by means of an ordinary r. m. s. voltmeter we are able to make correction for the eddy-current loss.

(c) For a given line of sheet steel, the hysteresis loss per pound may vary a great deal depending on the annealing process and handling, but the eddy-current loss is relatively very slightly affected by these factors. This means that the eddy-current loss of a line of steel may be considered fairly constant without serious error, and hence, calculated corrections applied for it, when necessary, as described below.

When the excitation voltage is set by the flux voltmeter, the desired maximum flux density, and hence the correct hysteresis loss, is obtained. If the voltage wave is distorted, however, the a-c., r. m. s. voltage will be different from the flux voltmeter voltage, and therefore the actual eddy-current voltage under test will be different from that corresponding to the rated sine-wave voltage in the ratio

$$\frac{\text{True eddy loss}}{\text{Observed eddy loss}} = \left(\frac{\text{r. m. s. voltage}}{\text{flux voltmeter reading}}\right)^2$$

A correction, therefore, has to be applied for the changed eddy loss. The method used in the tests described below was as follows. If, in a normal sample at sine-wave voltage, the percentage values of the eddy and hysteresis losses are known over the desired range of densities, then, if the eddy-current loss is left unchanged and the hysteresis loss altered and if for the test purpose the voltage is set by the flux voltmeter, it follows that the

True sine-wave core loss

$$= \frac{\text{Observed total loss} \times 100}{\text{Per cent hysteresis} + k \times \text{per cent eddy loss}}$$

where k is the square of the ratio of the a-c. voltmeter reading to the flux voltmeter reading. The relative values of the eddy and hysteresis losses in the iron sheets may be obtained from the Epstein test[2].

2. Since the preparation of this paper, an excellent method used by the Bureau of Standards has come to the attention of the writer in which no assumption whatever is made about the percentage values of the eddy and hysteresis losses but two measurements are made at different wave shapes to obtain the separation of the actual eddy and hysteresis losses. The method, of course, involves the use of either the flux voltmeter or its equivalent in some form. The method is quite simple.

The core loss test is made at two different wave-shapes, setting the voltage by the flux voltmeter. Assume that W_1 and W_2 are the observed total losses, and E_1 and E_2 the corresponding observed effective a-c. voltages. Then the true total core loss W_s for the rated sine wave voltage E_s indicated on the Flux Voltmeter is

$$W_s = \frac{W_1(E_s^2 - E_2^2) + W_2(E_1^2 - E_s^2)}{E_1^2 - E_2^2}$$

This is derived from the following basic equations:—

$$W_1 = H + W_0 E_1^2$$
$$W_2 = H + W_0 E_2^2$$

in which H is the hysteresis loss and is the same at both wave-shapes for the same flux voltmeter voltage; while W_0 is the eddy-current loss for unit effective voltage, and when multiplied by the square of the actual effective voltage gives the total eddy-current loss for that test.

The fact that the percentage eddy loss varied at different densities is to be taken into consideration by using the characteristic curve of the material similar to the sample characteristic curve shown in Fig. 13. It is to be granted that in large built cores the ratio of eddy to hysteresis is not necessarily exactly the same as in small samples, due to increased intersheet eddies resulting from the closer contact of the sheets under pressure from highly tightened bolts. Large cores, however, have also increased hysteresis loss due to pressure of bolts and other reasons, so that in large cores the ratio of eddy to hysteresis probably does not increase as

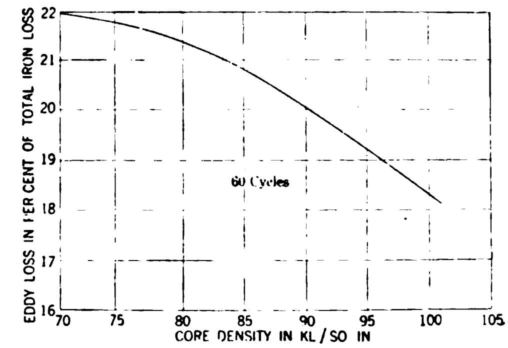

Fig. 13

much as one might expect. Furthermore, it may be shown by an example that the error that may result from this variation is not very large.

Example

Flux voltmeter setting 100 per cent rated voltage
Actual r. m. s. voltage 105 per cent rated voltage

$$k = \left(\frac{\text{r. m. s. voltage}}{\text{Flux voltmeter voltage}}\right)^2 = 1.10$$

True core loss = Observed loss

$$\left(\frac{100}{\text{Per cent hyst.} + k \text{ per cent eddy}}\right)$$

If the eddy loss is 20 per cent,

$$\text{True core loss} = \text{Observed loss} \left(\frac{100}{80 + 1.10 \times 20}\right)$$

$$= \text{Observed loss} \quad \frac{100}{102}$$

The correction for error in the eddy-current loss thus amounts to two per cent. If the flux voltmeter were not used at all and no correction applied, the observed loss would be about ten per cent in error.

To show that the assumption of a considerably different percentage value of eddy loss would not affect the foregoing result appreciably, we may suppose that

the percentage is 30 instead of 20 and recalculate the true loss. We would then have

$$\text{True loss} = \text{Observed loss}\left(\frac{100}{70 + 1.10 \times 30}\right)$$

$$= \text{Observed loss}\ \frac{100}{103}$$

Comparing this with the previous result, it will be observed that a 50 per cent error in the percentage value of the assumed eddy loss has influenced the final result by only one per cent.

Test Data. In the data tabulated below, a given transformer was tested on two or more generators of widely different wave shape, thus using the degree of agreement among the results so obtained as a measure of the accuracy of the instrument in this application. An attempt was made, of course, to make one of the wave shapes in each instance as near sine wave as possible and the other, or others, as distorted as possible. Oscillograms of wave shape are shown for each instance. Furthermore, to give to the reader an idea as to how much the wave-shape error would have amounted to if no attempt at correction for wave shape were made, the losses observed when the voltage was set by an a-c., r. m. s. voltmeter are also given for each instance.

Since in these tests the comparative values of the losses rather than their absolute values are of interest, the loss data, to facilitate comparison, have all been reduced to percentage values calling one of the readings as 100 per cent.

TABLE I

Item	Trans. Kv-a. Rating	Generator Kv-a. Rating	Per cent Load on Generator	Core Loss with Flux-volt	Core Loss without Flux-volt	Oscillo-gram Fig.
				Per Cent	Per Cent	
No. 1	1,500	500	20	100	81.6	6
	"	1,500	7	100	94	7
No. 2	1,667	500	30	100	88.5	8
	"	3,000	5	100	94.2	9
No. 3	8,000	500	55	100	87.8	10
	"	1,500	18	100.5	92.2	11
	"	12,000	2.2	99.5	98.8	12
No. 4	10,000	500	50	100.3	83	—
	"	3,000	9	100	93	—
	"	12,000	2	100	101.5	—
No. 5	28,866	1,500	45	100	82	
	"	24,000	3	100	90.8	

These data would seem to indicate excellent commercial accuracy for the flux voltmeter, inasmuch as practically the same result is obtained no matter how distorted or how pure the waveshape is. The distortion of the wave in some instances was so great (see item No. 1) that more than 18 per cent error would have existed in the core-loss measurement if the voltage had been set by an r. m. s., a-c. voltmeter.

Comparison With Other Methods

Two very similar methods have in the past been used for the purpose of reducing core-loss measurements to a sine-wave basis. It may be of interest, therefore, to present data as to how the accuracy of the flux-voltmeter method compares with theirs.

In the two older methods, use is made of a little "Standard" transformer the core loss of which has been calibrated on pure sine-wave voltage. In both methods, this "standard" transformer is excited, through potential transformers when necessary, in parallel with the power transformer under test. In one of the schemes, the voltage of the circuit is adjusted to a value such as to make the core loss of the "standard" the value corresponding to the desired sine-wave voltage. In the other scheme, the desired voltage is set by an r. m. s. voltmeter and the actual losses in both the power transformer and the little "standard" are observed. The factor which would convert the observed core loss of the little standard into its sine-wave value (known from its calibration curve) is used to convert the observed loss of the power transformer to sine-wave basis.

Tests indicated in Table I for the flux voltmeter were repeated, making corrections by these two schemes. The items in the following tabulation refer to the same apparatus and conditions as the corresponding items in Table I.

TABLE II

	Core Loss by		
	Flux-Voltmeter	Scheme No. 1	Scheme No. 2
	Per Cent	Per Cent	Per Cent
Item No. 1	100	90	91.7
	100	95	95.4
Item No. 2	100	93.3	94.2
	100	95.3	98.2
Item No. 3	100	95.2	98.8
	100.5	97.6	99.2
	99.5	99.2	102.
Item No. 4	100.3	95	96
	100	97	103.5
	100	109	111
Item No. 5	100	90.2	93.6
	100	97.4	97.4

It is interesting to note that (1) core-loss measurements made by the older schemes are influenced a great deal by differences in wave shape and that with badly distorted waves they would be very unreliable, and (2) that in eleven cases out of twelve, the losses obtained by the older methods were considerably less than those obtained by the flux voltmeter (and the one instance, in which they were more) might be somewhat doubted.

Outfits of this type have no doubt served an excellent purpose in the past, and even now, when the wave distortion is not large, they may give results which are entirely satisfactory. On the other hand, however, it appears that conditions have so changed in recent years that the average accuracy which was obtained

by the aid of such outfits five or ten years ago is not readily obtained under present conditions. The reasons for this may be seen as follows:

1. These older schemes do not attempt to maintain a known flux density in the core, but aim at drawing inferences from the losses of a small unit to the losses of the main transformer. If the two transformers were operated at the same density, this might be possible, assuming that other conditions are favorable. It is not practicable, however, to duplicate the density of the main transformer in the auxiliary "standard" core, and therefore the greater the difference in density the less reliable is the result. Scheme No. 2 described above utilizes an extra theoretical correction based on the difference in the density of the two transformers and it will be observed that it gives, in general, more correct results than scheme No. 1. Still, it is not by any means as consistent and accurate as the flux voltmeter.

2. Transformer sheet steel is constantly being improved, so that hysteresis characteristics and the eddy-current ratio are modified as time goes on, and the assumed "standard" core, even when operated at the same density as the transformer under test, ceases to be representative in a short period of progress. Even at a given time, a great variety of sheet steels are used, and it would be impossible for a given "standard" core to duplicate the characteristics of them all.

3. Although the kv-a. capacity of transformers built in recent years has steadily increased, the kv-a. capacity of generating units used for testing the core-loss of the transformers has not proportionately increased, and as a result, the core-loss load on generators in testing departments is a much larger percentage of their capacity and as a consequence the wave distortion is on the average much larger than formerly. It may be noted that generator voltage wave distortion due to transformer exciting current load is far more than that due to other loads, on account of the fact that the former draws a badly distorted current. Even in a carefully designed generator, the harmonics of the transformer exciting current will produce a large distorted regulation through the usually high synchronous impedance of the generator.

Application of Flux Voltmeter to Alternating Flux Networks

In a magnetic network, the flux density in different branches may be badly distorted, even with sine wave line voltage and sine-wave total flux. In such cases, observing the r. m. s. voltages in exploring coils on different branches would not indicate the true flux densities in the respective branches, whereas voltage observations made by the flux voltmeter would definitely and correctly indicate the corresponding densities regardless of the shapes of the waves, provided, of course, that the voltage wave does not cross the zero more than twice per cycle. This application is too simple to require any further comments.

Conclusions

1. A voltmeter, suggestively called "flux voltmeter," is described for a-c. circuits, the indications of which are proportional to the arithmetic average value of the voltage wave and hence proportional to the maximum flux density, if the voltage is the reactive drop corresponding to the flux.

2. The primary application of the instrument is to the reduction of the core-loss measurements of transformers to sine-wave basis. The method is to set the desired value of the voltage by means of this instrument, in which case the maximum flux density in the core corresponds to the desired sine-wave voltage, even though the impressed voltage is badly distorted. Methods are indicated for taking into consideration the error in the eddy-current loss. Accuracy of the meter in this application is believed to be within one-half of one per cent.

3. In comparison with other and older schemes for the reduction of core loss to sine-wave basis, it is noted that the flux voltmeter has the following advantages:

a. Its results are unaffected by the rated flux density of the transformer core.

b. It is unaffected by the quality of the core material used.

c. It is applicable to all commercial frequencies.

d. In general, core losses obtained by other schemes are smaller than those obtained with the aid of the flux voltmeter.

e. The flux voltmeter puts practically no load on the instrument transformers.

4. The flux voltmeter may also be used for exploring alternating flux networks.

5. The only limitation of the flux voltmeter seems to be in those instances in which the voltage wave crosses the zero line more than twice per cycle. Such distortions of voltage waves, however, are so rare commercially that it is difficult to conceive of encountering them in practical core-loss tests.

The author is indebted to Mr. C. A. Read for the taking and analysis of the oscillograms; to Messrs. M. G. Newman and A. Boyajian for advice in the progress of the investigation; and to Mr. L. de Nagy for assistance in making the tests.

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Excellent Seminars for Practising Engineers:

A Challenge to Engineering Teachers

BY EDWARD BENNETT[1]

Fellow, A. I. E. E.

STATED in broad and comprehensive terms, the *primary responsibility* of the engineering colleges is for the development of four groups of men; for engineering work namely,

a. Undergraduate students
b. Graduate students
c. Practising engineers
d. Engineering teachers.

The responsibility of the colleges of engineering for the first two groups is evident and is not discussed in this paper. On the other hand, the possibilities of educational activities with the third group are just beginning to appear on the educational horizon, and the question naturally arises as to the grounds for listing such activities as a responsibility of the colleges.

Two considerations seem to warrant our regarding educational activities with practising engineers as responsibilities, or at least as promising fields of service for the colleges of engineering.

First. An appreciable percentage of practising engineers and of engineering teachers contend that an adequate foundation for an engineering career cannot be obtained in the four-year course. They advocate the plan of keeping the engineering students within the college walls for an additional year or two. If this contention is well founded, but if, for one reason or another, it is not deemed best to require engineering students to remain on the campus for a fifth year, it seems logical to consider the extent to which it may be feasible to carry the college to the young engineer in practise.

Second. It is a commonplace that most engineers (and this applies equally to all of the professions including the teaching) are unable to keep abreast of the rapid scientific developments in their field, and as a result are not in a position to do clean cut effective work. There would seem to be a distinct opportunity for the colleges to be of service to engineers whose training along scientific lines may have been quite adequate at the time they entered practise but who have come to feel the need of a fundamental re-examination of certain fields.

In view of these considerations and others to be presented later, it would seem that the engineering colleges should, by trial, determine the feasibility and desirability of conducting in nearby engineering centers *seminars* or *conferences* of one or more of the following types for practising engineers.

Type A. Advanced studies of the kind given in residence in postgraduate work; studies n mathematics, physics, engineering subjects, etc.

Type B. Seminars dealing with recent developments, designed to enable he older graduates to keep abreast of the scientific advances.

Type C. Seminars for the discussion, in the light of fundamental theory, of

a. Allied or common research problems
b. Allied or common design problems
c. Allied or common operating or manufacturing problems

A brief sketch of two seminars for practising engineers sponsored by the University of Wisconsin may be of interest.

Two years ago a group of technical graduates of ten or more years' experience, and all in responsible positions in the metallurgical industries, requested the opportunity to work for an advanced degree and to carry on this work in Milwaukee, 85 miles east of Madison, the seat of the University. Since an experimental research in some technical subject would be a necessary part of the proposed graduate work, the proposal was welcomed because it held promise of opening the way to a very desirable type of cooperative research between the engineering industries and the college. I refer to the type of research in which problems are not brought to the college laboratory to be solved, but, in which the facilities and views of the college, are carried to the industrial laboratory or the engineering office, and in which the primary function of the college in research—namely, the training of men in engineering research—is emphasized and is given wider scope. The positions held by the eight men in this group are as follows:

Works Manager of the Milwaukee Steel Foundry Company
Vice-president of the Badger Malleable Company
Works manager of the Globe Electric Company
General superintendent of the Federal Malleable Company
Metallurgist of the Federal Malleable Company
Metallurgist of the Glancy Malleable Corporation
Metallurgist of the Vilter Manufacturing Company

The *significant* thing about the list is that these men are in competing industries and are cooperating in a highly effective manner in the solution of their common problems.

During the past two school years this group has met in Milwaukee each Friday evening for a conference extending from 7:30 to 10:30, or later, with Professor R. S. McCaffery or other members of the Mining

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Presented at the A. I. E. E. Regional Meeting of District No. 5, Madison, Wis., May 6-7, 1926.

or Metallurgical Department.[2] On Saturday, the professor visits one or possibly two of the members of the seminar at his plant or laboratory and discusses the research project which is under way. The research projects, which were selected by the men themselves, are as follows: A study of the reactions which take place in a basic steel furnace; an electrical method of rapidly determining the quality of the molten metal in malleable air-furnaces; the determination and comparison of the heat balances of hand-fired, oil-fired and pulverized-coal-fired malleable furnaces; the effect of silicon and manganese on the properties of malleable iron; and the study of the reactions of combustion in a malleable furnace for the purpose of obtaining greater accuracy of control of the finished product.

In the conduct of a seminar for the discussion, in a fundamental way, of allied questions, the first and most difficult problem which presents itself is that of getting the members of the group to talk the same technical language. This requires a review of the experiments, concepts, postulates, definitions, sequences and principles which underlie the branch of science with which the group is concerned. Accordingly, the Friday evening conferences during the first five months were devoted mainly to a review of the fundamentals of physical chemistry applied to metallurgy. This involved a study of equilibriums in chemical and metallurgical reactions and of equilibrium diagrams, the application of the phase rule, mass law, atomic structure and the velocity of reactions.

The impression made by this work is indicated first, by the fact that some of the concerns listed above have established fellowships at the university in order that the holder of the fellowship might collaborate with the member of the seminar by carrying on supplementary researches at the university, and second, by the fact that some 26 grey iron foundaries operating in the Fox River Valley have formed a local association to carry on and finance cooperative research at their own plants and in Madison; a similar group of about 20 grey iron foundries in Milwaukee is organizing to carry out a program of the same kind.

The second seminar was organized at the solicitation of electrical engineers in Milwaukee. The men in this group, which started with 18 men and ended with 13, are electrical engineering graduates with from two to six years of experience. During the past year this group met in Milwaukee each Thursday evening with a professor from the university for a seminar of the A type,—a seminar for the discussion of *transient phenomena and waves in electric circuits*. This course was largely a mathematical development of circuit theory, with, of course, constant illustrations of the application of the theory to transformers, generators and power and communication systems. As a result of the experience of the men with this seminar, courses of a similar nature have been solicited and will be given during the coming year. At least one industrial organization has under consideration plans for meeting all or part of the tuition expense of its employees who successfully complete courses of this kind.

The Significance of the Seminars to Industry

It may be well to list the significant possibilities to industry of seminars conducted by the engineering colleges for men engaged in engineering practise. They are:

Such seminars, if available, will enable some graduates of four-year engineering courses to obtain a more thorough scientific training for engineering work.

Seminars of the B type might be used to serve as the line of communication between the advance scientific workers and the main body of engineers, or to enable engineers who, in the press of work, have lost touch with certain allied fields, to "come back" in these fields.

During the apprenticeship period of the first few years after graduation, many engineering graduates slip in their grasp of mathematical methods and analysis. A course of the A type, if pursued during this period, should be of value in more firmly fixing these methods and in warding off the mental slump which frequently occurs during a depressing apprenticeship period.

That both industry and engineering education have much to gain by closer cooperation in engineering work, particularly of the research type, needs no argument. The kind of cooperation which has received more attention in the past is that in which certain research problems have been taken to the college laboratory for solution. By seminars of the C type, the views and the methods of the college are carried to the industrial laboratory, and the primary function of the college in research—namely, the training of its own staff and of its students in research—is made more apparent and is given wider scope. More research for engineering teachers both in the college and in industry is badly needed.

Engineering seminars sponsored by associations formed by the smaller industrial enterprises for the fundamental examination of their common technical problems may be a means by which the smaller enterprises with their desirable social characteristics may retain a place in the sun by the side of the modern corporation.

One of the barriers in the way of more effective cooperation between the industries and the state colleges results from a difference in the social philosophies in the two fields of action, namely, in the industrial field and in the professional field in general, or the teaching field in particular. In the educational and scientific field, the rewards and increased opportunities come from the sharing and free disclosure of all

2. For a more detailed statement of this work, see the paper by Professor R. S. McCaffery entitled "Research Cooperation between University and Industry," Canadian Inst. of Min. & Met., Vol. XXIX, 1926.

achievements which result in the advancement of knowledge. In the industrial field, the careful guarding of trade secrets is still regarded in many industries as highly essential, and the obtaining of exclusive rights through patent control is frequently the main consideration which leads to the support of research work. These conflicting demands—for the unreserved disclosure and for the exclusive use of knowledge—are the greatest barrier in the development of cooperative relations in those fields in which important improvements and inventions are likely to be made.

The most promising sphere for the organization of seminars for the consideration of allied or common engineering problems is with associations of manufactures or of public utilities. In this case it would seem quite possible to formulate a policy with reference to the granting of preferential but not exclusive patent rights which would harmonize the views and rights of all parties in the enterprise. The essential features of such a policy are outlined in Sec. VIII and IX of Circular No. 9 of the Engineering Experiment Station of the University of Illinois, entitled "The Functions of the Engineering Experiment Station of the University of Illinois," by C. R. Richards.

Not the least among the possibilities for good of these seminars is the possibility that the advantages of cooperation may be shown to be so great that it may become obvious that the thing to do is to modify those features of the patent law which make the existing law a barrier to cooperation.

The type of seminar which holds the greatest promise of achievement is a seminar of experienced engineers from the same or allied fields who have come together to conduct a critical analysis of certain cases or certain lines of engineering practise. It may seem like presumption to suppose that men from the colleges can be of much service to such a group. The presumption is tempered somewhat by the consideration that the introduction of a foreign body into saturated solutions frequently initiates crystallization. In a group of experienced engineers, the man from the college may at least play a role not unlike that of the foreign body in the chemical solution. The achievements should come mainly from the contributions of the practitioners to the conference. Judgment should not be passed as to the relative contributions to be expected, however, until we have considered the significance of these seminars to the engineering teachers.

Significance of the Seminars to Engineering Education

The fourth responsibility of the engineering college is for the development of engineering teachers. One of the strongest arguments for sponsoring seminars for practising engineers is the part which these seminars will play in the development of engineering teachers.

The seminars will compel and will reward a broader and a more thorough training than is common in the teaching ranks today.

They will afford greater opportunities to determine the adequacy, the relative importance, and the real significance of the principles and the methods taught to undergraduates.

They will make teaching attractive to a wider range of engineers by making it possible for men in teaching to have closer contact with engineering practise.

They will help to supply one of the greatest needs of the engineering colleges of the country; namely, the atmosphere, the spirit and the prestige which will accompany more examples of engineering work in progress or carried to a successful conclusion in the colleges or by the engineering teachers.

The opportunity to develop these seminars comes to the teaching profession as a challenge; a challenge because the task is no light one but one beset with difficulties and even with an element of danger to undergraduate instruction; but above all, a challenge because the acceptance of the opportunity means the acceptance of a goad and the acquirement of an incentive which will bring the work of the engineer and of the engineering teacher to a higher plane.

WELDING LARGE METAL STRUCTURES

The American Bureau of Welding, 29 West Thirty-ninth Street, New York, N. Y., is planning an extensive investigation of welded steel structures. James H. Edwards, assistant chief engineer of the American Bridge Co., 71 Broadway, New York, N. Y., one of the directors of the American Bureau of Welding, is interested in this method of fabrication, which may have many advantages over riveting.

Electric arc welding was used by Mr. Edwards' company to fabricate some steel plates in order to determine the difficulties which might arise in using this process. The result was a plate girder 15 feet long, having a web plate one-half inch thick and 24 inches deep. The flanges were 12 inches wide, one $1\frac{3}{4}$ and the other $1\frac{7}{8}$ inches thick. A cover plate $9\frac{1}{2}$ inches wide and nearly as thick as the flange was used on the top and the bottom flanges. Nine stiffeners on each side were welded to both flanges and the web.

To determine the strength of this structure, particularly whether or not the welds were satisfactory, it was tested by the Bureau of Standards in cooperation with the American Bridge Co. The Olsen hydraulic machine, having a capacity of 10,000,000 pounds, was used, loading the girder at the middle of a $13\frac{1}{2}$-foot span.

It was gratifying to find that the maximum load was somewhat greater than this estimate, and that the welds connecting the web to the top flange failed at the ends only after the web was buckled and the girder had deflected several inches.

The investigation will enable an engineer to design safe welded structures. It is probable that a saving in the cost of steel structures will result.

Discussion at Midwinter Convention

THE CALCULATION OF MAGNETIC ATTRACTION[1]
(LEHMANN)
NEW YORK, N. Y., FEBRUARY 11, 1926

C. O. Mailloux: This is another of the papers of the kind which, like one by Mr. Fortescue[2] published some years ago and one by Mr. Rice[3], written more recently, serves to advance our knowledge of ways and means of attacking problems that have baffled all others before these authors, and at the same time gives us very interesting evidence of the fact that the methods of mathematical treatment of previous generations—say of the days of Maxwell, Kelvin, Mascart, Helmholtz, etc.—are still capable of giving magnificent results. Mr. Fortescue, in an epoch-making paper, showed the valuable use that can be made of the principles of the *potential energy function* and of their application to the discussion of equipotential surfaces, etc., as a means of mapping out the field of electric force around insulators that are subjected to high electrostatic stresses. Those who may have had doubts at that time in regard to the utility of the study of the potential function as a preparation for the analysis of phenomena in fields of force, and were disposed to look more sympathetically upon the more "modern" methods devised or elaborated by Bjerknes, Lorenz, and others, found that their fears in regard to the "staleness" of the older methods were not wholly well founded. What Mr. Fortescue did was, in a sense, an extension of Maxwell's work, and his diagrams of lines of electric force in electrostatic fields show at least a family resemblance to some given in Maxwell's treatise. Mr. Rice's able paper furnished further valuable evidence of the great usefulness of this method of attack on seemingly difficult problems of like character.

In the present paper, we have the very interesting case in which the theory and the principles of the potential function enable the author to perform an entirely new *tour de force* that would have done credit to Maxwell himself, showing such a simple and practical way of "surveying" and *appraising* the magnetic force in an air-gap that we wonder how such a clever expedient has remained so long undiscovered. Every student of the theory of the potential function knows that the concept of the "tube" of magnetic force, even though it may be after all only a figment of the scientific imagination, does account, in a very simple way, for differences of magnetic density and distribution that are often impossible to describe by any other method, notably by the measurement or expression of variations in magnetic density in different parts of the magnetic field. It was an inspired idea of the author to decompose the magnetic field in the air-gap into *elemental tubes of magnetic force*, with boundaries (or envelopes) enclosing spaces in which the magnetic flux is constant. This amounts virtually to the same thing as finding paths across the air-gap where the magnetic density may be treated as if it were constant. In this way the author found a means of getting across the air-gap without having to stop midway to rearrange and readjust the magnetic density; and with the aid of the principle of "solenoidal distribution" and of equipotential surfaces, all of which is a part of the theory of the potential function, he had the absolute certainty of being able to get across safely before he started. The only problem that remained to be solved was that of making "landings" at both ends of the path followed in crossing the air-gap through a tube of magnetic force when that path is not exactly straight across, *i. e.*, when the tube of magnetic force is not "normal" to the surface of the poles or other ferromagnetic portions of the magnetic circuit on the two sides of the air-gap. The author solved that problem in the well-known, simple way, familiar to mathematicians, of replacing any contour line by an equivalent broken line, on the principle that a circle may be regarded as a polygon of an infinite number of sides. Now, the fundamental fact that makes this method rigorous as well as interesting and effective is the well-known principle that whenever a potential energy function *exists*, as is the case in an air-gap, the *initial* and the *final* stages of the potential developed (which in this instance is magnetic potential; that is to say, the conditions determining the *strength* of the physical *bond* between the two edges of the air-gap) are really independent of the locus of the path through which the tube of force is "laid." Indeed this far-reaching generalization, a great achievement and precious inheritance from the mathematical physics of previous generations, was the key that unlocked the secret of the wide power and range of the method and that inspired confidence in it by showing how far it can be relied upon.

The paper deserves to be regarded as a pathfinder, pointing the way to new and really wonderful applications of old but still "up-to-date" and most effectual methods of attacks on difficult problems. It is seen that the figments of the scientific imagination, to which I have just referred, can play a most important role and can lead to highly useful concrete results as they did in Mr. Fortescue's paper. As in that case (aside from the useful practical applications) the result is a contribution to general theory and will add value in a permanent way to the TRANSACTIONS of the Institute.

The paper may not prove as easy of perusal and comprehension as might be, because some of the ideas in it are presented somewhat tersely and are not, therefore, placed within as easy reach of the ordinary reader as might have been, perhaps, had the author realized the desirability of so doing. The mathematics are simple enough; in fact, they are elementary to those who have studied the theory of the potential energy function and mathematical physics to even a slight extent, although they may seem abstruse, imposing, and forbidding to those who have not done so. The paper really deserves to be made accessible to a very large constituency. This could have been done easily by taking a little more space for the presentation of the mathematics in slightly more "dilute" form. The objection most often made to papers of this type is, indeed, that their authors do not sufficiently recognize the importance of making them entirely clear to those who do not know or remember as much as they do themselves about the "short cuts" in mathematical transformations and demonstrations. A few notes given in an appendix, clarifying the more abstruse portions, would help greatly to remove the impression that the paper is merely a "high-brow" product which will, or can, interest only mathematical students and experts. In this respect, however, the paper will be found to be not nearly so formidable as it may look. Moreover, those who are interested in this general subject will find such additional information and elucidation in other articles by Dr. Lehmann which have appeared in the *Revue Générale de l'Electricité*; notably in the article published in the numbers of July 12 and 19, 1924. This was written at about the same time as the present paper and covers substantially the same ground, but does it in a more detailed manner, and also throws full light upon the theoretical considerations which the author kept in mind and which underlie the methods described in the paper.

J. Slepian: It is usual to derive the forces acting on material bodies in a magnetic field by starting with the principle of conservation of energy, calculating the electrical energy input and the increase in magnetic energy, and assuming that the difference in these quantities gives the work done by magnetic forces on bodies which are displaced. This is the procedure followed by Doherty and Park in their paper.[4] Mr. Lehmann, however,

1. A. I. E. E. JOURNAL, February, 1926, p. 167.
2. TRANSACTIONS A. I. E. E., 1913, p. 907.
3. TRANSACTIONS A. I. E. E., 1917, p. 905.

4. *Mechanical Force between Electric Circuits*, by R. E. Doherty and R. H. Park, A. I. E. E. JOURNAL, March, 1926, page 231.

starts with Maxwell's expression for the stresses in a medium in which a magnetic field exists.

In the time of Maxwell, the great program of physics was to explain all phenomena mechanically. Therefore it was very natural to try to explain the transmission of force over distance through the mediary of a magnetic field by a mechanism similar to that by which force is transmitted mechanically through material bodies, namely by a system of mechanical stresses. Maxwell was led to believe that the following system of stresses would account for the mechanical forces in a magnetic field: a tension equal to $H^2/8\pi$ per sq. cm. across any surface perpendicular to the lines of magnetic force, and a pressure equal to $H^2/8\pi$ across any surface parallel to the lines of magnetic force.

In applying these stresses to determining the forces on material bodies, however, a difficulty arises, for these stresses are supposed to exist in empty space or in the ether as well as in material bodies. And since the ether pervades all material bodies, we cannot tell how much of the stress at any point acts on a material body there, and how much is limited to the ether. Maxwell resolved this difficulty to some extent by showing for a stationary magnetic field that although these stresses do not give the actual ponderomotive force at each and every point of a material body, when integrated over a closed surface, they do give correctly the total ponderomotive force on all the material bodies enclosed in that surface.

Herein lies one of the difficulties which I have found in trying to follow Mr. Lehmann, for apparently he integrates the stresses over a surface which is not closed. Such a procedure if carried out, for example, over a portion of the surface of a wooden body would give a resultant force, and yet we feel quite sure that no such mechanical force exists on any portion of such a body. If the integration is carried out over the whole surface of the body, the correct zero resultant is obtained, but not if the integration is limited to a part of the surface.

It is easy to see that if a body has infinite permeability, then integration over any portion of its surface will give correctly the mechanical force on that portion, and it so happens that the example which Mr. Lehmann has worked out is for a body with infinite permeability. But if the method is applicable to the case of finite permeability, it seems to me that some further justification is necessary. I would be very happy if Mr. Lehmann could clear up this point for me.

The formula which Mr. Lehmann has obtained is similar to that obtained by Doherty and Park by considering displacement of a magnetic body under constant flux, and I presume is intended to apply also for the case of saturation. However, Mr. Lehmann does not limit himself, as do Doherty and Park, to special magnetic circuits where the flux density is constant in the air gap during the displacement, but suggests that the result is general. This is a question of very great importance and I therefore considered it worth while to try to derive this result from the principle of conservation of energy. In so doing I ran upon a difficulty which Mr. Lehmann hints at in his paper but which I have not been able to surmount. Perhaps Mr. Lehmann can show how to take care of it.

I used the following artifice: In the magnetic system under consideration, assume that all currents which are flowing are in resistanceless circuits so that no impressed voltages are required. Now assume that with the bodies in the position for which the force is to be calculated, all bodies which are subject to magnetic saturation are made infinitely conducting. No change in the magnetic force results from these hypotheses. Now let one of the saturating bodies be displaced a small amount, Δx. Then currents are induced in the various circuits and conducting bodies, the magnetic field changes, and work is received by the moving body. Now, since the electromotive forces are zero, there is no input of electrical energy. Hence the work received by the moving body must be equal to the decrease of magnetic energy. Since the saturating bodies are by hypothesis infinitely conducting, there will be no change in the magnetic field within them at any point, so that the magnetic energy in their interior remains constant. Hence the whole change in magnetic energy is external to the saturating bodies. This change in the external magnetic energy may be resolved into two parts. First we may consider the change which would take place if the energy density at every point remained constant, so that the motion of the saturating body merely changed the boundaries of the external field. This change may be determined by multiplying the energy density at each point of the surface of the body by the normal component of the displacement of the surface and integrating over the whole surface. This change in magnetic energy considered by itself leads directly to Lehmann's formula. However, there is the second part of the change in magnetic energy which must be considered; namely, that due to the change in energy density at the various points of the field. If ΔW is the change in magnetic energy density at any point of the field, resulting from the displacement of the saturating body, then the volume integral,

$$\int\int\int \Delta W \, dx \, dy \, dz$$

taken over the whole external field gives the other part of the change in magnetic energy.

If Mr. Lehmann's result is correct, this integral must be equal to zero. However, I have not been able to establish the fact that this is necessarily the case and would like to ask Mr. Lehmann if he can suggest how this is to be done.

R. H. Park: Two methods of calculating the mechanical forces due to magnetic attractions have been presented at the 1926 Midwinter Convention; namely, a method of calculation based on analysis of flux through circuits, and a method based on the analysis of stresses acting at each point of a closed surface bounding the volume on which the force is to be calculated. Both methods have special fields of application in which they are of particular value. In the formula

$$F_l = \frac{\phi^2}{8\pi} \quad \frac{\delta R_o}{\delta l}$$

of the paper by Dr. Lehmann, he has given a useful simplification of the known methods of calculating force on the basis of stress acting on bounding surfaces. For this particular result and also for his introduction of the general method of calculating force from stresses on bounding surfaces to problems of practical character, Dr. Lehmann deserves much credit. Without wishing to detract in any way from the practical value of Dr. Lehmann's paper, I should like to mention a few considerations which may deserve attention.

In particular, the application of formula (1) of the paper to problems in which saturation exists both within and without the volume in which the force is to be calculated may be open to question. In his "Electrical Papers," Volume I, pages 542 to 553, and Volume II, pages 543 to 574, Oliver Heaviside shows definitely that formula (1) applies in the case of saturation when there is no saturation outside the region on which the force is to be calculated. He also gives a formula which applies in the more general case and in the interior of saturated regions. This result would indicate that formula (1) of the paper was correct in application in the case when there is iron both within and without the region on which the force is to be calculated, if the intersurface does not pass through saturated material. The arguments employed, however, in establishing these results are not entirely clear since no explanation is given that the assumptions on which the proof is based are in accord with experimental facts.

In regard to Dr. Lehmann's definition of his reluctance R_o, it may be pointed out that the determination of this reluctance requires a previous knowledge of the distribution of the field in the region under consideration. It therefore depends on the character of the medium at points outside of the particular

region under consideration. Also there is a difference between the term $\frac{\delta R_0}{\delta l}$ and the ordinary total derivative of $R_0 \frac{d R_0}{d l}$. The derivative $\frac{\delta R_0}{\delta l}$ corresponds to a change in δl with the flux density and direction of the field fixed at the bounding surfaces.

C. O. Mailloux: With reference to the remark made by two of the discussers that the method is of direct application to questions where the permeability is independent of the field, that statement is brought out in the paper itself. The author concedes that point and there is no question about it. At the end he does refer to the fact that the formula can be completed by a saturation factor, but there is no detailed reference given to that, so we may assume that he didn't feel sufficient confidence in that new development to introduce it into the paper.

The inquiries made by one of the speakers are partly answered in the paper itself; notably where the author speaks of a complete integration around a circuit and counter-balancing effect produced by the integration of the second part of the circuit that is already shown diagrammatically in Fig. 10.

In regard to the detailed analysis of the formula, he preferred the purely practical method of finding what allowance, if any, could be made for the variation of magnetic field, when the length of the air-gap is increased or decreased, by calculating two cases where it has been done, proceeding with one from the inside and the other from the outside. He thus finds the difference between the two is within one per cent.

Now, for the cases with which he was interested in dealing, that error certainly is sufficiently small and, while the theory might be very interesting in a question of splitting hairs, it is not of immediate concern in connection with the present paper. I hope, however, that the author will be given an opportunity to explain himself to any such extent as he may deem necessary.

In the paper he does not mention the potential function, but anybody at all familiar with the subject knows that it is based upon that. One of the characteristics of potential function is that it goes into no speculation as to action at a distance. That may be the difficulty encountered by the gentleman. It is independent of all speculations as to the intervening medium or the actions at a distance. Had the author wished to go into it, he would have to begin by discussing the physics and mathematics of a tube of force, itself. He has assumed that as implicitly as one would assume the multiplication table in mathematics. Hence, if that is accepted as a fact and the explanation is sought for in some other books on mathematics, it seems to me a great many of the difficulties will disappear.

Th. Lehmann: I am indebted to Mr. R. H. Park and to Mr. J. Slepian for giving me, by their remarks, an opportunity to define further the scope of my paper. I also thank Dr. Mailloux for already having replied in part to their discussions.

My A. I. E. E. paper is a condensed summary of articles which have already appeared in the *Revue Générale de l'Electricité*, (Paris), July 12th and 19th, 1924, in which I made explanation (especially in paragraph VIII) of the fictitious character of Maxwell's stresses and pressures. In writing the A. I. E. E. paper it appeared to be desirable to leave out that paragraph and certain others to avoid lengthening it too much. In saying in the introduction to my paper, however, that I was taking into consideration only the resultant magnetic effort produced in a ferromagnetic body entirely surrounded by air, it seemed to me that there could be no doubt that the formulas (**1**) and (**4**) should be integrated along the *whole* of surface S in the body, especially since the letter S was added at the bottom of the integral sign to show that a *surface-integral* was intended.

Maxwell himself observed that the vectorial function, $P/8\pi$, which appears in the integral expression, is of fictitious character, inasmuch as it represents magnetic effort per unit of surface. The fact of having shown how this function may be evaluated and used in the determination of the true resultant does not at all imply that a real entity is attributed to the elemental effort per unit of surface, $P/8\pi$.

This point now having been made clear, I wish to assert that, for any closed surface of integration, the formula

$$F = \int_S B_{2\alpha}^2 \, d\, S, \qquad (\mathbf{4})$$

is equivalent to formula (**1**), the range of validity of which seems to have been determined previously by Oliver Heaviside. In any case, formula (**4**) gives exactly the *resultant* magnetic effort exerted upon a ferromagnetic body, C, having a surface, S, entirely surrounded by air, whether the permeability of the body be variable or not and even when the body, C, has hysteresis[5]. In the external medium, (the surrounding air), there may be other saturated ferromagnetic bodies and also some currents, provided the whole of the surface, S, of the body, C, be separated from the other ferromagnetic bodies by an air-zone.

Here I shall go no further than to state that I have given elsewhere (in the *Revue Générale de l'Electricité*, 1925, Vol. XVII, p. 167) the demonstration of the validity of formula (**4**) for a body, C, that is saturated but free from hysteresis, this being done by means of a schedule of the virtual potential energy involved, obtained by applying the theorem of W. Thomson. Another demonstration which does not use this theorem but which also includes the case where the body C is not free from hysteresis will appear shortly in the *Revue Générale de l'Electricité* (in September or October, 1926).

The same conditions, as regards validity hold also in the case of the formula

$$F_l = \frac{\phi_0^2}{8\pi} \; \frac{\delta_{R0}}{\delta l} \qquad (\mathbf{7})$$

If, for the value of the flux, ϕ_0, we take the circumflux[6] and, for the reluctance, R_0, the value obtained by means of the formulas (**3**) and (**3'**), with that flux, then for example formula (**7**) will give the *true resultant* in the direction of δl, on the armature of a dynamo. Of course, $\delta R_0/\delta l$ is the *virtual* derivative of that reluctance, and, as pointed out correctly by Mr. Park, it should not be confused with the ordinary total derivative, $d R/d l$. Naturally the formula can be applied also to each pole or to each magnetic circuit in turn. The respective magnetic efforts thus obtained should then be considered as being component portions of the total magnetic effort, and their vectorial sum will give the *true resultant effort* rigorously, whether the magnetic circuits be saturated or not.

The effort actually exerted upon a pole or upon a tooth can be determined in the manner which I have already indicated in the *Revue Générale de l'Electricité*. When there is no deformation (*i. e.* when the magnetic effort produces no change in geometrical figure) in the pole and in the tooth, the method of procedure is as given on page 101 of the issue of July 19th, 1924, in paragraphs VI and VII; and when deformation is produced, the method corresponds to the formulas (**9**) and (**11**), as given in the April 4th, 1925 issue. If Mr. Slepian will kindly refer to these earlier papers, I dare say that he will recognize the fact that the fictitious character of Maxwell's stresses and pressures had not escaped me in the least. But all this was quite outside the scope

5. It should be stated that A. Liénard has already pointed out (in the *Revue Generale de l'Electricite* of October 20th 1923, p. 563) that the formula (**1**), when integrated on the *air* side along the surface of a ferromagnetic body with hysteresis gives exactly the resultant magnetic effort. Moreover, A. Guilbert has given a very satisfactory experimental confirmation of formula (**7**) in his paper (Paris, 1926) which was published as a supplement to the Bulletin of the Société Francaise des Electriciens for January 1926.

6. That is to say, the absolute sum of the fluxes per pole which are common to all the poles; this, in the case of an armature which is not excentric in the magnetic field, is the same as the product of the number of poles and the flux per pole.

of my A. I. E. E. paper; in that I intended to take into consideration only the effort exerted upon a ferromagnetic body that is entirely surrounded by air.

The evaluation of the virtual derivative of the reluctance of the air, $\delta R_0/\delta l$, should be made by reference to Fig. 4 to 7A whenever the boundary air-surfaces may be considered equipotential, of which condition the reader is duly warned at the beginning of paragraph V (by the condition $\mu = \infty$ in the iron). In the case of superficial saturations of the pole-pieces of the armature, up to B = 18,000 c. g. s. (or $\mu > 100$), the departure of the lines of magnetic force passing through the air from the orthogonal direction with respect to the boundary surfaces, is still scarcely noticeable, and the methods described are still applicable with a degree of precision that is amply sufficient for practical purposes. The case given by way of example for a half-pole, should, naturally, be extended to all the poles when the magnetic field is excentric; this can be done by making δx coincide with the direction of the axis of excentricity. When the field or the armature is saturated to such a point that the lines of magnetic flux are no longer normal to the boundary surfaces, it becomes necessary to determine the segments σ' and σ'' along the whole of the air-surface for each tube of magnetic flux in accordance with the method indicated in Fig. 8; and, in that case, by following the external contour of the armature, we have

$$F_x = \frac{\phi_0^2}{8\pi} \sum \frac{1}{m^2} \left(\frac{1}{\sigma'} - \frac{1}{\sigma''} \right) \qquad (10)$$

In making the summation along a portion of the poles and of the outermost lines of force of the flux per pole that is common to both parts of the magnetic circuit, it is necessary to add, for each outer line of force, a term[7] which corresponds to

$$\frac{\phi_0^2}{8\pi m_n^2} \left(\frac{1}{\lambda_1'} + \frac{1}{\lambda_2'} \right).$$

As I pointed out in the *Revue Générale de l'Electricité* of July 19th, 1924, at the end of paragraph VIII, the elemental contributions per tube should be considered fictitious for the same reason as in the case of Maxwell's effort per unit of surface, $P/8\pi$, in formulas (1) and (4).

As to the last question asked by Mr. Slepian, it will be found to be answered fully in the article already mentioned, which is to appear soon in the *Revue Générale de l'Electricité*, and in which the magnetic attraction between bodies that are saturated and that also have hysteresis is deduced from a schedule of the actual energy involved, in a virtual displacement, without abstractions or hypotheses.

For the convenience of those who do not have ready access to the files of the *Revue Générale de l'Electricité*, a brief reference to the article published in July, 1924, may be useful.

As stated in the preface of that article, the following points are considered in it: (1) simplification of the physical formula for attraction; (2) definition of magnetic reluctance when the field is bounded by non-equipotential surfaces; (3) calculation of the virtual variation of the reluctance due to any displacement whatever of the limiting surfaces; (4) demonstration that the magnetic effort between two bodies depends only upon their common flux, ϕ, and upon the virtual gradient of its air-reluctance, R_0, and that the formula

$$8\pi F_l = \phi_2 \, \delta R_0/\delta l$$

which gives the attraction in any direction whatever, l, is as exact and general as the formulas of physics; (5) direct deduction of the attraction from the lines of flux of a magnetic figure without having to determine the components of the field; (6) evaluation of the local magnetic effort exerted upon a tooth or pole that is inserted in a groove, when the permeability is a function of the field.

The article contains nine sections, of which the last four include material that supplements the A. I. E. E. paper, which latter, as a matter of fact, was submitted to the Meetings and Papers Committee early in 1924, or before the publication of the articles in the *Revue Générale de l'Electricité*. In Sections VIII and IX, many points in regard to the validity and applicability of the formulas are made clear. Section VIII perhaps, ought to have been included in the paper. It is reproduced here (translated) with equation (13), taken from another part of the paper which could not be understood unless reproduced.

(Extract from *Revue Générale de l'Electricité*) (July 19, 1924)

"VIII. DIGRESSION. The formulas of physics for magnetic attraction are not much use in practise. Are physical hypothesis at all responsible for this? It cannot be denied that at first glance our sense of practical intuition, refined by the concept of the magnetic circuit, finds it difficult to admit the figment that excludes all disturbance in the magnetic field during a virtual displacement. But that figment, although it may lead to a state of disequilibrium, can be justified by the theorem of Thomson applied to two neighboring states of distribution, one of which corresponds to a minimum of potential energy."

It may, perhaps, be better not to look so far but simply to attribute the above reflection to the dilemmas that one meets when Maxwell's stresses are applied to surfaces which are not closed. An example will make the difficulty more clearly apparent.

Let us suppose a mass of soft iron of constant permeability, μ, and free from all internal currents. The effort exerted upon such a body in an air medium of permeability, μ_0, may be evaluated according to formula (13) in either of two ways. We have

$$\int_s P \, d\,S = \int_v \{2\,H \operatorname{div} B - H^2 \operatorname{grad} \mu - 2\,(B, \operatorname{rot} H)\}\, d\,v \qquad (13)$$

The term on the left-hand side is a surface-integral which is equal to (3), or

$$F = \frac{1}{8\pi} \int_s \{\, 2\,H\,(B, N) - N\,(H, B) \,\}\, d\,S \qquad (3)$$

The term on the right-hand side in (13) is a volume-integral which is obtained by the aid of the generalized theorem of Ostrogradsky (See Vaschy, *Théorie de l'Electricité*, 1896, p. 66).

The first of the two ways of evaluation is by means of the surface-integral,

$$8\pi F = \int_s P_0 \, d\,S \qquad (25)$$

and the second is by means of the volume-integral

$$2\pi F = -\int_V H^2 \operatorname{grad} \mu \, d\,v \qquad (26)$$

Since the permeability, μ, has been assumed to be constant, we have, in the iron, grad $\mu = 0$, except at the surface S, where grad $s\,\mu = N\,(\mu - \mu_0)$. For each surface element, $d\,S$, the volume integral, it will be recalled, will receive the contribution

$$(P_0 - P)\, d\,S = N\,(H, H_0)\,(\mu - \mu_0)\, d\,S$$

where the subscript zero refers to the surrounding medium. But the Maxwellian elemental effort being given (outside of the factor $1/8\pi$) by the value of the quantity P_0 under the integral sign in equation (25), in air, it is clear that the quantities to be integrated in (25) and (26) cannot both give the true elemental effort. It is commonly admitted that the quantity under the integral sign in (26) corresponds to the true effort, so that the Maxwellian effort P_0, considered as an elemental effort, appears

7. In formula (10') of my paper, the last term should be

$$-\frac{1}{m_n^2}\left(\frac{\cos\gamma_1}{\lambda_1} + \frac{\cos\gamma_2}{\lambda_2}\right) \text{ instead of }$$

$$-\frac{1}{m^2}\left(\frac{\lambda_1}{\cos\gamma_1} + \frac{\lambda_2}{\cos\gamma_2}\right)$$

to be fictitious. and it leads merely to the same resultant effort as (26).

For the condition μ = constant, formula (26) becomes, in effect,

$$8\pi F = \int_s (P_0 - P)\,d\,S \qquad (26')$$

But, by virtue of theorem (13), when integrating along the *inside* contour (the iron side) of the *closed* surface S, (since grad μ then vanishes) we have,

$$\int_s P\,d\,S = 0,$$

and we thus see that (26′) actually becomes identical with (25) for any closed surface.

If we consider $-\dfrac{1}{8\pi}H^2$ grad μ as the true effort per unit of volume, we can then scarcely attribute any real meaning to the Maxwellian stresses except in so far as they can be applied in the case of a surface of integration that is entirely closed.

The same remarks apply to the efforts deduced from the variation in the reluctance, which do not prevent us, of course, from assembling the efforts represented by tubes when these are considered component parts of the total effort.

STARTING CHARACTERISTICS AND CONTROL OF POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS[1]

(NORMAN)

NEW YORK, N. Y., FEBRUARY 10, 1926

B. F. Bailey: I should like to point out the use of the following formula

$$\eta = \frac{0.142 \times \text{Lb-Ft.} \times \text{Sync. Speed}}{\text{Volt-Amperes}}$$

in which η is the volt-ampere torque efficiency. By substituting the input to the motor in watts for the volt-ampere input we have the watt-torque efficiency. This formula is of course correct for any speed of the motor, although it is most useful in computing the starting efficiency.

In the case of a squirrel-cage induction motor the starting efficiency will usually be about 20 per cent. The wound-rotor induction motor will show higher values and a high-resistance; squirrel-cage motor still higher values. Split-phase induction motors have starting efficiencies of about 10 per cent.

This formula gives us a ready means of comparing the starting performance of different types of motors.

It can readily be shown that the starting torque of a polyphase motor expressed in synchronous watts is equal to the input to the rotor, but the demonstration is based upon the supposition that we have a rotating field which does not change shape as it rotates. In practise, the field does change its shape somewhat and in fact there may be backwardly rotating components of the field which directly subtract from the torque. In addition, there is some loss of torque due to bearing friction. The result is that the torque as measured by a brake is always somewhat less than the torque as computed from the input to the rotor. My experience has been that usually the actual torque will be from 85 to 90 per cent of the theoretical torque, although instances are common where somewhat higher or lower torques are developed.

K. L. Hansen (communicated after adjournment): Aside from containing useful suggestions and formulas, Mr. Norman's paper assists materially in advancing problems pertaining to the transient phenomena of acceleration and retardation from the rough approximation stage on to a sounder, mathematical foundation.

1. A. I. E. E. JOURNAL, February, 1926, p. 153.

Under the assumption of negligible resistance load, the author has found the secondary copper loss, when accelerating from slip s to slip S, to be

$$\text{Watt-seconds} = 0.00744\ (M\ I)\ N^2\ (s^2 - S^2)$$

And the primary copper loss to be the secondary loss multiplied by $\dfrac{r_1}{r_2}$.

In the October 18th, 1924 issue of the *Electrical World*, I published the following formula for the secondary copper loss: (on account of lack of space, derivation of formulas was not shown)

$$W_s = \frac{W\,G^2\,N^2\,(s^2 - S^2)}{4324} = 0.000231\ W\,G^2\,N^2\,(s^2 - S^2)$$

where the moment of inertia $W\,G^2$ is expressed in lb-ft. changing to poundal-ft. by introducing gravity acceleration 32.2, it becomes

$$W_s = 0.00744\ (M\ I)\ N^2\ (s^2 - S^2)$$

which is identical with the one in the paper. An interesting point in this connection which Mr. Norman does not seem to mention in his paper is that, when accelerating from standstill the secondary; loss is equal to the energy stored in revolving parts.

In discussing motors in intermittent service, I made the following statement in my article:

"Comparing (3) with (1), it will be seen that when a motor accelerates from standstill to synchronism, the secondary energy loss is equal to the stored energy and the primary loss is the stored energy multiplied by $\dfrac{r_0}{r_1}$. As the secondary loss is independent of, and the primary loss inversely proportional to the secondary resistance, it follows that the ratio of secondary to primary resistance should be as high as the rate of acceleration permits in order to reduce the energy loss of the system to a minimum."

It will be noticed that this paragraph covers substantially the discussion on the second and part of the third page in the paper.

It might also be of interest to know that I have used the author's speed-time formula and found it satisfactory in applications where the resistance load is small and the inertia load is high, as, for example, in centrifugal extractors. When there is an appreciable resistance load in addition to the inertia load, however, other formulas give better results.

P. L. Alger (communicated after adjournment): Mr. Norman has given us a complete synopsis of the starting behavior of an induction motor. As he points out, the object of studying starting conditions is to design the motor and the control so as to secure minimum losses at starting and a reasonable, but not excessive, factor of safety in design.

To bring out some of Mr. Norman's ideas more emphatically, there are two points which seem to be worthy of mention. Both of these points arise from the fact that a motor designed primarily for starting duty should have different characteristics from one designed for steady operation. In order to obtain the best starting torque per ampere, it is necessary to have a high rotor resistance, and, in order to obtain low starting losses, it is necessary to have a low primary resistance. These two things naturally result in the designer's making a starting motor with few primary turns and therefore with a very high magnetizing current.

A high magnetizing current results in an appreciable difference between the primary and secondary currents during the starting period. Though Mr. Norman suggests that this difference can be neglected, it is often quite appreciable. As Professor Bailey stated in his discussion of the paper, the torque efficiency, defined as the ratio of the starting torque as measured with a

brake to that as calculated from the copper loss due to the measured primary current and the measured secondary resistance, is usually appreciably below unity. If the secondary resistance used in calculating the torque is the apparent value obtained by dividing the primary input at standstill, less the primary copper loss, by the square of the primary current, the torque efficiency is 100 per cent. But if the true value of secondary resistance is used, the calculated value of torque will be too high, due to the secondary current being smaller than the primary current.

Thus, in the attempt to make a motor with good starting characteristics, the magnetizing current is exaggerated, and so the accuracy of the simple theory which neglects magnetizing current may be said to be less, the better the motor is for starting duty. Mr. Norman, also points out that the existence of eddy currents in the rotor during starting again makes the theory less accurate and generally requires some approximations to be employed in calculating the primary copper loss. These eddy currents are exaggerated, in the attempt to obtain high starting resistance and low starting current without too seriously impairing the running efficiency by the increasing employment of the double squirrel-cage type of winding. However, if a double squirrel cage is so designed as to obtain the maximum possible starting resistance with a given running reactance, expressions for the secondary resistance referred to primary of the form

$$\frac{R}{S} + \frac{S\,X_0}{1 + S^2},$$ and for the secondary reactance of the form

$$X + \frac{X_0}{1 + S^2},$$ may be employed in place of the simpler ones,

$\frac{R}{S}$ and X, and, with their aid, accurate formulas similar to Mr. Norman's may be derived for the time of starting and other characteristics.

H. M. Norman: In answer to Prof. Bailey's remarks concerning what he calls efficiency of the starting torque, I should say that there is nearly always a discrepancy between the measured starting torque by brake and that indicated by the watts loss in the rotor at start. The brake value is sometimes lower and sometimes higher than that given by the secondary loss. However, the average value obtained from a large number of different motors showed that there is only about a four per cent difference.

It should also be remembered that there is difficulty in measuring the input watts correctly, and also in estimating the proper value of the primary resistance (variation due to temperature) to use for calculation of the watts in the primary so as to obtain the correct watts loss in the rotor. In view of these difficulties, the best guide is the average of a large number of motors.

I think this is a very important point because it touches on the accuracy of the loss formulas in the paper. If it were true that this starting efficiency were appreciably below 100 per cent then the starting losses would be greater than the formulas in the paper indicate.

If there is no unbalance of phases, however, then it is my opinion that any adjustment of the constant 0.00744 in the loss equations need not exceed the addition of the four per cent already mentioned.

In reply to Mr. K. L. Hansen's remarks, I think it unfortunate that the same formula should have to be worked out independently at two different times, but in this case it has the comforting feature that we are both in exact agreement.

Regarding the fact that when starting from rest and accelerating to synchronous speed the secondary loss is equal to the stored energy of the system (this includes the energy of all the moving parts). I should like to point out that I purposely avoided mentioning this fact as it is subject to misuse for the following reason. Suppose that for a given system on account of the nature of the application the rotor of the motor has high resistance so that the full-load speed is say 90 per cent of synchronous speed. Then if the secondary loss be taken as equal to the stored energy of the system, it would be found to be 81 per cent of what it would have been had the system been accelerated to synchronous speed. This is not true, however, as the loss in the rotor under these conditions is equal to 99 per cent of this value.

This error is approximately equal to twice the full-load slip and even for low-resistance rotor motors is not altogether negligible.

Fig. 1 herewith gives a diagrammatic representation of the proportions of loss in the rotor of the motor and the stored energy of the moving parts. Consider a motor that has been accelerated from rest and has reached a speed proportional to $F\,C$ on this diagram where $F\,A$ represents synchronous speed. The area $F\,C\,D$ bears the same ratio to the stored energy of all the moving parts as the area $D\,E\,G\,F$ bears to the loss in the rotor. These areas become equal if the motor starts from rest and accelerates to synchronism so that for this particular case (*and this particular case only*) the loss in the rotor equals the stored energy of the moving parts.

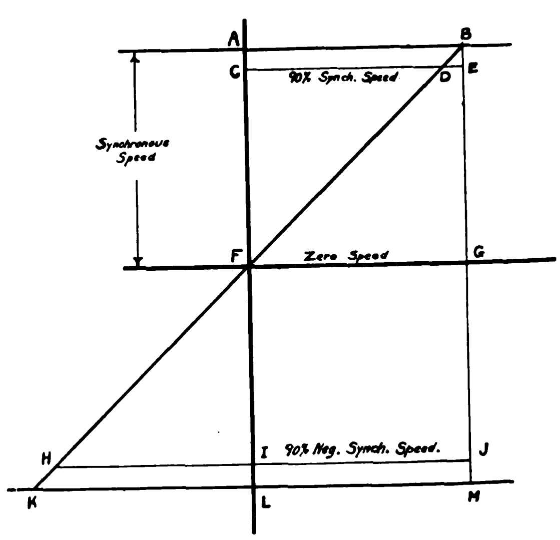

Fig. 1

This diagram also shows the ratio of lost and stored energy to the loss in the rotor when the rotor is plugged by extending the diagram into the negative-speed region. If a motor is running at say 90 per cent of synchronous speed and is plugged, the rotor reversing to 90 per cent synchronous speed in the reverse direction then, (referring to Fig. 1,) the energy lost in the moving parts by bringing them to rest is represented by area $H\,F\,I$, the energy gained by bringing the moving parts up to 90 per cent synchronous speed is represented by area $C\,D\,F$, and the energy lost in the rotor by area $D\,E\,J\,H$.

Referring to Mr. Hanson's statement that the short paragraph in his article covers substantially the discussion in part of my paper, I should point out that on the second page immediately following the loss formulas, I made a statement of approximately the same length and more or less equivalent to that in Mr. Hansen's article, and as I did not repeat myself in the subsequent paragraphs, I cannot see that his claim is well founded. Further, where there are only a few cycles of operation per minute I do not agree with Mr. Hansen's statement that the secondary resistance should be as high as the rate of acceleration will permit in order to reduce the energy loss to a minimum. This is neglecting entirely the losses during the running period. There are so many different cycles of operation that it is not desirable to

compile an abundance of formulas to give the best value of secondary resistance for each, but as there is one cycle which is perhaps the most common, I might add the following formula:

$$r_2 = \sqrt{\frac{0.00744\,(M\,I)\,N^2\,(1 - S^2)\,r_1}{\phi\,I_2^2\,t\,K}}$$

(For inertia starting loads only)

Where

I_2 = Secondary load current.

r_2 = Value of secondary resistance which gives the minimum losses over an entire cycle consisting of a start from rest to speed of $N\,(1 - S)$ and a full-load run for a time $= t$ (seconds) and a shut-down of any length of time. The constant is the ratio of effective resistance at start to that at full load and is slightly greater than unity.

The value of r_2 as obtained from this formula is for the load condition, $K\,r_2$ being the effective resistance at start.

Mr. Hansen seems to understand that I say that my speed-time formulas applied to all types of loading conditions. However, the method by which they were evolved, combined with the paragraph on the last page of my article drawing attention to friction or hauling loads, shows this impression to be incorrect.

In reply to Mr. Alger's statements, I should like to point out that the object of making the secondary resistance high for motors which are used for frequent starting is two-fold. It not only reduces the starting current, but also reduces the total losses during acceleration. The reduction of the primary resistance by means of reducing the primary turns has little or no affect on the starting losses, however, when measured in joules, and motors intended for frequent starting may sometimes be designed by changing the secondary winding only.

Motors to be used for special starting duty can be built with either a high rotor resistance, few primary turns to strengthen the field, or a combination of both, depending on the nature of the application.

If the starts are very frequent then the first method gives the best results as the starting losses are lowered and this results in a lowering of the total losses over a complete cycle of operation provided the rotor resistance is not increased excessively.

If the number of starts are very few and high starting torque is required on account of, say, excessive static friction, then the second method can be used provided the increased starting current is permitted and that low power factor is not of any great consequence.

When there are limits placed on the starting torque and current and the full-load power factor and efficiency, then the combination of more rotor resistance and fewer primary turns is used to meet these requirements. Again it may be used when the application requires high starting torque and a medium number of starts and stops.

From this it can be seen that the designer does not always use few primary turns.

Regarding Mr. Alger's statement that the use of few primary turns exaggerates the magnetizing current and so upsets the simple theory that during acceleration the primary and secondary current can be considered of equal value, I cannot agree. Neglecting saturation, the magnetizing current changes inversely as the turns squared. The starting current also changes in the same ratio. Therefore, the ratio of these currents is the same no matter what the primary turns may be. Should saturation be taken into account, then the consequent increase in current applies much more to the starting current than to the magnetizing current during acceleration because at start the main field is only one-half or one-third of its value at synchronous speed, while the leakage paths are saturated.

The difference between the primary and secondary current of the motor of average size and speed is about three per cent so that the value of the secondary resistance as given by formula (1) in the paper is about six per cent too small. Since the secondary loss (measured in joules) during acceleration is independent of the secondary resistance, then this error does not effect the rotor loss.

Now consider the primary loss during acceleration: the exact value could be obtained by multiplying the secondary loss in watts by the ratio of the primary resistance to the true value of secondary resistance and then by the mean square of the ratio of primary to secondary current over the starting period.

It so happens that this ratio of the mean square over the entire starting period is very nearly equal to the ratio of the square of the primary to secondary current at the instant of starting which is also the ratio of the true value of secondary resistance to the value obtained by using formula (1) in the paper. Therefore, by using formula (1) to get the secondary resistance and assuming the primary and secondary currents equal, very little error is introduced.

To illustrate how negligible this error is, consider a 50-h. p., 6-pole, 60-cycle motor. The ratio of the mean squares of the primary and secondary currents up to 90 per cent synchronous speed is equal to 1.041. The ratio of the true value of secondary resistance to that calculated by formula (1) is equal to 1.031, so

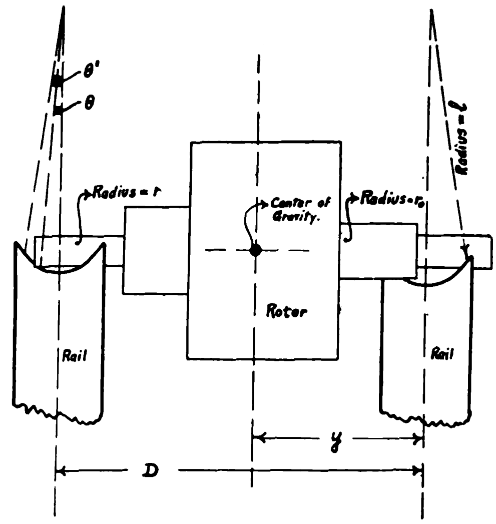

Fig. 2

that there is only one per cent error in calculating the primary loss. Consider an extreme case of a 50-h. p., 20-pole, 60-cycle motor with only 4¾ times starting current and 68 per cent full-load power factor. The ratio of the mean currents to 90 per cent synchronous speed is equal to 11.37 and the ratio of true to calculated secondary resistances is equal to 11.17 which shows that there is less than two per cent error even in this extreme case. From this it is obvious that it is sufficiently accurate to use the method given in the paper.

Mr. Alger seems to be under the impression that the work on reversing motors, in which I made correction for eddy-currents in the rotor, had something to do with a difference in the primary and secondary currents. This is not so; the reason for finding the primary loss by the method worked out in the paper was on account of a varying ratio between primary and secondary resistance while retarding the speed.

Regarding the statement that similar formulas to those given in my paper could be worked out for double-cage windings, I think that these formulas would be very complicated and therefore would not be extensively used. Further, it is doubtful if

such a motor would have any advantages over a high-resistance rotor motor as the higher full-load efficiency is misleading, the true guide being the total losses over a complete cycle of operation. Also there would have to be a decided advantage in favor of a double-cage winding to warrant its use as it is more complicated and expensive.

I should like to add the following formula which gives the radius of gyration for rotors which have journals with bearings of different diameter on each end. This measurment can be made by using the circular rails illustrated in Fig. 7. Squirrel-cage motors have usually the same diameter of bearing on each end but it is sometimes necessary to know the radius of gyration of other rotors. This can be done with the same equipment. Referring to Fig. 2 herewith

let

v = vel. of center of gravity of rotor.

R = radius of gyration radially (feet).

R_1 = radius of gyration about axis perpendicular to the shaft and through the center of gravity.

ω and ω_1 are the respective angular velocities.

Then gain in kinetic energy

$$= \frac{1}{2} M v^2 + \frac{1}{2} M R^2 \omega^2 + \frac{1}{2} M R_1^2 \omega_1^2$$

Loss in potential energy

$$= M g (\theta'^2 - \theta^2) \left[\frac{1}{2} \left(\frac{r_0}{r} \right)^2 (l - r_0) \left(1 - \frac{y}{D} \right) + \frac{1}{2} (l - r) \frac{y}{D} \right]$$

Substituting $\omega_1 = \omega \dfrac{r_0 - r}{D}$

$$\omega = \frac{l}{r} \frac{d\theta}{dt}$$

$$v = \left(\frac{D - y}{D} r_0 + \frac{y}{D} r \right)^{\omega}$$

Equating these two quantities and integrating gives:

$$R = \sqrt{\left(\frac{P}{2\pi l}\right)^2 g \left[r_0^2 (l - r_0) \left(1 - \frac{y}{D} \right) + r^2 (l - r) \frac{y}{D} \right] - \left[r_0 \left(1 - \frac{y}{D} \right) + r \frac{y}{D} \right]^2 - \left[R_1 \frac{r_0 - r}{D} \right]^2}$$

The term $\left[R_1 \dfrac{r_0 - r}{D} \right]^2$ can be neglected.

From this equation it can be seen that the short-cut method which suggests itself of taking the average of r and r_0 and then substituting in the formula given on the tenth page of my paper does not give sufficiently accurate results.

Discussion at Madison Convention

TESTS OF PAPER-INSULATED HIGH-TENSION CABLE[1]

(FARMER)

MADISON, WISCONSIN, MAY 7, 1926

W. S. Clark: In connection with the figures given in Mr. Farmer's paper, one should not lose sight of the fact that there is no insulation of which we know in which the strength increases in direct proportion to the increased thickness of insulation.

The company by which I am employed makes small static condensers or capacitors for power-factor correction. These are operated with a stress of about 300 volts per mil, the total thickness of insulation being about 4 mils. We have found that if we desire to increase the voltage from 1200 to 2400 volts on these condensers, to secure the same factor of safety and freedom from breakdown it is necessary to more than double the thickness of the insulation.

In a general way the strength of saturated paper insulation, assuming uniform quality, appears to increase only about as the 0.8 power of the thickness and not directly as the first power.

With reference to the test referred to in Mr. Farmer's paper, regarding formation of wax or X compound in oil, the test as at present specified apparently cannot be duplicated in different laboratories with the same material. When the test is brought to a condition in detail where it can be duplicated in different laboratories with the same results, then I think it will be good.

E. C. Willman: We noticed that the X compound was greatest at the surface and in the layers of paper nearest the conductor; that is, at the point of highest stress. We therefore attempted to form the compound by stressing petrolatum placed between variously shaped electrodes, but without success. With the thought in mind that occluded air might be responsible for the formation, we tried bubbling ozone through melted petrolatum. This did not produce any X.

Later we dissected a piece of badly wrinkled cable which had a deposit of X in the wrinkles in the lead,—the point of least stress,—and had only traces at the conductor. This led us to believe that the formation was due to electric stress in combination with rarified atmosphere. We then made up a Geissler tube of glass 8 in. long and ¾ in. in diameter. An electrode was sealed into one end and the other end was provided with a rubber stopper through which an electrode and a smaller glass tube were inserted. Some petrolatum was placed in the tube, which was then exhausted to 28 in. of mercury and potential from a one-in. spark coil was applied to the terminals of the tube. In a short time the peculiar granular structure of the X compound became apparent on the surface of the petrolatum. Its identity was established by chemical and microscopic tests.

D. M. Simons: To my mind, the outstanding point of this paper is Fig. 7. If the breakdown strength of three-conductor cables under long-time application of voltage is only half that of single-conductor cables, or even if it is considerably less than single-conductors while not being as low as this figure suggests, then this is a fact of outstanding importance in the cable industry. I am interested in it not only for its general bearing, but also because it is a point that the engineers of the company with which I am associated have been claiming for many years, especially in connection with the use of three-conductor Type H cable in place of the usual belted construction for the higher voltages, say, 22,000 volts and higher. This form of cable is of course equivalent in its electric field to three single-conductor cables under one lead sheath, and our claim has been that this form of cable would avoid many of the troubles that have been observed in the outer layers of conductor insulation and especially in the filler spaces of the usual form of three-conductor cable and joints when used in the upper range of voltage. It is very significant to have this effect confirmed in such a striking manner by Mr. Farmer.

Percy Dunsheath: Mr. Farmer referred to the relative importance of the cable and the other part of the installation. The cable is, after all, from a financial point of view, *the* part of an installation to watch for possible improvement with a view to cutting down the costs of development work.

One point I should like to make is that the first thing to do is to settle this question of acceptance tests. If we can arrive at a

1. A. I. E. E. JOURNAL, May, 1926, p. 454.

test that will prove quality, then I think quality will follow. If there has been any delay in improving quality, it has been because we have not known what we wanted and have not been able to recognize quality when it already existed. We are still using the standard pressure test in spite of the fact that after a cable has been pressure-tested in a factory, if it isn't a good length of cable, the pressure test may leave it on the point of breakdown and it is sent out of the factory in this condition.

Unfortunately, after the completion of these three papers we are not left with a clause which we can put into a specification,—an acceptance clause; but I think we are all agreed that the work, particularly Mr. Farmer's analysis of the time–voltage curve, does bring us very much nearer arriving at a clause of this kind. I don't know whether it has been done before (to me it is quite new) but I see that Mr. Farmer has analyzed the time–voltage curve into a number of component time–voltage curves, some for the bad parts of the cable and some for the good. I think that that is a very important observation to make because if a cable consists of a number of different parts, some with a low time-voltage curve and some with a high time–voltage curve, then a short-time, high-pressure test is a means of finding out weakness in the cable. If there is only one time–voltage curve for the whole cable, then a short-time high-pressure test can be carried out but it may be destructive.

Page 8 of Mr. Farmer's paper advocates adopting a standard load. Generally speaking I think that that is a good thing. If we could have a standard load which we could put onto any method of measuring losses,—dynamometer, bridge, or any other means,—and so arrive at a distinct, definite calibration, it would be a considerable step forward. I should suggest, however, that instead of the type of load which he proposes and which has to be measured, itself, we adopt a load which can be built up to a known power factor. I should suggest a condenser with negligible loss combined with a definite pure resistance.

On the eleventh page of Mr. Farmer's paper, those curves showing the variation of rising power factor with time are important and interesting and I am wondering whether the rise which he sometimes gets and sometimes does not get is due to a very slow increase of hydrostatic pressure. If so, possibly we can follow out that line with a view to getting an acceptance test, a cable which didn't give that original rise being a better quality than one which did.

Mr. Farmer describes the end which he uses for a three-conductor cable. I should just like to set forth a suggestion which I found useful in taking off ends for that type of test. To avoid the cost of a wiped joint, I have used ebonite cones about ½ in. thick, with a taped joint. Over the thickened dielectric on each core, I have carried tin-foil clear up to the crotch, with the result that no breakdowns can take place in the crotch. It is quite easy to bring an end of this kind to the highest voltage required.

I agree that the preparation of these samples is important. It is really astonishing the differences one can get on time—voltage tests on the same make of cable by first inverting the cable and putting the ends in oil, then turning the ends upward and putting on oil pockets. If anything should be standardized, it should be the method of making the ends. If an end is made which prevents the escape of any gases generated, up goes the time–voltage curve.

R. J. Wiseman: Referring to Fig. 1 of the paper, we find existing a rather interesting property aside from the wide variation in insulation resistance. The variation is very much greater for the compounds giving high values of insulation resistance.

Fig. 4, showing the distribution of failures for five-minute tests bears out what some of us believe; namely, that failure on a reel test is due to mechanical defects and will be detected with a reasonably high voltage. Too few tests are reported for 15 min. to be able to draw any conclusions. It is quite likely that Mr. Farmer is right, that, due to pre-testing by the manufacturer, failures on short time are eliminated before inspection.

Table I shows an improvement in breakdown voltage for each year; but there is still room for improvement. When the maximum dielectric strength at the conductor approximates the dielectric strength of a sample between flat plates we shall have reached the limit.

Figs. 5 to 10 inclusive are of interest in suggesting the limiting stress we can put on a cable indefinitely. At the present time, for methods of manufacture I believe 125 volts per mil is nearer the safety limit of operation than 150 volts per mil. This will give a factor of safety of about four or five on strength of material.

Mr. Farmer's suggestion of a standard load for checking dielectric-loss testing equipment is a very good one; besides the load he describes, I should like to advise his considering a load giving larger charging currents and higher power factors. I have found this important in making check tests on equipment.

A study of the change in power factor with time for different stress values is one of the best means to determine the aging quality of a cable. We would expect a slight increase in power factor for about 50 hours and then either constant or decreasing values.

I hope Mr. Farmer will be able to solve for us the proper manner of preparing samples of cable for high-voltage test. At present we do not get the real short-time breakdown voltage due to flashovers. Potheads are of great help but still not sufficient. The time consumed in preparing ends for test is enormous. Any means of reducing it and still permitting of higher voltages is welcome.

I should suggest that Mr. Farmer replot Fig. 30, using the maximum voltage stress at the conductor. Even though he may not think it accurate, he will get a better comparison of the test on cables and condensers for wax formation.

W. A. Del Mar: Unfortunately, the test for X which is described in Mr. Farmer's paper is open to the serious objection of giving discordant results. A case which came up quite recently was in relation to a barrel of compound which we had had in our laboratory for some weeks. We took out a sample which we designated A, divided it in two, sent half to the Electrical Testing Laboratories and kept the remainder ourselves. The Electrical Testing Laboratories sent back a report, "Abundant wax formation." Our laboratory, using apparatus as described in Mr. Farmer's paper, reported "none"; so we thought we would make a check test. We took another sample B out of the same barrel, again divided it in two, sending one part to the Electrical Testing Laboratories and keeping the remainder ourselves. They reported no wax and our laboratory reported considerable wax.

That bears out the general condition we have in our own laboratory; *i. e.*, we cannot obtain consistent results. We get X in a given compound perhaps in three or four tests in succession, and then, for some unknown reason, without any apparent change, the opposite result is obtained.

Even if the test can be perfected so as to be susceptible of unfailing check, insufficient evidence has been offered to connect the test with operating results.

Another interesting feature of Mr. Farmer's paper is the apparently greater dielectric strength of insulation on single-conductor cables as compared with triplex cables, as shown in his Fig. 7. This diagram, however, shows maximum stresses, as computed from the ordinary logarithmic formula. Recent researches by P. L. Hoover[2] have shown that the maximum stresses at failure cannot be derived from that formula, and that average stresses are a better criterion. As the average stress in a single-conductor cable is a much smaller fraction of the con-

2. *The Mechanism of Breakdown of Dielectrics*, by P. L. Hoover, A. I. E. E. JOURNAL, September 1926, p. 824.

ventional maximum than in a triplex cable, the discrepancy which is made to appear in Fig. 7 disappears.

F. A. Brownell: For testing purposes Mr. Farmer has pointed out the need of an end bell that could be constructed or connected in a minimum of time. This is one of our chief difficulties at the factories today and it seems that more time and thought should be given to this subject. We have used, with some modification, the end bell shown in Fig. 22 of Mr. Farmer's paper and have had very satisfactory results, the only objection being the time required for wrapping the conductors with varnish cambric. I believe this can be overcome by the use of the roll of tapered paper that the Pirelli Company used in making up the joints on the 45-kv. line of the United Electric Light and Power Company of New York City. This paper could be made up into rolls and placed over each of the three conductors and tightened. This would give a snug-fitting insulation and the crotch would be entirely filled. It may be that the taper of the paper would have to be changed somewhat to give the desired fitting.

F. M. Farmer: First, I desire to make two corrections. In the advance copy printing the note under Fig. 7 refers to Fig. 12. This should refer to Fig. 6. In the captions for Figs. 25, 26 and 27 the word "wax" was used. This is unfortunate, since the product produced is not wax in the sense that the term is used in industry. In fact it is quite different from any known substance familiar to oil technologists and has none of the characteristics of any variety of wax. Furthermore, it is not soluble in any of the ordinary solvents. Mr. Del Mar has suggested the expression X. In view of our lack of knowledge of this substance, this designation seems particularly appropriate.

From the tests which he describes, Mr. Willman implies that this deterioration is due to the action of ultra-violet light resulting from a sufficiently high electric stress across microscopic air voids in the compound. Whether this X formation is due directly to the application of stress or due to the action suggested by Mr. Willman, which, in turn, requires the presence of stress, is, from a practical standpoint, immaterial to the user. He is interested in knowing whether or not the compound in the cable remains stable under the conditions of use which involve only two variables, namely, stress and temperature.

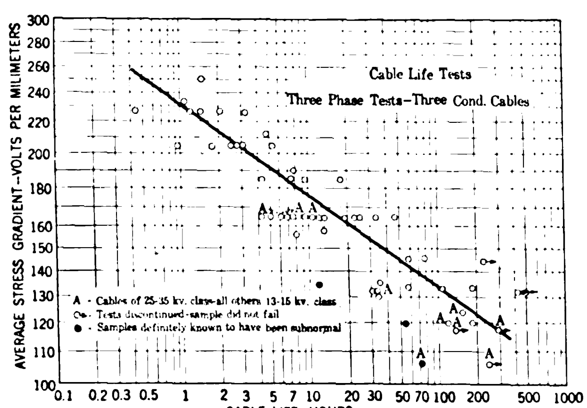

Fig. 6a—Cable Life Three-Phase Tests—Three-Conductor Cables

Mr. Del Mar has indicated that the test proposed for X formation is not dependable. It is probably true that it is not very sensitive where the compound forms X with difficulty so that X is formed at one time and not at another. Just why this variation occurs we do not know as yet but it is believed that the test being so simply and easily made justifies its use as a rough indicator of the probable performance of the compound.

Mr. Del Mar also raises the point that it has not been definitely demonstrated that this kind of deterioration in compound in a cable necessarily results in ultimate failure. This is true, but while we haven't positive proof that X in cable is objectionable, there is altogether too much circumstantial evidence available to justify engineers assuming that X is *not* objectionable. Since compounds can apparently be developed which do not form X and which are otherwise satisfactory, it seems only good engineering to avoid the use of X-forming compounds, even though we are not positive that they are objectionable.

Referring to Figs. 6 and 7, some additional data have been obtained since these diagrams were made and new diagrams are given herewith,—Fig. 6a corresponding to Fig. 6 and Fig. 7a

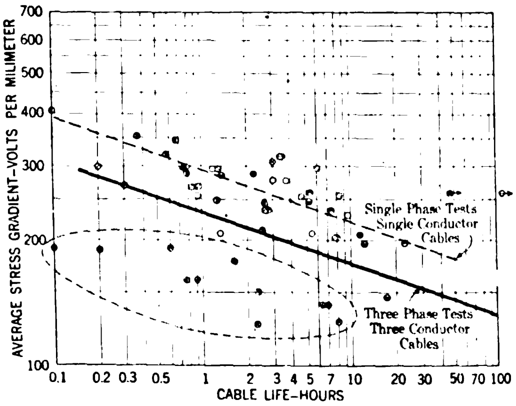

Fig. 7a—Cable Life Tests—Single-Conductor Cable

corresponding to Fig. 7. It will be observed that the slope is the same so that we are quite convinced that the seventh-power relation is approximately correct for at least the types of cable involved in these tests. Of course, if there is a pronounced change in the method of construction or in the kind of compound used in high-tension cables, the slope of these curves will undoubtedly be affected.

The point mentioned by Mr. Simons,—namely, the apparent superior showing of single-conductor cable over three-conductor cable,—is obviously of great importance; so much so, in fact, that a rather elaborate systematic investigation is being planned with specially constructed cable to determine the correctness or otherwise of this indication. Mr. Del Mar points out that if average stress instead of maximum stress had been used in preparing these diagrams, the apparent difference between single-conductor and three-conductor cables would have been less. This, of course, is quite correct. For instance, the average *maximum*-stress gradient to give a life of 10 hr. in three-conductor cable is 215 volts per mil and in single-conductor cable, 400 volts per mil, or an apparent increase of 86 per cent. The average *average*-stress gradient to give a life of 10 hr. is 175 volts per mil in three-conductor cable and 220 volts per mil in single-conductor cable or an apparent increase of 26 per cent. But which of these two bases is the true measure of dielectric strength of the cable as a whole? As we all know, there has been much discussion of this point and papers have been presented before this Institute giving evidence which apparently favors both of these gradients as well as intermediate ones. Eventually we shall have the true answer; and while it is highly probable that it will not be the maximum-stress gradient, it is also probable that it will be something higher than the average gradient. It seems reasonable to conclude, therefore, from the evidence presented here, that the inherent dielectric strength of single-conductor cable is on the average substantially higher than that of three-conductor cable and that the difference may be of the order of 40 or 50 per cent. However, as previously stated, this apparently large difference must be confirmed by further investigation before a final conclusion is justified.

Referring to Capt. Dunsheath's suggestion in connection with the proposed standard load for dielectric loss testing that various power factors be obtained by the use of series resistance, I should say that we have had this point in mind.

THE EFFECT OF INTERNAL VACUA[1]

(Del Mar)

Madison, Wisconsin, May 7, 1926

Wallace S. Clark: In connection with Mr. Del Mar's paper it should be remembered that the Pirelli idea is to keep in the cable, at all times, a pressure in excess of atmospheric pressure.

Percy Dunsheath: I think Mr. Del Mar has gone a little bit too far although probably not intentionally. I am rather afraid the impression that his conclusions will give is that all cables for high voltages should be supplied with oil ducts. I don't think he intended that and certainly I should resent any such suggestion, because I am sure that our experience with 33,000-volt cables, unhappy as it was years ago, today proves definitely and quite conclusively that a 33,000-volt cable can be made to give satisfactory service without oil ducts, whatever conditions of high voltages are called for.

R. J. Wiseman: Mr. Del Mar has presented to the public the views some of us have had for some time as to the effect of voids in cables. However, I think it would have been better if he had eliminated reference to atmospheric pressure. Voids are created in a cable due to the oil contracting as it cools and endeavoring at the same time to maintain a balanced pressure. This means that if a cable is sealed and the oil cools, it is below atmospheric pressure. A cable in operation with sealed ends is rarely at atmospheric pressure, usually above, and below only when cooled.

The size of voids in a cable will depend a great deal upon the type of oil and the freedom of motion. The size of the voids increases as we lower the temperature. This results from the capillary attraction of the oil to the paper. A tacky oil holds best and is likely to produce small voids rather than large ones, the latter being more objectionable.

Fortunately, shortly after a cable is installed at 0 deg. cent., it assumes the temperature of the ground and therefore heats up, eliminating most of the voids produced at low temperature. It is most desirable to load a cable up for a few days after installing it in order that the oil may become stabilized locally before making any voltage tests. Here the purchaser could help very well by actually putting a cable into service for a week and then making the acceptance test. This should be done on all high-voltage cables.

Take the case of the cables when they cool down after the load is removed, but the voltage is still on. Here it is advantageous that the dielectric loss be sufficient to heat the cable a few degrees, thus preventing the formation of voids. This brings out an important point. A reasonably low dielectric loss at low temperatures is preferable to a very low loss.

Creation of voids in joints is most probably due to the draining of the oil into the cable. It is not a case of stabilizing pressure, but rather improvement in cable impregnation. In such a case, the heating of the cable with load does not help the joint. The joint is on the way to failure unless refilled.

Herman Halperin: The impression is given in the paper that transient voltages cause many cable failures. In meetings of the A. E. I. C. Subcommittee on High-Voltage Transients on Underground Cable Systems, no information was given to show that transients cause any deterioration of the insulation. As expressed at a meeting of the subcommittee a few weeks ago, the opinion seems to be that the transients cause failures at unusually weak spots in the insulation; that is, the cable has usually been found obviously deficient at the point of failure, which cannot be said about cable failures in general.

1. A. I. E. E. Journal, July, 1926, p. 627.

The failures due to transients have generally been distributed over all parts of the underground systems, and rarely have they been located at any particular point, as may be inferred from the paper. This experience has been reported by several companies and is checked by the experience of the Commonwealth Edison Company.

In recent klydonograph investigations of surges on eight large systems, it was found that 85 per cent of the surges were less than twice normal voltage. About 1 per cent of the surges exceeded four times normal voltage, and it appears that surges must reach this magnitude to be disturbing. The latter surges may be slightly in excess of the full-reel test voltage at the factory. On the other hand, samples of high-tension cable will usually withstand test voltages of 7 to 12 times rated voltage of the cable for about one minute. The duration of the transient voltage is only a fraction of a second and Peck and others have presented data to show that the dielectric strength of insulation increases very rapidly as the time is reduced to a fraction of a second. One manufacturer has reported a case where the insulation withstood transient voltages of about three times the breakdown voltage he had been obtaining on dielectric-strength tests on samples. In regard to the decrease in dielectric strength on account of the higher frequency of the surges, it appears that this is more than counterbalanced by the increase in dielectric strength due to the shortness of the application of the transient.

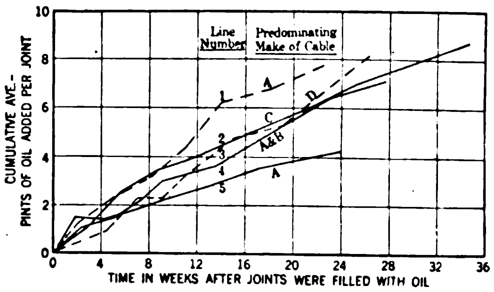

Fig. 1—Curve Showing Addition of Oil to 22-Kv. and 33-Kv., Three-Conductor Oil-Filled Joints With Insulation Formed

In general, with cable of high quality, such as indicated as being desirable in the paper on the Quality Rating of High Tension Cable by Mr. Roper and myself, evidence seems to show definitely that transients will cause no failures or have any deleterious effects on the insulation.

In regard to the point in the first paragraph of the paper, that sections upon removal from ducts will withstand severe high-voltage tests even though they have failed in service, the failure occurred at the spot of lowest quality. These weak and irregular spots have been found repeatedly in accelerated life tests in Chicago, and the experience has been that if a portion a few feet long were removed from a section of cable, the voltage rating of the section would then be increased from 15 per cent to over 100 per cent. In the last part of the paper, there are listed the essential characteristics for successful high-tension cable, but the item of uniformity is omitted, although experience shows that it is of paramount importance.

In connection with expansion and contraction incidental to the operation of cables and the consequent formation of voids, the Commonwealth Edison Company has had an interesting experience with oil-filled joints on several lines of 22- and 33-kv., three-conductor, impregnated paper-insulated cables with fair impregnation. The joints were filled with a switch oil having a viscosity of about 200 seconds (Saybolt) at 25 deg. cent. Periodically the joints were checked as to the level of the oil in them, and sufficient oil was added (or removed in a few cases) to restore the level to its normal plane. Fig. 1 herewith shows

the cumulative average number of pints of oil per joint added to these joints during the period of 5 to 8 months. In the average case, a total of about one gallon has been added in six months to each joint. This means that each length of cable had sufficient void space for one gallon of compound, which is sufficient compound to impregnate completely about 9 ft. of cable.

F. A. Brownell: Apparently Mr. Delmar's paper explains why so many of our cable failures occur during the off-peak when the cable is cooling or cool.

In 1923 we had 107 failures in our 13-kv. cables. Sixty-one of them could not be classified as to cause. Forty-two of this group failed during the early morning hours while the cables were carrying practically no load. Other years have shown similar results. If it is possible for vacua to form in our present cables at a temperature they would attain on an off-peak load, it would seem that this condition could be overcome by a rapid equalization of oil under pressure, the use of a less viscous oil than is used at present, and the installation of a reservoir on joints filled with the same oil that is used for impregnating the cables.

We have found the formation of X in cables operating at 26 kv., while in the laboratory it has required a potential of 100 kv., on the same make and type of cable before formation occurred. In cables impregnated with a rosin-content compound we were unable to produce it at potentials up to 210 kv. We have had cables that have failed in service operating at 26 kv. and have shown signs of ionization. This would indicate that the pressure in the cable must have been below atmospheric to have had ionization at this voltage.

D. W. Roper: Mr. Del Mar's theory seems to be borne out in a number of instances in our experience. He refers to the contraction of the compound in the cable; we have had a similar experience with compound in the joints. In some of our 33-kv. joints, we use a compound similar to that used in the cable; that is, a petrolatum. This particular line was operated practically without load for weeks at a time during the winter months. It was a tie line between generating stations and it was largely a reserve line on the generating capacity in the two stations.

After some weeks of operation during the winter season, we began to notice a bulging of the joints. We tried to discover the cause of this bulging, and as nearly as we could determine, it was due to the formation of small vacua or voids in the compound in the joint. Had this cable been operated every day at a load which would warm the compound up to the melting point, the voids, when they reappeared, would probably not have reappeared at the same location. You can find these voids if you will take a mass of compound, either in a can or a glass vessel, and expose it to low temperature; you will find small voids perceptible to the naked eye, distributed throughout the entire mass of compound. If you take a different kind of a compound which has more cohesion between the particles,—a more viscous compound,—then when the compound cools there will be more of a settling of the horizontal surface so that there will be a serious depression, but with a compound of this kind, there is no great amount of settling of the surface; the cooling occurs by the formation of these minute voids throughout the mass of the compound.

It appears that these small voids will occur now and then adjacent to the conductor insulation which is in the joint, and when these occur, the ionization, due to the discharge in the voids, will occur, and in the course of time these voids will enlarge. By careful examination of the joints when opened, we actually found some voids of approximately the size of the joint of the thumb, and adjacent to such voids, we found the evidences of ionization in the factory-applied insulation in these joints.

There was undoubtedly some pressure within these joints as shown by the bulging of the lead sleeve at the joint, although these lead sleeves were covered with broken cement, so that it not only stretched the lead sheaths but cracked the cement. The trouble has been cured by removing those joints so as to remove this petrolatum and refill with a thin oil. This is the oil referred to by Mr. Halperin in his discussion and diagram. No such trouble occurred when the joints were filled with oil; in fact, trouble could not occur in a thin oil which was so thin as to be fluid at even the minimum operating temperature of the cable. The nature of the compound used in the joint, as nearly as our experience shows, must either be fluid or be of a character which will not permit the formation of these internal voids throughout the mass of the compound.

T. F. Peterson: One must recognize that the burden of failures resulting from conditions characteristic of long jointed lines, must be borne by operating companies. Failure due to vacua in installed cable falls into this class. The following is submitted because it is thought that too much importance has been attached to this condition.

Spaces or air pockets in insulation may be due to:

1. Contraction of oil after impregnation
2. Expansion of lead due to bending
3. Contraction of compound due to cheese formation.

Mr. Del Mar makes no attempt to show the harmful effects of pockets containing gases at atmospheric pressure. Indeed he attaches no importance to these. Failures are considered to be due to the fact that *after* cables are installed, vacua are invariably produced, ionization takes place and ultimately failure results. This reasoning tends to exonerate the manufacture and shift cause of failure to a rather unfortunate condition with which operating companies must cope.

It is my contention that air spaces, even at atmospheric pressure, constitute a very important cause of failure (the action being somewhat slower than for vacua, nevertheless very pronounced) and since, in a large measure, they are due to causes 1 and 3, which are of manufacturers' concern, it follows that the latter must assume some part of the responsibility for failure. To substantiate this claim, consider the following:—Assume an air pocket at atmospheric pressure in a valley between turns of 5-mil paper; breakdown of this film, 0.0127 cm. thick, occurring at 68.3 kv. per cm. If the dielectric constant is assumed to be 3.5 the potential gradient in paper will be $\frac{68.3}{3.5} = 19.5$ kv. per cm. or 49.5 volt per mil. This is not an uncommon value for average gradient under operating conditions and so it appears that harmful results may easily result.

It remains, then, to explain the differences observed by the author between breakdown results on long and short lengths of cable. A partial explanation is given; namely, that of vacua. There is, however, another factor which tends to account for the results in-so-far as it assists the case of the short length. The latter is usually tested under oil where chances for reimpregnation are especially good; hence better test results.

The last paragraph of the paper gives ways of avoiding vacua. In the light of this discussion, it would seem that ways of diminishing possibilities of forming air pockets would have been a more appropriate subject for consideration.

W. F. Davidson (by letter): I am glad to note that Mr. Del Mar has attacked the problem of high-voltage cables from an angle which seems to be more in the direction of a real solution than many of our discussions of the "transient bugaboo." After all is said and done, our cables must be able to withstand such normal and transient voltages as do exist.

There is one phase of the paper which I wish to discuss; namely, the formula for this X or "cheese." When we have once definitely ascertained this factor we shall have made a long stride toward determining the true cause of its formation and definitely stating the effects of internal vacua, etc.

In the first place, I am surprised that it has been found possible to determine a chemical formula for X, because the original oils are known to be highly complex mixtures of several compounds and it is difficult to understand how we may be assured that the

resulting X is really one chemical individual. Until we have this assurance, a chemical formula has no significance. Possibly Mr. Del Mar can give his data.

In the second place, as I understand the processes of analysis used in such cases—assuming that we have proved the existence of a single chemical individual—we would obtain the oxygen ratio by determining what was left after the hydrogen and carbon have been determined. This should give a definite value for n.

Finally, we have no evidence presented to substantiate the statement that "it is apparently highly polymerized." Here it is necessary to assume again that the substance is a chemical, individual for it is usual to ascertain the degree of polymerization by determining the molecular weight; and a mixture of several chemical substances cannot have a single molecular weight. But even so, the determination of molecular weight seems almost impossible in the case of a solid substance which is non-volatile and almost insoluble.

J. A. Duncan (by letter): Mr. Del Mar's formula $(C_{12}H_{28}O)_n$ is of special interest to those of us who have been studying the deterioration of impregnating compounds and it is this formula which I wish to discuss. In order to include all possible interpretations of such a formula, one must discuss all possible values of n. This means all values of n from plus one to plus infinity, since zero or negative values have no meaning.

Let us begin with the case n equal to unity. The formula is then $(C_{12}H_{28}O)$, which is very remarkable, because 26 atoms of hydrogen alone completely satisfy all the available valency bonds in a single molecule of 12 carbon atoms and it is difficult, if not impossible, to imagine how the other two hydrogens and one oxygen are attached to the molecule. The straight chain structure in normal paraffins contains the maximum number of hydrogens possible if we attribute to carbon the valency four which, I believe, has always been found to be its maximum value. It is seen from the diagram of a paraffin (dodecane for example)

$$\begin{array}{cccccccccccccccc}
 & H & H & H & H & H & H & H & H & H & H & H & H & H & H & \\
H- & C- & C- & C- & C- & C- & C- & C- & C- & C- & C- & C- & C- & C- & C & -H \\
 & H & H & H & H & H & H & H & H & H & H & H & H & H & H &
\end{array}$$

that the maximum number of hydrogens per molecule is two plus twice the number of carbons. No carbon except the two at the ends of the chain can hold more than two hydrogens because two of its four bonds are occupied in holding the chain together. Each of the two end atoms holds three hydrogens.

The only way for a paraffin molecule to increase its oxygen content is for an oxygen atom to replace two hydrogen atoms or for a hydroxyl group O H to replace one hydrogen atom. In the former case, the hydrogen content is decreased and in the latter, it remains the same. If one O H group replaces a hydrogen in $(C_{12}H_{26})$ we should have $(C_{12}H_{26}O)$.

If one oxygen atom alone is placed within the molecule, it must replace two hydrogen atoms in order to find bonds for its two valencies. This would give us two hydrogens less than we had to begin with and the formula would be $(C_{12}H_{24}O)$.

It is thus highly improbable that one can have a compound with the formula $(C_{12}H_{28}O)$

If n had any value greater than unity, the case would be even worse because this would mean a molecule consisting of two or more groups of $(C_{12}H_{28}O)$ and one valence bond of each group would be occupied in holding the two together. The possible number of hydrogens too would be still further decreased. One of the first two terms of the formula must be incorrect or Mr. Del Mar has a new arrangement of the oxygen atom with valency greater than two or a carbon atom with valency greater than four. The only case I've ever heard of before where oxygen has a valency greater than two is in the so-called oxonium compounds; and I think it is true that the science has never known a case of carbon with valency greater than four.

Of course, Mr. Del Mar may not mean his formula as that of a chemical individual, but merely gives it to indicate the proportions of carbon, hydrogen and oxygen in a mixture of substances which he found in a cable. If we allow mixtures, we can mix the original oils in the cable in many ways which would give us any specified ratio of carbon to hydrogen from the ratio one-to-four to the ratio infinity; and we could add air, moisture, or moisture and air, to take care of any amount of oxygen from zero to whatever number of oxygen molecules there are in a cable.

It is fairly well known that mineral oils usually used in cables consist of mixtures of several hydrocarbons of various carbon contents.

For example, suppose we had any number of molecules of normal hexane C_6H_{14} and half of the same number of oxygen molecules in a mixture which we shall call A. The proportions of carbon, hydrogen and oxygen would be 12 to 28 to 1 as Mr. Del Mar indicates.

Or suppose we had any number of molecules of normal dodecane $C_{12}H_{26}$ mixed with an equal number of water molecules H_2O. Let us call the mixture B. The proportions of carbon, hydrogen and oxygen would again be 12 to 28 to 1.

Any mixture consisting of any amount of A with any amount of B would obviously still have carbon, hydrogen and oxygen in the proportions 12 to 28 to 1. Such a mixture we should properly call X, following Mr. Del Mar's happily selected notation.

Let us assume a cable oil with 0.1 per cent each of hexane and dodecane. One gram of this oil would contain 0.001 gram of each substance. Let p be the actual number of molecules of hexane and q the number of molecules of dodecane in 0.001 gram. Then

$$p = \frac{N}{86.112 \times 1000}$$

and

$$q = \frac{N}{170.208 \times 1000}$$

where N is Avogadro's number, Millikan's value of which is $(6.062 \pm 0.006) \times 10^{23}$ and 86.112 and 170.208 are the molecular weights of the two substances. One can have then a mixture of any number of molecules from (1 to p) of A with any number from (1 to q) of B and still have the proportions of carbon, hydrogen and oxygen indicated by Mr. Del Mar. The number of possible different kinds of X, no two of which are identical and each of which would fit Mr. Del Mar's formula is

$$p \times q = \frac{N^2}{86.112 \times 170.208 \times 1000 \times 1000}$$

or

$$p\,q = 2.5 \times 10^{37}.$$

The formula indicates no way except by guessing to tell which of the possible mixtures it represents. If each of the one hundred and ten million people in the United States would make a thousand guesses a day for fifty years this would be 2×10^{15} guesses. The chance of one of these guesses coinciding with Mr. Del Mar's X is a little less than one in 1.25×10^{22} or in other words one in twelve and half thousand billion billion and the guessing would be further complicated by the 99.8 per cent of the oil which we did not consider specifically in the above p and q.

C. F. Hanson (communicated after adjournment): In some localities, high-voltage cables operate at relatively low temperatures. From the point of view of dielectric loss and the possibilities of cumulative heating, these low temperatures of operation are considered favorable. However, from the point of view of internal vacua, these low temperatures are detrimental, if the cable is not permitted to "breathe."

The conditions upon which I base my calculations in arriving at the foregoing conclusions are as follows:

1. The maximum operating temperature of the cable insulation during summer months is 40 deg. cent. (104 deg. fahr.)

2. The minimum operating temperature of the cable insulation during winter months is 20 deg. cent. (68 deg. fahr.)

3. The temperature of the cable insulation at the time of installation during summer months is 30 deg. cent. (86 deg. fahr.)

4. The temperature of the cable insulation at the time of installation during winter months is 15 deg. cent. (59 deg. fahr.)

5. It is assumed that an internal pressure of one atmosphere is established throughout a length of cable while the ends of the cable are open for splicing purposes.

6. The impregnation of the cable is expressed in terms of per cent of air by volume based upon the total air in the cable prior to impregnation. The air content is considered to be that which prevails at 25 deg. cent. (77 deg. fahr.)

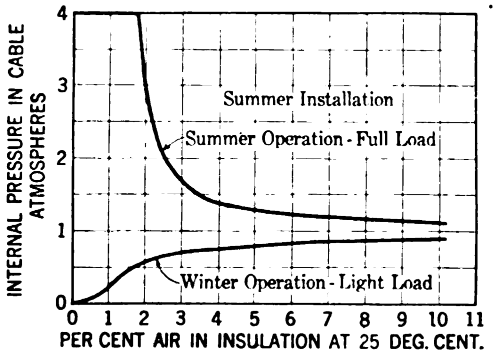

Fig. 2

7. The temperature coefficient of expansion of the impregnating compound is considered to be 0.1 per cent per deg. cent.

8. The internal pressure in the cable which will cause a permanent stretch in the lead sheath is considered to be 4 atmospheres. (Approximately 44 lb. per sq. in. gage pressure.)

9. The impregnating compound and the fibers of the paper are considered incompressible.

10. The temperature coefficient of expansion of the lead and of the copper is considered negligible, particularly in view of the fact that an expansion in the lead is partly counteracted by a simultaneous expansion in the copper conductors.

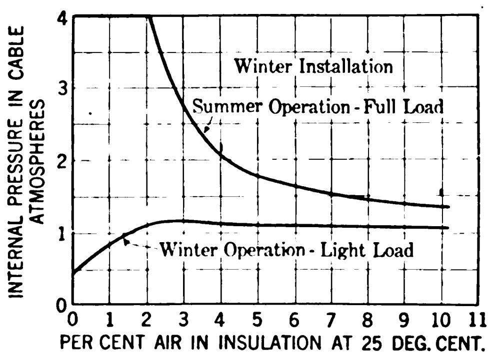

Fig. 3

11. A length of cable is considered sealed at each end by virtue of a non-flowing splicing compound.

12. The volume of air varies according to Boyle's law in regard to pressure.

13. The volume of air varies according to Gay-Lussac's law in regard to temperature.

Within the foregoing conditions, I have calculated for various percentages of air, the internal pressures which will prevail in a cable during maximum load in the summer and during minimum load in the winter when the cable is installed during summer months. The results of these calculations are shown in Fig. 2 herewith. I have also made corresponding calculations for a cable which is installed during winter months, and show the results in Fig. 3.

In Fig. 2, the lower curve shows that the internal pressure of the cable is always less than atmospheric during light loads in winter. If the ionization voltage of air is proportional to the pressure, then it is evident from this curve that a poorly impregnated cable is superior to a well impregnated cable. For example, if, in a cable of a particular wall and voltage, the ionization pressure is 0.8 atmosphere, then the cable having an air content of five per cent or more would operate without ionization. On the other hand, the cable having an air content of less than five per cent would operate during winter months with ionization which will produce carbonization.

If cables are installed during winter months, then operating conditions are more favorable in regard to internal pressure. A cable would have to be well impregnated before its internal pressure would be less than one atmosphere during winter operation. For example, only those cables having an air content of less than 1.5 per cent would have an internal pressure of less than one atmosphere during light load in winter. The reduced pressure in this case is brought about by a permanent stretch in the lead sheath. The permanent stretch is produced during heavy-load periods in summer.

A comparison of Figs. 2 and 3 indicates that when non-flowing splicing compounds are used, winter installation is more desirable than summer installation. Furthermore, the curves in these illustrations, indicate that cables deteriorate mostly in winter, particularly if the cables are installed in summer.

It is not advocated that cables should always be installed during winter months. Winter installation is only a means for partly alleviating the unfavorable conditions caused by the use of non-flowing splicing compounds. The proper installation is that which will permit a cable to "breathe" as the temperature of the cable changes. Such installation is exemplified in the present-day use of very liquid splicing compounds and the application of syphons.

W. A. Del Mar: The principal discussion of my paper has taken place in the personal meetings and correspondence before and since the Madison meeting, and I have been surprised and gratified by the great interest manifested.

As I intimated in my paper and as repeated by Mr. W. S. Clark, there is nothing new in the basic ideas presented, but the implications which bear on ordinary cables seem to have been ignored almost completely by operating men and manufacturers alike. If any manufacturer had these ideas clearly in mind, his duty to the industry was to pass them on without delay to the cable users. So far as I know, this was done for the first time when I gave copies of a memorandum on this subject to several members of the Underground Systems Committee of the N. E. L. A., nearly a year ago.

We all recall the classic 1919 papers by Shanklin and Matson,[2] and Dubsky,[3] wherein it is shown that films of air entrapped in a cable ionize at an insulation stress of about 19 kv. per cm., but perhaps we neglected to note, as the three authors named above were silent on the subject, that this stress applies to air at atmospheric pressure only.

We recall, moreover, the work of such experimenters as Peek, proving that the ionization stress of air is approximately proportional to the air pressure.

Combining these researches, we obtain Table I, showing the

2. Transactions A. I. E. E., 1919, p. 489.

3. Transactions A. I. E. E., p. 537.

relation between ionization stress in cable insulation, and air pressure.[4]

We are now equipped with an important tool which, in our hands three years ago, might have saved the electric power industry and the cable manufacturers a considerable amount of worry. In order to understand this, consider the matter in Table II, which shows the maximum stresses for several typical triplex cables and the air pressures required to prevent ionization at these stresses, taken from Table I. The table may be summarized in a few words:

Cables of the 13,000-volt class do not ionize even though the pressure may be somewhat below atmospheric.

Cables for 22,000 volts have an ionization pressure of about one atmosphere.

Cables for all higher voltages as listed require an internal pressure of between one and two atmospheres. This is a conclusion of great importance which seems to have escaped the attention of the industry. It is well known that cables for over 22,000 volts belong in a different class, from an operating standpoint, from those for lower voltages. The former have had either excessive failures or at least show deterioration of the insulation, except in a small minority of cases. The latter give little or no trouble.

TABLE I

Air pressure, atmospheres	Relative ionization voltage as fraction of that at 1 atmosphere (Peek)	Ionization stress taking 19 kv./cm. for 1 atmosphere
0.1	0.2	3.8
0.2	0.3	5.7
0.5	0.53	10.0
0.7	0.70	13.3
1.0	1.00	19.0
1.25	1.22	23.2
1.50	1.44	27.4
2.0	1.90	36.1
2.5	2.35	44.7

TABLE II
TRIPLEX 350,000-CIR. MIL CABLES

Working voltage between phases, Kv.	Insulation each conductor, 64ths in.	Maximum stress, kv./cm.	Internal pressure required to prevent ionization, atmospheres
13	12	16	0.8
13	9	19	1.0
22	19	20	1.0
22	18	21	1.1
24	18	23	1.25
26.4	18	25	1.35
27.6	19	25	1.35
33	19	30	1.65
33	23	26	1.40

Similar information for single-conductor cables is given in Table III, from which it appears that cables for 132-kv. circuits with 60/64-in. insulation require about 3½ atmospheres, which is near the limit of strength of an ordinary lead sheath.

It is also a curious fact that the trouble seems to increase the more carefully the cable is made. This is because of the difference in impregnation; the more thorough this is, the greater the vacua due to contraction. This has been very clearly brought out by Mr. Hanson's discussion. For this reason, some of the cables of five years ago seem to be more reliable than those of today.

4. If the air films are very thin, this relation does not hold; but experience shows that it is approximately correct for most of the films of the dimensions found in cables.

The effects of ionization in the order of their occurrence are—formation of *X*, carbonization of oil, formation of dendritic patterns, and eventually failure. The action may, however, stop at any point, as cables are in operation which have been full of *X* for years and carbonized oil has been known to exist for years in cables without further deterioration, probably because of increased internal pressure.

Let us consider what has been done by operating engineers to influence the internal pressure of high-voltage cables.

First, they have written specifications which compel the furnishing of "over-saturated" cables, *i. e.*, cables in which high vacua are formed if operated as they have been in the past.

Second, they have done most of their installation work in summer, thereby insuring the occurrence of vacua in winter.

Third, until recently they have used splicing compounds which seal each length of cable and make pressure equalization impossible.

Fourth, they have given no consideration to the installation and operating conditions which influence internal pressure, thereby leaving the pressure to take a chance value which might or might not permit their cable to survive.

It seems necessary to put a definite predetermined pressure on high-voltage cable insulation and maintain it with scrupulous care. Forward-looking practise points to the use of spindle oil splices and syphons. I believe that by this means some cables which have had their operating voltages lowered due to continual failures will be successfully restored to their rated voltages.

TABLE III
SINGLE-CONDUCTOR 500,000-CIR. MIL CABLES

Working voltage to ground, Kv.	Insulation, 64ths in.	Maximum stress, kv./cm.	Internal pressure required to prevent ionization, atmospheres
23	40	24	1.3
26	40	27	1.5
43	52	38	2.1
43	60	35	1.9
76	60	62	3.4

When all high-tension cables are equipped with pressure gages and pressure-maintaining devices, the guarantee clauses in cable specifications will assume a legitimate significance. Mr. Petersen sensed this point very clearly in his discussion.

I agree with Mr. Dunsheath that all high-tension cables do not have to be supplied with special oil ducts, as it is possible to maintain adequate pressure in most cases by relying upon natural interstices in the cable.

My paper supports Mr. Halperin in his views about transient voltages, by furnishing an explanation of certain failures which, in the past, have been blamed on transients.

Mr. Petersen's explanation of the higher breakdown voltage of short lengths as compared with complete feeders,—namely, that oil from the terminal tanks is sucked into the cable,—cannot be correct, both because the opposite action occurs due to the heating of the cable, (*i. e.*, the cable oil is expanded and driven out), and because the same relation holds if the short lengths are tested without oil terminals or tanks.

Mr. Brownell has brought out an interesting point in mentioning that *X* forms more readily at 26 kv. in service than at 100 kv. in the laboratory.

Mr. Davidson seems to have taken my formula for *X* more seriously than I had intended. I used a formula only because the results of analysis as percentages are hard to visualize. The

evidences of polymerization are to be found in high specific gravity, solidity, insolubility, and infusibility considered in connection with the known origin of the material.

Mr. Duncan's discussion of my formula for X is very much to the point. He shows clearly that the suggested formula is untenable, and I am rather inclined to believe that the explanation is that the oxygen atom is superfluous. We can now form X in such vacua that it seems that no atmospheric element can enter into its composition. The chemists obtained the oxygen by difference and not by any positive test, so that its existence is at least open to doubt. The formation of X is preceded by an apparent increase of surface tension, *i. e.*, the oil acts as if its surface tension had increased very greatly, causing it to form into drops. Perhaps the polymerization which characterizes X formation is a result of this surface tension; *i. e.*, it may be nothing but a further drawing together of the molecules.

Mr. Roper's and Mr. Halperin's discussions add important material to our general store of knowledge on this subject. There are more of this kind of data which bear on pressures and vacua in cables to be gathered from the experience of operating engineers. For instance, it has been found that splices which are equipped with unweighted syphons have a lower breakdown voltage than identical splices without the syphons, and some people would interpret that as indicating that the syphons might be an objectionable feature. The explanation as furnished by one of the earliest users of syphons is that splices tested with them are at atmospheric pressure inside, whereas those tested without them, being heated by the dielectric losses, have an internal pressure which may be very considerable. The internal pressure naturally increases the dielectric strength and raises the breakdown voltage at the splice. The obverse of this is seen in the trouble experienced with both cables and joints where vacuum joints have been used.

A full realization of the significance of cable vacua and pressures should materially assist in the design of cables for much higher voltages than now considered practicable, without departing from the diameters which ducts and handling difficulties now impose.

Discussion at Niagara Falls

CIRCULATION OF HARMONICS IN TRANSFORMER CIRCUITS[1]

(Lennox)

Niagara Falls, N. Y., May 27, 1926

D. C. Prince: There are, in general, two ways of regarding such waves as those set up by commutating devices whether of rotating or static character. Fig. 4, in Mr. Lennox's paper, is typical of the waves encountered. Such a wave may be regarded as made up of a series of constant-amplitude waves of different frequencies, as Mr. Lennox has done, or it may be regarded as a succession of simple states.

From this latter point of view, the wave shown consists of direct-current portions joined by portions of constant slope. Both these states must independently obey Kirchoff's laws. This enables the wave forms, at least in the simpler networks, to be made up, taking into account the various impedances.

In particular, the transition portions of rectifier waves have as their driving force the impressed sine-wave so that the transition currents are sine waves of fundamental frequency superimposed upon either steady or decaying direct currents. These lend themselves readily to quantitative analysis where the harmonic analysis may present some difficulty.

From the point of view of inductive interference, some error may be invited if the analysis method is used. For instance, a square wave under harmonic analysis may give waves of all frequencies which are multiples of the fundamental. Some of the frequencies with the indicated amplitudes might set up objectionable interference. Physically, however, the inductive effect is in the form of impulses sent out at half-cycle intervals. These impulses set up a series of damped wave trains in a resonant circuit or simply a series of pulses in a circuit damped beyond the critical point. Neither of these responses is necessarily objectionable. The difference is that, when a wave is analyzed, the effect of all the components must be included. Many of these will have cancelling effects which might be lost sight of in treating any given problem by harmonic analysis.

A FLUX-VOLTMETER FOR MAGNETIC TESTS[1]

(Camilli)

Niagara Falls, N. Y., May 27, 1926

R. L. Sanford: For the determination of the average value of an alternating electromotive force a rectifier of some kind is necessary. While somewhat difficult to keep in good working condition, the rectifying commutator, either mounted directly on the generator shaft or driven by a synchronous motor, has been, up to the present time, the only satisfactory apparatus for the purpose. The commutator has a number of disadvantages which are obvious to any one that has had occasion to use it and the development of a really satisfactory method for measuring average volts represents a distinct advance in the art.

The device described by Mr. Camilli has the advantages of simplicity and portability. While the evidence of its reliability presented in the paper seems to be fairly conclusive, it was felt that a really crucial test would be a direct comparison with the rectifying commutator using a sine wave of voltage and also with various degrees of distortion. This was done at the Bureau of Standards. In making the test, the commutator brushes were adjusted for rectification at the zero point on the wave and its condition was checked by noting that the reading of an a-c. voltmeter was the same whether connected to the source directly or through the commutator. The average volts were read by means of a Brooks deflection potentiometer and a volt-box. Simultaneous readings were taken by different observers with the potentiometer and the flux voltmeter, and the values in all cases agreed well within the limits of the allowable error. It appears, therefore, that the flux voltmeter measures average volts with a satisfactory degree of accuracy and should prove to be a very useful instrument for a number of purposes.

As pointed out by Mr. Camilli, the total core loss with a distorted wave is somewhat high, as the eddy-current loss is proportional to the square of the effective voltage rather than to the average voltage. He has indicated an indirect method for making the correction. It would appear better, however, to determine the correction directly by making measurements with different degrees of distortion, noting the effective voltage in each case. The correction can then be made by simple calculation. This method has the advantage that no assumption as to the ratio of eddy currents to hysteresis is necessary.

W. H. Cooney: Any one who has endeavored to obtain a given core loss twice on the same transformer when using different generators on each test with consequent variations in wave form will appreciate the development of a meter which will give consistent results regardless of how distorted or how near sine wave the wave form is.

In the past, many core-loss correction outfits have been based on setting voltage by an a-c. voltmeter, thus getting the r. m. s. value. Since, as Mr. Camilli pointed out, only the eddy loss is a function of the r. m. s. value, the correction which had to be made was almost entirely in the hysteretic component. That this was not the proper end from which to tackle the problem can be realized by considering the general proportion of hysteresis and eddy losses.

1. A. I. E. E. Journal, August, 1926, p. 755.
1. A. I. E. E. Journal, October 1926, p. 989.

Eddy losses are very rarely more than 20 per cent of the total loss and are usually much less. By the use of this scheme, which holds the average voltage corresponding to the effective sine-wave voltage desired, the correct hysteresis loss is maintained and the correction need be made only on the eddy component, which, as has been said before, is comparatively small.

Some of the previous core-loss corrections consisted essentially of a small "standard" transformer excited in parallel with the transformer under test, and one of two methods was used: (1) The available voltage was varied until the "standard" transformer held the desired core loss; or (2) the available voltage was adjusted to the desired root-mean-square value (regardless of the wave form) and the loss of the transformer under test was corrected in the same proportion in which it was necessary to correct the "standard" transformer in order to put the latter on a sine-wave basis.

The objections to the use of a small "standard" are quite apparent. The chief objection is that the "standard" is very seldom at the same density as the main transformer and thus is not operating on the same part of the density-loss curve which has a decided "knee" in it. It is necessary to maintain all sorts of calibration curves with the increased liability of introducing errors. There is finally the general objection that a small model in tests of this sort cannot be expected to duplicate the phenomena occurring in large apparatus.

The only correction which needs to be applied to this meter (for eddy loss) can be made very easily, as very few calibration curves will be necessary since the division of hysteresis and eddy losses can be determined closely enough for any given line of steel. The only possible case in which this meter will be inaccurate is where the wave goes through zero more than twice in a cycle, and this should never occur in commercial testing.

Aram Boyajian: The simplicity of the theory, construction and method of application of the flux voltmeter may tempt us to underestimate the excellent engineering which has been incorporated into this outfit. It is true that such parts of the outfit as d-c. voltmeters and vacuum-tube rectifiers have been available separately, and it is also true that the mathematical relation between maximum flux density and arithmetical average voltage has been known to the electrical art for a long time. It remained for Mr. Camilli, however, to bring together the theory and these pieces of apparatus into an outfit which accomplishes a new function in a new and very satisfactory manner. The accuracy and consistency of core-loss tests made with the aid of this outfit are surprisingly good, especially in comparison with the older schemes. The extent to which the older schemes underestimate the core loss under conditions of bad wave distortion will no doubt interest very strongly inspectors on acceptance tests as well as those engineers who draw up specifications.

T. C. Lennox: I should like to point out the advantage of this device for determining the core losses in interphase transformers for rectifiers. These interphase transformers have voltages which are not of sine-wave form and furthermore have different wave forms for different conditions of load so that it is difficult to obtain loss measurements which are representative of actual losses under load. The flux voltmeter could be very easily applied to obtain the actual flux densities under load conditions and thus aid greatly in obtaining a correct measurement of the efficiency of the equipment as a whole.

CURRENT TRANSFORMERS WITH NICKEL-IRON CORES[1]

(Spooner)

Niagara Falls, N. Y., May 27, 1926

I. F. Kinnard: In the design of current transformers, it has long been recognized that a core material having low losses and high low-induction permeability is desirable. It is undesirable, however, to have the permeability of a transformer core changing very rapidly over its working range.

Wonderful strides have been made in perfecting magnetic materials in recent years. The material described recently by Messrs. Arnold & Elmen[2] known as "permalloy" has properties which recommend it very highly for the use Mr. Spooner has outlined. Mr. Spooner has not given us any specific magnetic or metallurgical data on hypernik, but it probably can be assumed that it is very similar in its properties to the series of iron-nickel alloys described by Yensen[3].

Permalloy in particular, and, to a lesser degree, other iron-nickel alloys, partially fulfill the requirements of an ideal core material. The reason they do not more completely fulfill these requirements is largely due to their rapid change in permeability. In fact, at a fairly low induction the permeability falls off so rapidly that the accuracy of the transformer is seriously impaired, as pointed out by the author. This is particularly troublesome in the through-type or bushing transformers where the operating density is necessarily high with secondary burdens usually met with in practise.

It is to be hoped that further improvement may make it possible to utilize the remarkable properties of these various alloys to greater advantage; that is, that their range of usefulness may be extended to transformers having less than 200 ampere-turns which will operate secondary burdens up to at least 15 or 20 volt-amperes.

I am interested in Mr. Spooner's description of utilizing the coordinate a-c. potentiometer for measuring the magnetizing and watt components of the exciting current. This is a big improvement over most methods used in the past. I believe it is possible to extend this general method so that a strictly null setting may be obtained and the possible accuracy made even greater. We must not lose sight of the fact, however, that the real criterion of a transformer's performance is the precision measurement of its ratio and phase angle.

Several laboratories are equipped to measure these quantities directly to a higher degree of accuracy than we can hope to reach by their calculation from a knowledge of exciting current and magnetic properties.

W. K. Dickenson: The ideal toward which every instrument-transformer engineer is working is to obtain a minimum error in the ratio of transformation of voltage or current, particularly that part of the error commonly called the phase angle, which is caused by the secondary voltage or current not being in exactly 180-deg. phase opposition to the primary voltage or current.

In current-transformer design, this has usually been accomplished by the use of a relatively high number of ampere-turns (usually 1000 to 2000) and by a considerable cross-section of core iron. This materially limits the use of the through-type or single-turn-primary type of transformer, since, as there is only one turn available, the current has to be 1000 amperes or more to give a sufficient number of ampere-runs for a good transformer.

A very considerable improvement in the characteristics of transformers, particularly current transformers, has been obtained by the now very common use of silicon steels. It is very encouraging to note the further improvement in both the ratio and phase-angle errors by the use of high-permeability steels, such as hypernik and other nickel-alloy steels, such as nicaloi or permalloy. Mr. Spooner has shown that not only can the ampere-turns be reduced (he states a minimum of 200 ampere-turns) but the weight of core can also be reduced by the use of hypernik.

As pointed out by Mr. Spooner, however, it is to be regretted that only low secondary burdens may be operated by transformers having cores of these nickel-alloy steels, because of their characteristic of becoming saturated at quite low magnetic

1. A. I. E. E. Journal, June, 1926, p. 540.

2. *Journal* Franklin Institute, May, 1923, pp. 621-632.

3. A. I. E. E. Transactions, 1924, p. 145.

densities. It is unfortunate that in the particular application where the through-type or single-turn, primary type of transformer would be of greatest value, *viz.*, in large power stations, the secondary burden is likely to be fairly high, due to the necessary length of the secondary leads. These leads are seldom less than 100 ft. in length (200 ft. No. 10 A. w. g. wire equals 5 volt-amperes) and in one of the new stations in New York City the secondary leads are 1000 ft. in length, 2000 ft. of wire (50 volt-amperes for No. 10 A. w. g. wire).

It is to be hoped that means may be discovered that will enable us, through a wider range, to take advantage of the very encouraging results obtained by Mr. Spooner by the use of nickel-iron alloys.

Thomas Spooner: Mr. Kinnard is correct in assuming that hypernik is a nickel-iron alloy. The nickel content is approximately 50 per cent. Hypernik, however, is a very special alloy, in that it is made from very pure raw materials in a type of electric furnace which permits of no contamination. After being rolled to the proper thickness it is given a special, somewhat expensive heat treatment which was developed for this particular material.

Mr. Kinnard has perhaps misunderstood my purpose in using, to a large extent, calculated instead of test values for current-transformer performance. It was first shown that for through-type transformers, this is a reliable procedure. The calculated performance for a number of sizes of transformers was then determined, since this is much quicker than actually constructing the transformers and then testing them. If transformers are actually to be built, it is of course better to measure than to calculate their errors if accurate results are desired in order to take care of variations in the core material and, in any but through-type transformers, of the effect of joints in the magnetic circuit and of magnetic flux leakages.

Referring to Mr. Dickenson's remarks, while it is true that the nickel-iron alloys saturate at a considerably lower induction than do the silicon steels, the permeability of hypernik is nevertheless higher than that of the best laboratory-prepared silicon steel up to an induction of five or six kilogausses. This corresponds to a fairly large secondary burden, even for low-ratio through-type transformers, thus making hypernik superior to silicon steel even under these adverse conditions.

THE RETARDATION METHOD OF LOSS DETERMINATION AS APPLIED TO THE LARGE NIAGARA FALLS GENERATORS[1]

(Johnson)

Niagara Falls, N. Y., May 28, 1926

R. B. Williamson: The testing of large generating units after they have been installed in the power station is becoming more common than was formerly the case because the great increase in size has rendered satisfactory factory testing very costly; in many cases it is, in fact, impracticable because the machines are not completely wound and assembled at the factory. There is no doubt that a great deal of money has been expended in the past on unsatisfactory factory tests that could have been made to much greater advantage after installation. Any methods of testing, therefore, that are of advantage when machines have been set up ready for use are worthy of very careful study and we are much indebted to Mr. Johnson for the present paper which shows the application of the retardation method to some of the largest hydroelectric units so far built.

In factory testing the usual method of determining losses is by means of a calibrated driving motor, but this is often difficult to apply to large vertical units. When using a driving motor it is frequently difficult to hold the source of power steady enough to avoid periodic swings in the power input to the motor and this affects the accuracy of the readings. When large machines are tested in the power house by measuring the input with the generator operating as a motor supplied from a second water-wheel unit, the source of power is much steadier and correspondingly better results can be obtained. Even here, however, difficulties are sometimes met due to periodic variations caused by slight hunting of the water-wheel governor. One great advantage of the retardation method is that, after the machine has been run up to or slightly over speed, the driving power is cut off and all fluctuations due to variations in driving power are also cut off.

In applying the method to water-wheel units where it is necessary to leave the wheel connected and thus rotate the runner in the water-wheel casing, it is important that the casing be drained and also opened by removing the manhole covers. I recall one instance where a retardation test was being made and unaccountable variations were found in the speed. The casing had presumably been drained but the vents had not been opened and it was found that a considerable quantity of water was being thrown around in the casing. The manhole covers were then removed, the casing completely drained well below the level of the runner, and there was no further trouble.

As pointed out by Mr. Johnson, it is not essential that the fly-wheel effect of the rotating parts be known in advance provided means are at hand for measuring the kilowatts required to drive the machine as a motor at known speed. If the loss is thus measured, the fly-wheel effect for use in the other tests can then be calculated with a sufficient degree of accuracy. Usually, however, there is no difficulty in obtaining a close estimate of the fly-wheel effect from the manufacturer and the retardation tests are sufficient to obtain the losses by the methods described.

The analysis of the friction and windage of the three 32,500-kv-a. units in Table IV is of special interest. Unit *A X* as mentioned is equipped with shrouded steel-plate fans with curved blades, and baffles are provided to prevent eddies and short-circuiting of air around the fan. On account of the limitations imposed by the generator design, these fans have an efficiency considerably lower than that of regular blowers provided with a spiral casing, but at the same time it is true that a generator of this type with such fans and baffles will show in general less windage loss than one where the air is free to eddy around. Where the peripheral speed of the rotor is fairly high, as in the present instance, the difference in windage loss may be considerably in favor of the machine with fans as in Table IV, whereas the general feeling of many users is just the opposite, *i. e.*, that fans increase the windage loss. The spider arms of large generators stir up vigorous air currents which involve loss in power; hence shrouding the arms to cut off these currents is frequently well worth while.

It is of special interest to the designer to note that these tests indicate that the stray-load loss at a given speed varied as the square of the current. This, I believe, has been generally assumed to be the case and tests on many machines made by driving by means of a calibrated motor show this relation to be quite closely true. It is important, however, to have this confirmed by tests made on such a large generator and by a different method. The greater part of the stray loss is undoubtedly due to so-called eddy currents in the windings, but a considerable part is also due to stray induced currents in various parts of the machine structure caused by stray fluxes from the windings. It is fortunate, therefore, that notwithstanding the complicated make-up of the stray loss, it is found to be practically proportional to the square of the current.

We fully agree with Mr. Johnson that with the use of suitable instruments, such as he describes, the retardation method can be made of much more use than has been the case in the past. We also feel sure that with the more extended use of methods such as these, tests of machines after installation will supersede many of the factory tests now made on large or even moderate-sized

1. A. I. E. E. Journal, June, 1926, p. 546.

units, because such tests will be less expensive and very much more satisfactory.

E. M. Wood and G. D. Floyd: At the Queenston plant of the Hydro-Electric Commission, we have had the same problem of determining the conventional efficiency of large water-wheel driven alternators, and have in general solved it in a manner similar to that described by Mr. Johnson. Some of our conditions have been different from those described and have given rise to variants in the procedure, some of which may be interesting.

All our tests were made with the turbine uncoupled from the unit under test, as the units have two guide bearings. The units were started as described in the paper. Field current for approximately normal voltage at no load was required on each of two similar units for sure starting. Starting currents at times swung to ½ rated current of one generator of 55,000 kv-a. rating.

Manufacturers' calculations of $W R^2$ were taken but were checked by wattmeter measurement of input to the unit as synchronous motor, whenever the governor of the driving unit would hold speed sufficiently steady to give reliable readings. The calculation checked closely with the test values.

When conditions permitted this test, however, a complete curve of losses by wattmeter was taken down to approximately half voltage. Under proper conditions, these results are possibly more dependable than those from the retardation test but in most cases (but not all) the governor allowed the speed to hunt so that the results were of doubtful value.

The current transformers used were rated at about four per cent of the current rating of the generator and were connected across the blades of gang-operated disconnecting switches to protect them during starting and during changes of test conditions. A man was stationed at the switch with an ammeter and given instructions to close the disconnects quickly in case of a sudden rise of current.

On the first units tested, retardation tests were made using a stop watch and hand tachometer, varied by use of a tachograph and in some cases by use of a high-speed graphic voltmeter for the core-loss curves. We found these not very satisfactory for the reasons stated in the paper.

On the last three units tested, a Cambridge chronograph adapted by Messrs. Borden and Floyd was used. Two elements record on a tape the following:

1. One jog for each half-revolution of the generator.
2. One jog for each revolution of a machine running at synchronous speed (187½ jogs per minute).

From the tapes, speed-time curves were plotted, the rate of retardation at synchronous speed was found and the losses calculated. The average loss between one per cent above and one per cent below synchronous speed was calculated directly in most cases, as the average speed-time curve had been obtained very accurately between 110 per cent and 90 per cent of synchronous speed. In those cases where a curve of loss against speed was obtained, the loss at synchronous speed checked the calculated loss very closely.

The method of reading the record, tabulating the results and calculating the losses given in the paper is very neat and simple. The long intervals were apparently allowable due to the high fly-wheel effect and slow retardation. In our case, the intervals had to be much shorter. This could be varied by using longer overlapping intervals.

Curves of friction, windage and short-circuit losses were taken on one of our units by the retardation method with good results. The switching incident to this test is somewhat involved and must be carried out in a very short time, requiring careful preparation. In this test, it is of importance to observe the temperature of the armature windings.

Mr. Johnson's practise of running the retardation test to below 50 per cent of rated speed is new, and he has used it to obtain much interesting information.

V. Karapetoff: I am glad to hear a practical operating man recommend the retardation method because I have been urging its use for over 20 years. I learned about it in Europe where it has been used much more than here. The principal reason why, perhaps, it has not been used so much is that with small machines the rotating part stops too rapidly to allow an accurate measurement of retardation, and the second reason is the necessity for knowing the moment of inertia.

Of course these difficulties are not insuperable and those interested in this method will find both in the Continental and in the British literature, quite a number of ingenious and indirect methods of measuring deceleration and the moment of inertia. The general theory will be found in my *Experimental Electrical Engineering*, Third Edition, Vol. I, pp. 408-416.

Mr. Johnson suggests that a convenient and simple method be developed for directly measuring the rate of retardation. I wish to mention a condenser device which was proposed quite a number of years ago for measuring acceleration and deceleration of railway trains, and which, with modern measuring instruments, should be satisfactory for the purpose desired. Consider a capacitor connected to a source of direct voltage. Then we have the relation: $q = C e$, where q is the charge on the condenser, C is its capacitance, and e is the applied voltage. Taking a derivative of both sides of this equation with respect to time, we get $d q/d t = C d e/d t$. Call this current i; then $i = C d e/d t$.

Suppose that you have some device, such as a d-c. magneto generator, belted or otherwise connected to the generator under test, and let the induced voltage of this device be proportional to its instantaneous speed. Then $e = k v$, where v is the instantaneous velocity, and k a coefficient of proportionality. Substituting this value of e in the equation for the condenser current, we find that $i = C k (d v/d t)$.

The value of $d v/d t$ is the retardation of the machine, and the current flowing into or out of the condenser is proportional to it. In other words, if you have a magneto in series with a galvanometer and a condenser, the instantaneous indication of the galvanometer is a direct measure for the instantaneous retardation of the machine.

W. J. Foster: Mr. Johnson has described the retardation test and he has developed it, I think, to a higher degree of perfection than any other person.

There are three methods of testing large generators: the motor method, the retardation and the calorimetric. The first that I had experience with was the motor method and fairly good results were obtained, but it failed completely in the matter of the load losses or short-circuit losses. Since those losses have become very important the motoring method by itself is now obsolete.

The retardation method was developed and practised several years ago quite extensively in the shops of the General Electric Company. It was found to be a very convenient method when the speed could be determined with accuracy and the $W R^2$ from calculation, but when the rotor contained castings there were always some uncertainties about the $W R^2$.

In our work we sometimes found it well to obtain the speed electrically, which is especially easy where there are direct-connected exciters and a battery is used to excite the field so as to hold the excitation perfectly constant.

I regard the calorimetric method, however, as the coming method in most machines. Our hydraulic generators are going to become more and more totally enclosed and it is not in the far distant future when we will have the closed system, the same air being returned over and over again. So I think that the most accurate method and the method by which we will obtain the real efficiency will be the calorimetric method.

I say the real efficiency because the matter of taking the short-circuited losses as the load losses is an approximation to accuracy. It has been standardized and when it is used by the designers in calculations and in giving guarantees it, of course, should be measured in the test, and the total losses should include for load

losses the short-circuited losses. But by the calorimetric method the actual load losses are obtained and that is extremely important.

I think that in such generators as Mr. Johnson has worked with, where he has housings around them, he can very well check up the results obtained by the retardation method. I wish he would do so as a supplement before this paper is published in the A. I. E. E. TRANSACTIONS. It wouldn't take over two days on one of those machines to do all of it. He should vary the power factor of the machine under test from unity down to 80 per cent, and thus be able to furnish extremely valuable data for designers as well as for users.

I can't speak in too high terms of the work done by Mr. Johnson. I have been in contact with it somewhat and he certainly has used his brains.

It was just a trifle amusing to me to notice his remarks with reference to the unusual opportunities that he had in having three generators of different design and also some combinations of hydraulic turbines to work with.

No doubt the engineers of all of the manufacturing companies will agree that each has some compensation for the disappointment he experienced in failing to receive the order for all three units,—in the excellent test data and the improved retardation method furnished by Mr. Johnson.

Mr. Johnson discusses the effective resistance and gives formula (8). I wish to remind you that there are other losses, eddy-current losses in the magnetic material, and what is needed now is for data to be collected that will look towards the determination of the effects of end magnetization.

P. A. Borden: It is particularly interesting to learn that in his tests of generators, Mr. Johnson has been making use of the chronograph for the precise determination of speeds through a cycle of velocity values. A method almost identical with Mr. Johnson's was developed independently by the Hydro-Electric power Commission of Ontario, and since then has been employed in all its tests of large units where there was required a permanent and accurate record of all speed values during the time of observation.

L. A. Doggett: (communicated after adjournment): In connection with the study of the losses of induction motors supplied with non-sinusoidal electromotive forces, some retardation runs have just recently been made at the Pennsylvania State College. These runs were on machines of 5 to 20 h. p. Although these machines are pigmies compared to Mr. Johnson's 65,000-kv-a. unit, it would seem worth while to have on record some of the problems occurring at the other end of the scale of sizes.

First, as to speed measurements, it soon developed that the attachment of a tachometer, whether of the mechanical or electrical type so altered the friction that the retardation curve was materially affected. For example, where it took 52 sec. to reach zero speed without the tachometer, it took 37 sec. to reach zero speed when a tachometer of the electric type was applied to the end of the shaft throughout the run, all other conditions remaining the same. To avoid this error a stroboscopic method was used, in which an arc was supplied by a current of known frequency. The light from this arc was directed upon a disk attached to the shaft. On this disk were arranged in the usual way circular rows of spots at uniform intervals, such as 45 deg. and 30 deg. The time was noted when these spots reached apparent rest. With this arrangement very satisfactory speed-time curves were obtained.

Second, as to $W R^2$ measurement, this value was determined in two ways. The first is as described by Mr. Johnson and involved a separate measurement of the friction and windage at a definite speed. This in conjunction with the retardation run gives a value for $W R^2$, which for one five-h. p. induction motor was 2.36 lb-ft². A second value was determined by another method. In this method the rotor was removed from the stator and suspended vertically as a torsion pendulum and in this condition its time of swing was determined. The time of swing was again determined when an additional known $W R^2$ was attached to the rotor. From these data the $W R^2$ came out 2.26 lb-ft². The torsion pendulum method is considered the more reliable.

J. Allen Johnson: Several speakers have made suggestions as to the technique of the tests such as the necessity for draining the wheel case and opening vents, the use of disconnecting switches to short circuit the small current transformers during adjustments, etc. These are desirable precautions. Messrs. Wood & Floyd have used a generator running at synchronous speed to measure time. It would seem to the author that much more accurate means of measuring time are available in the form of clock mechanisms.

The electrical accelerometer outlined by Professor Karapetoff is extremely interesting and if it could be worked out into an instrument suitable for field use might be of value. At present it appears to the author as a scheme which might readily be used in the laboratory but hardly a tool for powerhouse use. It has, however, interesting possibilities, and the author looks forward to the time when the inherent merits of the retardation method will have created sufficient demand for such an instrument to justify some manufacturer in undertaking its development.

Anyone who has carried out retardation tests and has observed the almost majestic steadiness with which these huge machines slow down under the influence of their own losses, completely unaffected by any outside influence, will share with him, the author believes, not only his conviction that in this method we have something elemental in its simplicity and trustworthiness, but also his desire for a means of making the necessary measurements of speed and rate of retardation as simple and direct and elemental as the method itself. Such a means seems to be provided in the use of a chronograph, revolution counter and timer. The author doubts if he could have equal confidence in the results obtained by any method less simple and direct, such, for instance, as electrical tachometers or accelerometers involving the accurate knowledge of electrical constants and the necessity of accurate calibration.

Mr. Foster calls attention quite rightly to the fact that in measuring the short-circuit losses we are only making an approximation to the actual stray-load losses. The author frankly recognized this fact in stating in this paper that these tests were to determine the "conventional" efficiencies of the machines in question.

Mr. Foster proposes the calorimetric test to determine the *actual* load losses. The author sincerely hopes that successful results may be obtained in this manner, but confesses to some skepticism in the matter, when recalling a test of this character, in which he assisted, made on a 7500-kw. generator in 1905 or 1906. The losses by radiation, the difficulties in determining accurately the average temperature of large volumes of air and of determining the mass and velocity of the air are a few of the practical obstacles which the author sees in applying the calorimetric method. He agrees with Mr. Foster, however, that no other method of determining the actual stray losses seems possible, and the desirability of finding out what these losses actually are probably justifies considerable trouble in perfecting the calorimetric method. He is of the opinion, however, that nearer two months than two days would be required to get any worthwhile results on the large generators by this method.

Mr. Doggett's method of determining $W R^2$ by using the rotor as a torsional pendulum is very interesting. To apply this method to a rotor weighing 400 tons, however, would seem to invoke some practical difficulties.

VARIABLE ARMATURE LEAKAGE REACTANCE IN SALIENT-POLE SYNCHRONOUS MACHINES[1]

(KARAPETOFF)

NIAGARA FALLS, N. Y., MAY 28, 1926

P. M. Lincoln: It would have added to our information if Prof. Karapetoff had gone a little further into the details of the amount of departure of this particular machine which he cites in the last part of his paper.

The reactance of our large machines is becoming very much larger than it was ten or fifteen years ago. At that time, internal reactance of generators was something of the order of 10 per cent —from 8 per cent to 12 per cent; nowadays, on account of the very much greater capacity of the machines, it is necessary to limit the amount of short-circuit current that will occur in order to secure safety in switching devices. And the best method of limiting of course, is to limit the reactance. The internal reactances of our large generators has gone from a matter of 10 or 12 per cent up to 15 to 25 per cent. It has more than doubled.

Now Prof. Karapetoff has indicated that this much larger internal reactance can be properly divided into two factors. One of them is a reactance which is independent of the position of the phase of the current-carrying coils with respect to the poles, and the other factor is a factor which depends upon that relationship.

I think it would add to the paper if Prof. Karapetoff would indicate the amount of departure between the tests and the assumption that the reactance is constant—how much is ΔL, what is the value of ΔL that he has discovered, what that relation is that it bears to the L.

E. B. Shand: Referring to Blondel's theory of two reactions, assume that the armature conductors of an alternator are carrying current of which the phase relation may be represented by the accompanying Fig. 1; the armature turns are concentric with the field winding so that they will either add to, or subtract

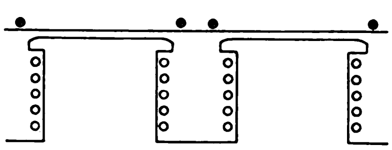

FIG. 1

from, the ampere-turns of the field. This component of current is that of direct magnetization. When the current is 90 deg. out of phase from the above condition, as is indicated in Fig. 2, the flux produced by the armature magnetizing force will pass into one side of the pole and out the other side. Thus flux has always presented some difficulty to me in the way of definition. If the ordinary transformer conception is adhered to, this flux, which

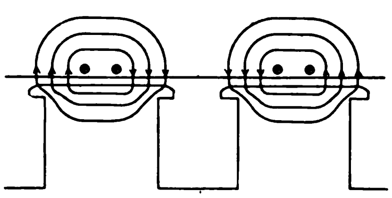

FIG. 2

does not interlink with the field winding, will be called leakage flux. On the other hand, the armature ampere-turns modify very materially the main flux of the machine and also may produce saturation effects so that it has always seemed to me that the definition "cross-magnetizing flux" in accordance with Blondel's ideas is the better term for it.

1. A. I. E. E. JOURNAL, July 1926, p. 665.

Any analysis of the kind given in this paper is greatly dependent upon where the line is drawn between armature cross magnetization and armature leakage reactance. I should like Professor Karapetoff to give us his ideas on this matter and the assumptions he has made in connection with the paper.

J. F. H. Douglas (communicated after adjournment): Professor Karapetoff's article shows clearly how many factors must be considered in theory when accurately predicting the performance of a synchronous machine, factors which do not enter into the performance at zero power-factor.

His treatment of linkages of flux has the merit of rigor which

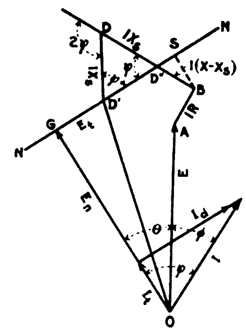

FIG. 3—ILLUSTRATION TO PROVE THAT THE BLONDEL TWO-REACTANCE DIAGRAM IS IDENTICAL WITH THE DIAGRAM INCLUDING A SUPPLEMENTARY REACTANCE DROP

the arbitrary assumption of two "reactances" seems to lack. His equations (8) and (9) in conjunction with his Fig. 1 lead to an important relation

$$X_s/X = \Delta L/2\,L < 1/2 \qquad (1)$$

on which it would be interesting to have an experimental check. He shows clearly that by considering theoretically derived constants X_t and M_d, and the more usually known reactance, $(X - Xs)$, values of the torque angle θ and of the internal phase angle ψ may be considerably in error.

The graphical construction given in his Fig. 3 follows along lines advocated by me in the discussion of an article in the

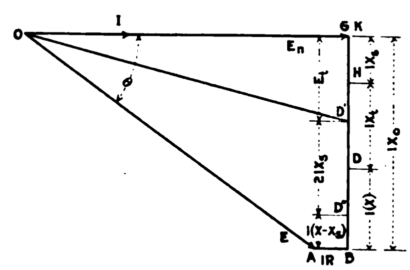

FIG. 4—BLONDEL DIAGRAM FOR CONDITION OF NO DIRECT REACTION

A. I. E. E. JOURNAL for Jan. 1925,[2] with the added advantage, of course, of including the factor X_s.

Fig. 2 of his article is susceptible of interpretation in several ways. It is important to note that one interpretation is not inconsistent with the two-reactance theory in general and that of Dr. C. P. Steinmetz noted in Footnote 4 in particular. Consider the accompanying Fig. 3, which is Fig. 2 in the article with the point S added. The lines $D\,S$ and $B\,S$ are

$$D\,S = I\,(X + X_s)\,\mathrm{Cos}\,\psi = I_t\,(X + X_s) \qquad (2)$$

$$B\,S = I\,(X - X_4)\,\mathrm{Sin}\,\psi = I_d\,(X - X_s) \qquad (3)$$

We may locate the $I\,X$ drop as $B\,D + D\,D'$, or as $B\,S + S\,D'$.

2. Douglas, Engeset and Jones, *Complete Synchronous Motor Excitation Characteristics.*

The latter interpretation of the figure is that the $I\ X$ drop consists of two separate components, (a) one caused by the direct component of the current I_d acting with a reactance, $X_a = X - X_s$, and (b) one caused by the transverse current I_t acting on the reactance $(X + X_s)$.

Another viewpoint might be to regard $S\ B$ as above and consider $S\ G$ as a sort of total transverse voltage drop, due to the transverse current I_t acting on the reactance $X_o = X + X_s + X_t$ using the notation of Karapetoff's equation (**15a**). Inasmuch as

$$X_o = X_a + 2\ X_s + X_t \quad (4)$$

it will be seen that to consider X_a and X_t and neglect X_s may result in considerable error. The graphical construction is in no way influenced by these interpretations but the theory becomes very much simpler, when we consider the constants M_d, X_o, and X_a, and disregard their components X, Xs and $X\ t$.

As is well known, the zero full-load saturation curve can be used to evaluate both direct reaction and armature reactance. The reactance evaluated is, I believe, that reactance I have called X_a, namely $(X - Xs)$. It would be most desirable to have an experimental method for the evaluating of the reactance $X_o = (X + X_s + X_t)$; the experiment which would be most useful would be to load a machine as an alternator, with a leading current such that the angle ψ was zero, that is, with the current wholly transverse. With this loading, the voltage terminal E, the torque angle θ, and the field current should be measured. Fig. 2 of the article then becomes the accompanying Fig. 4 below, and the reactance X_o and E_n can be computed by

$$X_o = (X + X_s + X_t) = (E \operatorname{Sin} \theta)/I \quad (5)$$

$$E_n = E \operatorname{Cos} \theta + I\ R \quad (6)$$

The value of E_n should check with field current I_f if the theory is correct, and the value of X_o could be obtained.

I wish to record the conviction that the attempt to separate Xo into components X, X_s and X_t, will be very difficult. First, physically, where shall we picture the $(X + X_s)$ linkages as ending and the X_t linkages as beginning? Experimentally X_o alone can be measured. If we calculate X_t theoretically from design data, and the residual $X + X_s$ is small, then there will arise the question whether our transverse coefficient is accurately known. For example, the whole effect could be attributed to an error in the theoretical derivation of the constant X_t. Stated in a somewhat different way, I could, with a single value of armature reactance X_a, and a somewhat larger value of X_t than Prof. Karapetoff uses, predict the same performance characteristics that he does, with the use of the three constants X, X_s and X_t. (I am referring to the phase angles θ and ψ, for the field current another constant, that of direct armature reaction would have to be used.)

Vladimir Karapetoff: In reply to Mr. Shand's question, I should say that from a physical point of view we have in an alternator a doubly excited magnetic circuit, which is excited by the field winding and by the combination of the polyphase windings on the armature. There is a complicated flux which varies in space and in time, and only part of which moves synchronously with the poles, the rest corresponding to harmonics moving at different velocities, some in the direction of rotation of the machine, some against it. Any division into various armature reactions and leakage reactances is only a practical makeshift which perhaps is not rational from the physical point of view. The best we can do here is to play the game straight and not figure out the same fluxes twice.[3]

The particular makeshift which Blondel proposed many years ago consists in resolving the armature currents into two components in time, one component which reaches its maximum when that particular group of conductors is opposite the center of a pole and the other group which reaches its maximum in the position midway between the poles. The magnetomotive forces due to these two components are considered separately and also in combination with the field m. m. f. For details see the references given above.

3. V. Karapetoff, "The Magnetic Circuit," p. 150; Doherty and Nickle, *Synchronous Machines*, presented at A. I. E. E. Annual Convention, White Sulphur Springs, June, 1926.

SAG CALCULATIONS FOR TRANSMISSION LINES[1]

(DWIGHT)

NIAGARA FALLS, N. Y., MAY 28, 1926

M. G. Lloyd: I want to say something about the problem in general, and how it has been handled elsewhere. There are two ways in which it may come up.

In a line that is already constructed, if you know what your sag is, you can get the tension very simply by this formula (2) which the author has given and which expresses the tension in terms of the sag, the loading, and length of span.

I think the more usual case, however, comes up in the design of a line where you want to know how to string the wire so that under the worst condition of loading which it will experience or which may be assumed, it will not be stressed beyond a definite fraction of the strength. In that case you start out with your loading and with your definite tension and you want to find the sag. Formula (1) does that very simply for that loaded condition.

The construction man puts it up, however, under some other condition, and he wants to know what the corresponding sag is under stringing conditions, and that is the thing which gives a lot of trouble.

As the author here points out, by using these formulas, one can work back by a method of trial and error or successive approximations, or you can, using formula (3) and others, work out a number of cases and get a set of curves from which then you may be able to read off directly the particular value which you want.

I want to speak, however, of another method of doing that which we have found more simple and time-saving in the long run. And I might say that at the Bureau of Standards I think perhaps we have done as much sag computing as anywhere in the country, in connection with the sag tables and curves for the National Electrical Safety Code.

In an Institute paper[2] which I think we may call one of the classics on this subject, Percy H. Thomas showed how, in plotting a curve between sag and stress, one could represent what we might call a generalized condition, by expressing sag as a percentage of span length and applying the loading in unit terms. That corresponds to the first formula of the paper and it is all right for the simple case which does not involve conditions of changing temperature, because it is changing temperatures that bring in the greatest difficulty.

A little later, two students, Messrs. Melvin and Wynne at the Massachusetts Institute of Technology, with whose thesis work I presume Prof. Dwight is not familiar, pointed out how a series of curves could be plotted to assist greatly in solving this problem. They plotted a whole family of curves which apply to different loadings of a given material, and then plotted on the same sheet of paper, another set of curves which are the stretch curves at different temperatures. The two families of curves intersect. (They used the parabolic relation in getting these but in the later work we have used the catenary relation in order to have them more accurate.)

What we call the stretch curve will represent conditions corresponding to some single temperature when the load on the wire is varied.

Now suppose the load is entirely removed from the wire; (and in that load I include the weight of the wire itself); we come all the way down on the stretch curve to the axis (the limiting member of the sag-stress curve being comprised of two axes)

1. A. I. E. E. JOURNAL, June, 1926, p. 564.
2. TRANS. A. I. E. E. 30, p. 229 (1911).

just as though the wire had no weight or load, and could be strung without sag or tension.

In using the old Thomas method, one would compute what we are now doing graphically; that is, take the load off the wire, get the condition of the wire with no load, then assume a change in temperature and find the change of the unstressed wire in length due to change of temperature. Upon arriving at that new length at the new temperature, apply the load again and then find the condition of the wire in sag and tension

The method of using the new charts is this: Pick out the point representing the stress,—that is, the tension reduced to pounds per square inch,—and the corresponding sag. You find what that is for your loaded condition.

Now then, if you want to find what the sag would be at some different temperature under the stringing condition of load,—that is, no load except the weight of the wire itself,—you follow the stretch curve to the axis.

The stretch curves are plotted for definite intervals of temperature, say, ten degrees. If the coefficient of expansion is a constant, it doesn't matter what the temperature is; one can shift the temperature scale to suit. Say you have taken the loaded condition at zero degrees and the stringing temperature at 60 deg.; you follow the axis for 60 deg. and return on another constant-temperature line to the load represented by, say, the weight of the conductor only. This point gives the stress and the sag for your stringing condition.

That gives a very rapid method of computing sags without any successive approximations and will fit any temperature and any loading. The only requirement necessary is that you have your chart to begin with.

If one has a great deal of this to do, it is worth while to compute the chart and have it on hand. Of course if one has only one problem to work out, it is easier to use the formulas. The author mentions a paper by Martin presented before the Engineers Society of Western Pennsylvania in which he has worked out some tables giving the catenary functions. They are very useful in a single case; in fact, we have sometimes found them preferable even in doing a lot of such work, since working over curves like these and attempting to interpolate between the drawn curves to obtain accurate results requires very close attention and careful work and it becomes very tiresome and exhausting if kept up for any length of time. On that score, it is easier to do computing, if you can do it, in a mechanical way with computing machines, as it takes a great deal less mental effort and less eye work.

I might say also that we have worked these charts out with the principal materials used, such as copper, aluminum and steel. In working them out, we used formulas somewhat similar to these in the paper, expressing the catenary functions in series.

H. B. Dwight: Has the work with curves for sag calculations, as described, been done for the case of supports at unequal heights or for cases of supports at equal heights only?

Mr. Lloyd: What I said applied to equal heights only.

H. B. Dwight: Is there any work on the other as yet?

Mr. Lloyd: No, not to work it out in the same way, except that with unequal heights, in considering the curve of the wire extended, you have always equivalent cases of equal heights of a span of greater length, of which your actual span is merely a portion; and you can always work it out in that way.

E. V. Pannell: The high degree of accuracy being striven for in transmission line-calculations is most noteworthy, but the question is whether the mathematicians have not gone a long way ahead of those responsible for testing the fundamental properties of material? While sag and tension calculations are being made to four, five, or even six significant figures, it must be admitted that knowledge of the physical properties of the wire does not come anywhere near this degree of exactitude.

The fundamental property in all calculations of wire extension is the modulus of elasticity. For copper wire, this is variously reported as from 16,000,000 to 18,000,000 lb. per sq. in. Here is evidently a difficulty and a possible error of 12½ per cent. In the case of aluminum, various investigators have reported a modulus of 9,000,000 and 9,500,000 and 10,000,000 lb. per sq. in., involving a possibility of error almost as great as for copper.

The properties of the wire when stranded into cables of various lengths of lay and characteristics become still more involved and except in the case of certain German laboratories, I know of no thorough tests having been made on a scientific basis by which attempt could be made to establish these properties.

It would seem as if the great degree of accuracy possible in a mathematical manipulation described by Dr. Dwight and other investigators is very nearly useless until the physical constants of wire and cable are more soundly established.

H. B. Dwight: The discussion by Mr. Pannell brings out a matter of considerable engineering importance. The physical characteristics of stranded cables, such as modulus of elasticity and temperature coefficient of expansion, are not known with exactness for standard conductors. Accordingly, further tests should be made to determine the average values of these constants and their usual amount of variation.

It is not necessarily obvious at first sight what is the effect of a certain percentage change in one of the constants, and it would appear to be a good engineering procedure to repeat a sag calculation using maximum and minimum values of a constant, so as to find what effect the variation has on the engineering decisions which depend on the calculation. If this were done for the two constants mentioned above, important changes in the results would be obtained.

In general, one should not write the values of engineering quantities with a precision greater by more than one significant figure than the precision of the measurements on which the quantities depend. Exceptions to this rule, however, are sometimes justified. For instance, one is justified in assuming the length of a span to be exact, as 800.00 feet. The sag calculation really deals with small changes in length. If the calculation should be repeated for a span of 801.00 feet the difference would be minute. If the length of span is considered to change after the application of a load, as by deflection of the towers, this should be taken up in a separate calculation.

When one wishes to compare two methods of calculation, one is justified in assuming for that purpose that all the constants are known with precision. The results are useful for the purpose intended.

Even where a constant is not definitely known, it is good engineering practise to adopt a standard value so as to design all the spans of a transmission line to have the same factor of safety rather than by irregular designing to have one span weaker than the others. Thus, a standard value of ice load or wind load is adopted even though the probable maximum value is uncertain. So also for the sake of uniform design of all the spans, it is proper to take a standard or average value of modulus of elasticity. The effect of possible variations in this constant can be made the subject of a separate investigation, as previously mentioned.

Where average values have been taken for several quantities, their deviations will probably cancel out to some extent in their effect on the final result, and so it is justifiable to carry out the computations based on the average values, with a moderate degree of precision.

The above mentioned reasons for making precise computations do not justify adding more than about one or two significant figures except in the case of the length of the span, or in the case of comparing two mathematical methods. In Table I of the paper by Dr. G. S. Smith[3], the modulus of elasticity is given as 29,000,000; that is, to two significant figures. This is multiplied by some quantities depending upon the section of the cable, and the result is given in section (13) of Table I as 3,153,306,102; that is, to 10 significant figures. This is due ap-

3. Transactions A. I. E. E., 1925, p. 938.

parently to the plan of writing the result of all multiplications with as many significant figures as a calculating machine will give, but when this is done, it does not seem possible to tell what figures have use and meaning and what have no meaning. Such a procedure masks the precision of the different parts of the calculation, and gives the impression that no attention is being paid to the relative precision of the calculation. It would seem better to give only such figures as are intended to be used.

The use of charts has a place in the calculation of sags, as described by Dr. M. G. Lloyd or as described in a number of A. I. E. E. papers. A chart method may give a sufficient degree of precision for a certain class of work, but this should be carefully determined. It should be remembered that a reading taken from a curve is correct to a certain number of significant figures, and the final result cannot be accurate to a greater degree than that determined by the curve reading. In sag calculations, especially where temperatures are involved, the discrepancies resulting from taking readings on curves may be greater than are desirable in designing.

The discrepancy between the values of deflections obtained in my paper and in that of reference (8) is due to the fact that two different catenaries have been assumed in the two papers, for the case of unequal supports with wind load. While the deflections are different, since they are measured to different lines, the difference in the stresses obtained by the two calculations is not appreciable for practical spans.

NOTES ON THE VIBRATION OF TRANSMISSION-LINE CONDUCTORS[1]

(VARNEY)

NIAGARA FALLS, N. Y., MAY 28, 1926

A. E. Knowlton: The principle of aerodynamics which Mr. Varney cites to account for the vibration of the transmission-line conductors is undoubtedly the same one which is found applied in the propulsion of Dr. Floettner's rotorship. The one difference is that he rotates the rotor and keeps the pressure always in one direction. That is not, of course, the case with the line conductors. The instability there results in alternation of the pressure and consequent vibration of the conductor.

Another and more important difference is that Dr. Floettner has made a useful application of it and one can't say as much in the case of the line conductors. The fact is that we get two distinct results; one useful and the other deleterious.

A committee of operating engineers is attempting to assemble the facts that have been observed and perhaps have been recorded in connection with this phenomenon, so that we can draw conclusions not merely as to the rigidity of the theory as Mr. Varney has set it up, but also upon the efficacy of certain preventive measures.

Theodore Varney: In closing, I think Prof. Knowlton's comment regarding Dr. Floettner's rotorship is appropriate. While Dr. Floettner turns the eddy effect of the wind to good account, the same influence accomplishes no good result in a transmission line conductor. It is not correct to say, however, that this effect is always deleterious in the latter case because cases are on record where vibration has been going for over ten years without interference in any respect to the continuous and successful operation of the line.

As the speaker views the matter, destructive effects will result from vibration only when the direct stress in the conductor increased by the stress due to vibration exceeds the endurance limit of the material of the conductor.

This is a complex problem, but it appears that the stress due to vibration is directly proportional to the stored energy in one half of each vibrating loop and inversely proportional to the distance over which that energy is dissipated. This energy is expressed by the mass of the half loop, the square of the amplitude and the square of the frequency of vibration. This energy passes back and forth freely between loops in the span away from the supports. At the supports there is an inevitable bump and increase of stress, which can be greatly reduced by care in clamp design.

The most beneficial remedy is to reduce the amplitude of vibration by dampers.

1. A. I. E. E. JOURNAL, October 1926, p. 953.

RECTIFIER VOLTAGE CONTROL[1]

(PRINCE)

NIAGARA FALLS, NEW YORK, MAY 27, 1926

R. H. Wheeler: The paper by Mr. Prince is a very interesting discussion of the potential possibilities of the use of the interphase transformer.

The interphase transformer has been utilized for a long time by Brown Boveri & Co., Ltd., and is incorporated in the circuit diagrams which the American Brown Boveri Electric Corporation has put forth in some of its proposals. We have not used the saturated-core type, however, for it long ago was demonstrated by many installations that the close regulation of the modern sets was sufficiently close for all traction purposes and very few industrial applications require the complications of the saturated interphase transformer.

Extended experience has also proved of late years that the compound rotary converter has not taken the position that it enjoyed some years ago when over-compounding was thought necessary. Wherever compounding is used of late it has been entirely of the flat compound type. To our knowledge, however, the shunt rotary converter has had a much greater application and appears to satisfy regulation and voltage conditions in all usual operations. To meet the flat compound or the over-compounded rotary converter, there has been introduced into the mercury-arc rectifier installation circuits an induction regulator which quickly compensates for the drooping characteristic of the rectifier and permits it to parallel at all loads with compound rotary converters.

There have been a number of schemes utilizing a variable-reactance core in the interphase transformer. The d-c., saturated core described by Mr. Prince has been utilized in a number of installations some years ago, but has since been abandoned because of a number of factors which limited the degree of compounding demanded by commercial practise. We have found that the rising voltage characteristic is not sought by purchasers of such conversion machinery.

The paper by Mr. Prince points out that the regulation is largely a function of the variation in load as it increases and decreases. The scheme as offered does not permit an independent voltage control. We have found that there are possibilities of utilizing shunt connections which will permit the movement of the voltage curves vertically upward or downward, at the same time obtaining the benefit of the control Mr. Prince has described. The Brown Boveri Review of 1919, Nos. 7, 8 and 9. describes such an installation and discusses the possibility of shifting the load by voltage control of the rectifier where a rectifier and rotary converter are operating in parallel.

During the extended development of the mercury-arc rectifier in large power sizes, as carried on by the Brown Boveri & Co. Ltd. of Switzerland, various schemes have been developed and patented, which permit of a flexible voltage control. These forms of control, however, include complications of circuits which demand additional reactance coils and machinery, and are not as commercially practicable as the circuits now offered, which provide for usual shunt characteristics. There is always available the induction regulator, transformer, tap changer, or similar device for changing the voltage of the sets.

The mercury-arc rectifier has been installed in heavy electric traction service at varying voltages up to 4000 volts, d-c. The limit of the phenomena of conversion by the mercury-arc rectifier

1. A. I. E. E. JOURNAL, July, 1926, p. 630.

does not seem to have been approached at the highest commercial d-c. voltages in operation today. The rectifier is causing a great deal of study to be made of its possibilities by engineers interested in the electrification of steam railroads, since the weights and dimensions are at a minimum not heretofore reached per kilowatt of substation output. No overhead cranes, heavy wall construction or heavy machine foundations are required in such substations. The operation of putting the machine in service or taking it out of service is no more complicated than throwing on the bank of transformers which serve the rectifiers, thus permitting the substation employee to be easily trained and of a type not essentially classed as "highly skilled." I can clearly visualize the use of the rectifier being established along the right-of-way of a steam railroad at much more frequent intervals than the rotating machinery type of substation providing much closer d-c. trolley regulation and obtaining alternating current from any commercial source of any commercial frequency, thus obviating the use of railroad-owned power stations and transmission systems.

It is interesting to note the control of the voltage and current curves as described in the paper by Mr. Prince. He sets forth the current characteristics in a very detailed fashion and we think that if it is possible to apply these schemes of voltage control to the twelve-phase rectifier, a very satisfactory current wave form will result.

Frequently we have been asked "What about radio interference?" because of the undulating character of the current wave form. Exhaustive tests were made by the largest utility company in the middle west, using very sensitive radio receivers which were moved about the substation, and placed in all positions, to determine the extent of interference with radio reception. The results of this test proved definitely that there is no interference caused by the wave form emanating from the rectifier and through the circuits it feeds. We believe this test is of interest, as the wave form of the theoretical circuit might cause an apprehension upon the part of some engineers if the practical test had not been made. Furthermore, full appreciation had not been given to the fact that the superimposition of many phases of rectification causes practically a flat wave rather than a sharply undulating wave.

Otto Naef: I think Mr. Wheeler is right when he says that in Europe not much use has been found for the interphase transformer with d-c. magnetization. The method proved successful from the point of view of voltage regulation, but this asset was not considered important enough to set aside the disadvantage of higher cost, lower efficiency and power factor in a plant thus equipped. Besides, there has been a marked tendency in Europe in the last few years to eliminate, so far as possible, any complicated features.

I may mention here that instead of using a saturated interphase transformer, saturated transformers or choke coils in the anode circuits may be used with equal success. In addition to, or instead of, a series winding, a d-c. shunt winding may be put on the core, which, if excited from the d-c. mains, makes it possible to raise and lower the characteristic of the rectifier in much the same way as in an ordinary shunt-wound, d-c. machine.

Mr. Prince's curve shows a very steep rise in the voltage at low loads, which is a characteristic feature of the interphase transformer. It can be avoided by using a booster transformer instead of the interphase transformer. It may be excited from the low side of the rectifier transformer through a reactance coil, the inductance of which is varied by the application of d-c. magnetization. In this way it is possible to vary the boost and thereby obtain compounding of the d-c. voltage without getting that first kick.

F. A. Fardon: Mr. Prince has removed one of the serious disadvantages of mercury-arc rectifiers when applied to railway service. A considerable proportion of the rectifier applications will be additions to systems where revolving apparatus having very definite characteristics is already in use. It is hardly conceivable that the characteristics of an existing system would be changed to permit the application of rectifiers with naturally drooping characteristics. On many occasions, it is necessary to install an additional unit in an existing station containing converters, and a rectifier with drooping characteristics would divide loads properly with the existing units at *only one* point. Beyond that, the converter would have a tendency to take too great a share of the load and at low loads the rectifier would cause reverse current to flow through the converter, which would at least force the converter off the bus and possibly cause other difficulties. This condition is analogous to attempting to operate a shunt-wound and a compound machine on the same bus, which we all realize is a very unsatisfactory arrangement.

It has been proposed that the rectifier be operated with converters where the regulation of the converter is poorer than that of the rectifier. This is a very unusual condition, and I am not familiar with any place where this condition exists.

With the method of compounding suggested by Mr. Prince, the interphase transformer may be arranged so that the saturating winding may be equalized with the series field of the converter, insuring load division at all points.

Compounding is desirable from an economic standpoint, as none of the features considered desirable in a rectifier are impaired and holding practically flat voltage at the substation is a condition which requires a minimum amount of feeder copper. This is applicable to approximately 90 per cent of the railway substations in this country.

A rectifier without compounding is comparable to a shunt-wound converter having about the same regulation, whereas, with the compounding feature, the regulation is practically the same as that of a compound-wound converter. Other methods, such as tap changing or use of an induction regulator, while applicable possibly to an isolated station, are objectionable on account of external devices requiring maintenance, and the fact that no induction regulator is fast enough to follow load swings on the average railway substation. If possible to build a regulator of this sensitivity, the maintenance would necessarily be high, as the unit would be in practically continuous operation.

The method of regulation offered by Mr. Prince is as simple as the series field on a converter. It will find large application and may be considered one of the most valuable additions to information on rectifier circuits made in recent years.

E. B. Shand: I more or less agree with Mr. Wheeler that the shunt-wound converter is becoming more popular now for traction and the value of the over-compounding or flat compounding is not as great as it used to be.

There is one point to be made, however. It will be noticed that with the core unsaturated you get the effect of the ordinary balance coil and that the anode current flows for one-third of a cycle, but that with the balance coil saturated it flows for only one-sixth of a cycle. That means the transformer will have to be about 25 per cent larger; so it will be economically at a disadvantage.

D. C. Prince: In the discussion of this paper, three questions have been raised: 1. Can the method be employed to give voltage control independent of line-current variations? 2. Is excessive transformer secondary heating introduced by the operation of compounding? 3. Will its popularity be reduced by the trend toward substation layouts which limit the load on one substation by dropping its voltage?

In answer to the first question, I should say that the problem of saturating the interphase transformer from a separate source is simpler than that of obtaining the correct characteristics by self saturation. If the latter problem is solved, the former follows automatically.

As a rectifier is loaded, the current waves in the several secondary windings spread out so that their utility factors improve. In a flat compound rectifier, the tendency of the compounding to make the utility factor worse is offset by the normal tendency of this factor to improve with load. The light-load utility

factors are three-phase 0.68, six-phase 0.55. The six-phase, short-circuit, secondary utility factor is 0.75 so that the transformer would not be expected to require materially greater secondary copper on account of compounding. Utility factor is defined as the ratio of no-load rectified voltage times rectified current to alternating sine-wave kv-a. for the same root-mean-square heating.

A very desirable thing about the compound characteristic is that by the use of high-reactance transformers it can be taken advantage of to hold substantially constant voltage to full load and yet with overloads the voltage breaks down more rapidly than that of a shunt machine so that the unit will shift its load to other substations. Since the rectifier cannot fall out of step, a generously designed set might be made to stand short circuit for a brief period without being tripped free of the lines.

LIGHTNING AND OTHER EXPERIENCES WITH 132-KV. STEEL TOWER TRANSMISSION LINES[1]

(SINDEBAND AND SPORN)

NIAGARA FALLS, N. Y., MAY 28, 1926

F. W. Peek: Messrs. Sindeband and Sporn's paper gives some very good data on practical lines in confirmation of experimental and theoretical work which I have been doing on this subject.

I have been very much interested as to the voltages that may occur on transmission lines due to lightning, the nature of these voltages and the ability of the insulation to withstand them. The spark-over voltage of an insulator is quite different for lightning voltages and 60-cycle voltages. Fortunately the lightning spark-over voltage is much higher than the 60-cycle, spark-over voltage and is not affected by dirt, rain, water or other foreign material on the insulator. About what voltages should be expected on a transmission line due to lightning and what is the insulator strength? If these factors are known it is easy to predict whether or not trouble is likely on any line. My investigation made partly in the field and partly in the laboratory on models with the lightning generator shows that the maximum voltage that can occur on a transmission line depends upon the height of the conductor above ground. In fact, the lightning voltage above ground on a line is equal to a constant times the height of the line in feet. Thus:

$$V = g\,\alpha\,H = G\,H$$

where H is the height of the line in feet, g is the gradient in volts per foot at the instant before discharge while α depends upon the rate of discharge of the cloud and the size of the cloud. It approaches unity for a large rapidly discharging cloud. The highest value of g is 100,000 volts per foot. The maximum voltage that can occur on a conductor insulated above ground is thus 100,000 times the height of the line in feet. For theoretical reasons it is easy to see that that value will apply only in case of a direct stroke. Since direct strokes are not a very common occurrence, data obtained on actual lines during flashover are of greater interest. Values of the apparent gradient of from 20,000 to 30,000 are quite common, while values of 50,000 have been observed.

The practical lesson that can be drawn from this formula, I think, is best illustrated by an example. I shall take height above ground and conductor separation approximately equal to Mr. Sindeband's case. Assume 40, 50 and 60 ft. as the average height of the conductors above ground. Assume further that the storm is about a quarter of a mile away and G is 25,000. The voltage on the top conductor is then $G\,H$ = 1,500,000 volts. On the next conductor down it is 1,250,000 volts and on the bottom conductor just 1,000,000 volts. If a 10-unit string of insulators is used the lightning spark-over voltage is 1,400,000.

For this particular storm and this particular insulator and tower the top insulator would spark over, while the middle and bottom ones would not. With a more severe storm the top and middle would spark over. At G = 35,000 all three insulators would spark over.

In confirmation, Mr. Sindeband's data show that most trouble occurs on the top conductor; next on the top and middle and finally on all three.

Incidentally, such data offer a method of measuring these voltages. If the top insulator sparks over and not the other two the voltage is known within the difference between 60 and 50 or about 20 per cent. From the voltage and height of conductor the gradient is known. If the top and middle insulators spark over, a similar measurement is made.

From the standpoint of lightning alone it is undesirable to have a high tower.

If the above conductors were placed in a horizontal plane 40 ft. high, the voltage above ground for this particular storm would be 1,000,000. There would be no potential difference between conductors as in the case of the vertical arrangement. For the storm in question there would be no spark-overs.

How about the ground wire? Theoretically and also from studies made on models in the laboratory a single ground wire approximately cuts the lightning voltages in half if it is installed under favorable conditions. If it is assumed that the above factor holds in practise it is equivalent, as far as lightning is concerned, to doubling the insulation of the line, but with one very decided advantage. Doubling the line insulation doubles the voltage on the apparatus while the ground wire cuts it in half. If it functions properly, there is thus a double gain in using the ground wire.

Whether or not there is trouble on a line from lightning is a matter of the height of the tower and the insulation and is entirely independent of the line voltage except as it governs the number of insulators and the height of the tower. Since high-voltage lines are better insulated, less trouble should be expected.

I wish to say a few words on Mr. Sindeband's work and experience. Arc-overs have been experienced first principally on the top insulator, then on the top and middle, and next on all three. Instead of putting a great many more insulator units on the line, Mr. Sindeband has installed ground wires hoping that the ground wires will materially reduce the voltages and thus reduce the trouble. In addition, he has added the device at the end of the insulator string, shown in Fig. 18. This device is known as a grading ring or shield and was first developed for 220,000-volt lines in California. Its object is, primarily, to make the voltage distribute evenly over the string and make each insulator take its share of the voltage. In this part of the country, where there are heavy lightning voltages, it causes them to divide evenly over the string and makes each insulator take its share of the voltage. However, another very important function of a device of this kind is in case of an arc-over. It seems impracticable to make most low and moderate voltage lines absolutely lightning-proof, though it can be done if the cost is justified by making the tower low, using a number of ground wires and extra insulators. It is very important, therefore, to have some device that will cause the arc to clear the string and prevent burning and cracking of the insulators until the arc is suppressed by sectionalizing or otherwise. A horn gap might be used for this purpose. Studies we have made with the horn, however, show that it is very difficult to make it effective. The reason is quite obvious. It is this: With the horn there is no appreciable grading; about 25 to 30 per cent of the voltage is on the line unit. The sudden application of a lightning voltage causes the bottom unit to arc over, then the next and so on up the string. A complete cascade results. Even though a horn is adjusted at 60 cycles to clear very well it does not clear when the arc is started by lightning unless the separation is greatly reduced. We have not found this to be the case with the ring; it causes an even distribution at the start and there is no tendency for the initial arc to cascade.

1. A. I. E. E. JOURNAL, July, 1926, p. 641.

It clears the string and the 60-cycle arc follows the path of the lightning arc. If the relays operate quickly there is no damage to the insulators.

There have been very few actual operating data on the value of the ground wire. However, recent work indicates that the ground wire functions as the laboratory experience and the theoretical work shows. You will observe in Messrs. Sindeband and Sporn's study, as would be expected, that most trouble occurred on the top conductor. In a similar tower equipped with a ground wire there would be practically the same voltage on all conductors. Data on a line with a ground wire should, therefore, show a more even distribution of trouble. That is exactly what has been found.

L. E. Imlay: We have one important tower line supporting six circuits on which we have five grounded guard wires. We have had no lightning disturbances on this line except in two instances when the lightning came in from connecting lines having two ground wires. From our experience we believe that five grounded wires on the top of these towers give practically complete protection.

L. C. Nicholson: The Niagara, Lockport & Ontario Power Company operates a system of some 2000 circuit miles, mostly at 60,000 volts with some 110,000-volt circuits. The practise of the company is to use ground wires. We have had experience both with and without ground wires. Our experience without them was very undesirable.

The construction that has gone up in the last ten years is of the A-frame suspension-structure type with square dead-end towers using two ground wires, the ground wires being used not only for electrical purposes but also, for mechanical reasons, to support the A-frame structures. The ground wires used are substantial in size and well grounded and have given little if any trouble.

While we can't say that flashover from lightning on lines equipped with ground wires is nil, yet it doesn't amount to a great deal. I think it would average, in rough figures, one flashover per summer per hundred miles on a double-circuit line. From five to seven insulator units are used on 66,000-volt lines. The 110,000-volt system is not very extensive and has not been in service very long so I am unable to give any conclusive figures on that.

The burning of conductors sufficiently to cause them to drop is almost unknown. I attribute this to the fact that the arc does not remain in one position long enough to burn the conductor in two or seriously damage it. I believe there have been occasions when small conductors dropped within a time period after the occurance, but the matter of burning of conductors is not a serious one.

Insulators do not puncture. This is another great measure of progress which has been made in the last 10 or 15 years. When we first started operating that was our main trouble. They now occasionally flashover, but are seldom destroyed or disabled.

E. S. Healy: There is one important phase of flashover trouble that should not be lost sight of. Under all reasonably possible wind conditions, adequate clearance must be maintained on every tower in a transmission line.

In rolling country, it is very easy to encounter special conditions that give short clearances. Any special construction requires a careful study.

Of course, any difficulties caused by insufficient clearance must be eliminated before a study of lightning effect can be made. In the two cases of flashover troubles that I have been entirely familiar with, inadequate clearance was at least a contributory cause. One of these was a tree which had probably caused occasional trouble for nearly two years before it was discovered. Aluminum and small copper conductors will blow out and carry the insulator into seemingly impossible positions.

S. S. Hertz: An entirely new engineering contribution in Institute papers has been made by the authors, and that is the analysis and publication of their *mechanical* experiences with overhead ground wires. Their contribution of field experience in its *electrical* aspect is also especially valuable, adding to the fund of data in several previous Institute papers on the electrical aspects of the overhead ground wire, such as those contributed by Dr. Steinmetz, Mr. Peek, Mr. Creighton and others. At the Midwinter Convention of 1922, Dr. Steinmetz strongly emphasized the electrical protective value of the overhead ground wire for certain types of lines, giving his preference to the overhead ground wire over the lightning arrester, principally because the advantage of the ground wire is that its function is preventive while that of the lightning arrester is merely curative.

Mechanically, the overhead ground wire has gradually undergone an evolution which is of value to note here. Starting years ago with barbed-wire and almost no standards of construction, the overhead ground wires have been gradually improved until today it is generally agreed that the overhead ground wire circuit should enjoy the benefits of the same standards of construction as are used in designing the power conductors. That is exactly what the authors have done in the lines described. Operating difficulties and troubles from mechanical failures of overhead ground wires which, on few properties, have prejudiced the use of any overhead ground wire, can be fully solved by improving construction standards. The overhead ground wire, if used at all, should rigidly adhere to at least the same standards of material and construction as used in designing the power conductors with which they are to be placed.

The following improvements in construction standards are the ones which appear most needed to bring the trend of overhead ground wire design to par with the general design of power conductors. These standards have been employed on several of the recently constructed transmission lines:

a. Use of suspension clamps and strain clamps for the ground wire of the same general design as used for the power conductors.

b. Placing slightly less sag in the ground wire than in the power conductors (in sleet districts). This is advisable to provide ample separation when the ground wire is carrying sleet while the power conductors have shed their sleet load.

c. Use of non-rusting wires, so that the natural life of the ground wire will be at least that of the power conductors.

d. Assigning a slightly greater factor of safety to the ground wire than is given to the power conductors. For example, where the power conductors are designed with a safety factor of 2, it may be advisable to have a factor of safety of about 2,25 in the ground wire. In emergencies affecting the supporting structures, the ground wire would have to bear the greater part of the strain and in any occurrence of trouble it is good practise to have the ground wire safer than the power conductors.

H. B. Vincent: I'd like to ask Mr. Sindeband two questions: Has he determined the most efficient setting of the arcing ring with respect to the wet flashover of the string? In other words, what percentage of the wet flashover of the insulators is the wet flashover of the arcing ring? If so, at what ohmage water is the wet string figured?

Has he any record of troubles which actually occurred during rain storms?

Is the flashover shown in Fig. 18 a wet or a dry flashover?

N. J. Neall: Something that has been said in the discussion prompts me to mention a feature of lightning-arrester performance that has been observed during the last year in connection with some comparative tests of lightning arresters on an 11,000-volt system where a number of circuits are carried in a parallel horizontal plane arrangement to a given substation over an H-frame construction. It was found that the arresters attached to the upper transmission wires, particularly those just under the overhead ground wires, were the principal ones to discharge and the inference, pending further information, is that we have a sort of succession of protective zones beginning with the over-

head ground wire and then downward from conductor plane to conductor plane.

A. O. Austin: With the rapid changes in transmission work, there is a tendency to make an installation which is copied in many instances before operating records are available which will show up difficulties or advisable improvements or modifications. Hundreds and even thousands of miles are put in before any real operating experience can be obtained. This time lag is unfortunate and leads to a serious situation because line trouble of any description affects not only the operation and subsequent expenditures but financing as well.

In 1916 I presented a paper before the Toronto Branch calling attention to the dangers which were likely to occur with an increase in the size of the system, unless the factors of safety were materially improved. The discussion today brings this out clearly, hence the extended interconnection of large networks should be given careful attention as the increased trouble frequently more than offsets any economic advantage. The splitting up of systems, during storm periods or where the margin of safety is rather small or the circuit breakers likely to blow up, should also have more attention. A short circuit on the line today is far more serious than it was a few years ago owing to the fact that conductors are generally larger and the amount of current fed into a short circuit will create far more damage, not only to the line but to the possible connected apparatus. The time of clearing a short circuit also tends to increase with the size of the system in order to obtain selective relay operation.

Today plants are penalized for poor power factor, which results in loading the motors more heavily so that a drop in voltage frequently allows much apparatus to drop out of step. This causes heavy losses in some plants and inconvenience in all, warranting considerable expense where even momentary drops in voltage or bumps on the system can be eliminated.

In addition to the increase in number and seriousness of transmission interruptions, the cost of transmission lines is becoming more of a factor in the total cost of power. Additional parallel circuits are required to offset interruptions where lines are subject to flashover. The additional cost must be incurred whether or not the line can be cleared with a relay and circuit breaker. On some of the large systems considerable time is required following what would normally be considered a momentary interruption on a small system, before the line can be put back into service. There can be little question but that the success of future transmission systems demands that flashovers be eliminated as any other method is too costly and uncertain of results.

The whole subject needs the most careful consideration. If we apply common sense and carry the analysis far enough it will be found that there is general agreement as to the fundamentals necessary for the construction and operation of a transmission system. Above all we should not expect results which are not justified either partially or wholly by consideration of fundamentals.

The ground wire is a good example in point. A poorly installed ground wire may cause much mechanical trouble and while it may be of some benefit in reducing induced voltage or in absorbing a surge, the trouble which it causes may more than offset any advantage. Where the ground wire is installed on a wood pole it may so reduce the insulation that flashovers will result even though the maximum voltage may be reduced. While the shattering or burning of poles may be prevented, the increase in bird troubles and the elimination of the insulation furnished by the wood may more than offset any advantage in the use of a ground wire in this case.

Where a ground wire is installed on a steel structure the situation is somewhat different since there is no insulation in the structure to cut out. If the ground wire has good mechanical reliability it will, of course, reduce the maximum voltage tending to flash the line and, in general, conditions will be improved. There are some cases where the ground resistance is exceedingly high and if this resistance is materially reduced by the use of a ground wire, short circuits from lightning and birds will be increased.

An analysis of the field conditions, as well as tests in the laboratory, shows that a very great improvement may be expected from the complete impregnation of poles which will eliminate a low-resistance core. This low-resistance core tends to cause the pole to be shattered under lightning. This shattering can be eliminated only by increasing its resistance or by providing a shunt path. The former may prove most economical for new lines whereas the latter may be necessary for lines already installed. A down lead or lightning rod on the side, while saving the pole, tends to eliminate the insulation unless the ground resistance is high. In some cases the use of a gap in this circuit may be used to advantage in increasing the effective insulation for a surge or to prevent bird or squirrel trouble.

In the construction of a new system better operating conditions will be obtained if the cost of a good ground wire is used to provide more insulation and tower clearance or a more favorable electrostatic field around the conductor or live parts in the vicinity of the tower.

The old method of using a compass in tower design to determine clearance should be abandoned, as two towers having the same clearance may set up widely different electrostatic-field conditions so that one tower may have many flashovers while another tower having the same clearance may have few, if any, under the same conditions.

The ground wire is an old device and outside of improving its mechanical reliability, its application has developed little, if any, over a number of years. Practically the only improvement has been the limited use of the insulated ground wire which has given very good results.

It would seem that an improved application of the ground wire is very necessary and desirable if we wish to improve its effectiveness, and it is predicted that a great increase in its efficiency will be possible in a short time.

Bird trouble is a serious problem on some systems but it may be readily eliminated if wood poles can be kept from shattering or burning. This subject is receiving careful attention and reports from the field as well as experimental results would indicate that material improvements are possible in this direction. I am certainly not against the use of a ground wire. If, however, we find an improved method of using it or increasing its efficiency we may do much to reduce trouble and the cost of transmission lines.

The discussion today apparently leans toward the low structure. While I do not believe that this is essential where the necessary factor of safety is provided to offset the greater voltage induced on the line, it has certain advantages. The low structure means more supports and more insulators. More supports will permit the use of lighter insulators with much longer economic life which more than offsets the increased quantity. Where the low structure with its lighter mechanical loads is used it is possible to provide towers or structures which will set up a more favorable electrostatic field and thereby provide a higher flashover voltage between conductor and ground for a given length of insulator.

Owing to the fact that the electrical problems in preventing flashover on the transmission line are not so generally understood as the mechanical problems, there is a tendency to develop the mechanical end of the structures at the expense of the electrical performance of the line.

Unless the ground wire is so situated that an effective shielding exists, the upper conductor receives the greatest stress. While this is generally recognized there are few lines which provide more clearance and insulation for this conductor. On the contrary, the upper conductor usually has the lowest flashover stress for operating conditions. This results in much more

trouble than would be the case were the insulation and clearance graded in proportion to the stress imposed, whether this be the top conductor or the lower conductor. If the location of the ground wire reduces the stress on the top conductors so that the lower conductors have a higher maximum induced voltage we should provide greater insulation and clearance for the lower conductors. An arc from conductor or live surface to a tower member or ground is bound to be destructive if there is any appreciable power connected to the system and the successful line of the future will be designed to prevent arcs to ground rather than minimize their damage after they form.

In some cases it is necessary to minimize the destructive effect of flashovers, as it may not be possible to eliminate flashovers without incurring a prohibitive cost. The success, however, of some rather low-cost lines leads us to believe that a great improvement may be possible through a proper consideration of tower design and clearance and a better realization and use of the ground wire itself.

While the ground wire has been improved mechanically, its electrical efficiency has not been improved over the earlier installations. In some cases I have used a ground wire effectively to eliminate troubles which were very serious. In others trouble has been materially reduced by the removal of the ground wire. Hence, its economic importance depends upon the particular application.

More attention must be given to the tower as many of the newer and more expensive lines have made a poorer electrical showing than some of the earlier and cheaper lines. This is natural in a way as building costs have gone up tremendously and the tendency has been to offset the increased cost by building towers of smaller clearance or greater mechanical strength to handle the larger conductors. Since fixed charges form an appreciable part of the cost of power on many systems we are likely to use designs which cut the factor of safety, causing increased troubles, particularly where there is no precedent upon which to draw. There is a tendency to use a relatively shorter arm with the increasing size of conductor. This, together with the high braces and wide face of the tower in the direction of the line, while economical from the tower standpoint, makes the problem of preventing flashovers exceedingly difficult. Tower clearances in the past have been laid out by means of a compass rather than by studying the electrical field set up.

Much time and thought has been given to this subject over a period of years and I feel that within the next year a material improvement will result in the construction of transmission lines as the relative performance of different constructions can be determined experimentally to a very large extent and it is gratifying to know that results in the field apparently conform to tests in the laboratory.

It is exceedingly difficult to improve the standard of an existing system although it is evident that if a system having a low standard of operation is connected to another portion having a high standard, both of them will operate on the lower standard. Usually anything within reason which will raise the standard of the old system is justifiable and much time has been spent upon this problem.

It would seem that a new system should go in with ample clearance. I should rather see a new line go in with ample clearance and no ground wire rather than have the system installed with a smaller clearance and an expensive ground wire, as the latter can always be installed later whereas increasing the clearance after installation is a difficult and costly proceeding. Owing to the more severe conditions which may arise through interconnection, a ground wire which was unnecessary on the smaller system may prove advisable and can be installed at little additional expense over that necessary were it incorporated in the first installation.

As systems grow the demand and value of greater reliability increases and if this is hampered by too small a clearance or poor field conditions at the tower, the problem of providing greater reliability will be exceedingly difficult. While certain fundamentals are recognized clearly in the laboratory, it seems to me more difficult to recognize the application of the same fundamentals in preventing flashover on the transmission line.

On the transmission line the problem is to prevent an electrical discharge between the conductor or live part and the tower and support. The problem is to prevent the break-down of the air; hence, anything which will affect the maximum stress on surfaces which will normally discharge will have an effect upon the flashover voltage. It is obvious that the density of the field surrounding a conductor or a live part may necessarily vary greatly for a given clearance with the wide range in tower designs so that general statements based upon a specific instance may be very misleading. In most lines the discharge starts probably from the conductor or live part while in others there is reason to believe that the discharge actually starts from the tower or ground side owing to the fact that the greater density in the air is produced on this side of the gap. Where the latter condition exists, increasing the size of the charged surface on the conductor will necessarily tend to lower the flashover voltage and increase troubles, although in other cases this might be a very material advantage. While this is too large a subject to go into detail, a consideration of the conditions between electrodes will illustrate the problem fairly well and not only show the inconsistencies but, what is even more important, a means for increasing the flashover voltage for a given clearance. While this is fairly simple between ordinary electrodes, the problem is more difficult in service owing to the effect of rain and mechanical considerations.

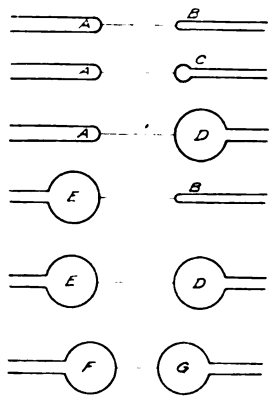

Fig. 1

Referring to Fig. 1, if we have a grounded electrode, A, and a live part, B, with a given distance between them, it is comparatively easy to determine their flashover voltage for conditions which are likely to exist on the line. If we maintain the same clearance between electrodes but use electrode C in place of B, the flashover voltage under the same conditions will be increased, particularly if we pay no attention to polarity. If, on the other hand, A remains the same and we replace the electrode C by electrode D, the flashover voltage will be reduced and may be even lower than that for A and B, owing to the greater concentration of stress in the air around electrode A. If we replace electrode A by electrode E on the ground side in combination A-B as in E-B, the flashover voltage may still be the same as in the previous case A-D, but will be lower than for A-B. If E represents the electrode on the ground side, and D on the line side, the flashover voltage will be materially increased over any of the previous cases. There can be no question about this and it only remains to make the application to the transmission line in order to improve the flashover voltage materially with the

resulting decrease in the number of flashovers. Up to the present time, there has been no line application which corresponds to the gap *E-D*, the applications being more on the basis of *A-C* which must necessarily have limitations compared to the possibilities of the gap *E-D*. There is one other case which it is well to consider, and that is the condition where we have a gap similar to *F-G*. In this case, while the electrodes apparently give a better field, their projection into the field or reduction in clearance reduces the flashover voltage until it is as low if not in some cases lower than the normal gap *A-B*. When we can make use of a dielectric which has a greater strength than air, together with some of the favorable conditions above outlined, it is possible to raise the flashover even for a given clearance far above anything now in use. Air gradient and not string gradient is the real problem.

There are three general schemes which may be used to advantage in connection with steel towers. One is to increase the clearance and improve the field conditions as discussed above. The second is to lower the maximum induced voltage by the use of a ground wire or lower the height of the structure. The third is to control the field in the vicinity of the conductor or at the upper end of the string so that the maximum flashover may be developed for any stress which may exist in operation. This is readily solved by the use of a sphere-gap in the laboratory and it may be approximated for transmission work. In the case of wood supporting structures the problem may be somewhat different as most wood structures furnish insulation which will provide a higher flashover voltage than exists on the largest steel tower line now in operation. The problem in this instance then is to make use of this insulation and increase the life of the structure. Complete impregnation apparently reduces the tendency to shatter and at the same time increases the life. In some cases it is further necessary to prevent burning due to leakage or due to discharge and experimental results would indicate that great improvement in this direction will be available shortly.

In the case of the steel tower, the economic problem is to develop the break-down strength of the air path and in the case of the wood structure to prevent burning or shattering. Much time has been spent on this over a period of years and possibilities in these directions are far greater and more nearly at hand than generally supposed. In many cases it may be advisable to effect a compromise of the several means to get the best economic results. It goes without saying, however, that improved flashover voltage over existing lines must be provided for the large system if high-powered transmission networks are to be extended much further. It seems that this problem together with the use of a lower transmission frequency are the most important ones facing the long high-powered line of the future.

J. H. Cox: Among engineers there seems to be a tendency to question the theory of a phenomenon and to question substantiating laboratory data until the case is proved by actual experience in the field. The theory of the ground wire has long been known. With typical arrangements, this theory indicates that by the use of a ground wire, surge voltages induced by lightning are reduced from about 40 per cent on the top wire to about 25 per cent on the bottom conductor, with vertical configuration. Mr. Peek's work with his lightning generator indicates a still greater protection, or about 50 per cent. Finally, these field experiences of Messrs. Sindeband and Sporn should establish beyond question the usefulness of the ground wire.

It seems strange, with theory indicating as it did a large measure of protection, that when trouble was encountered due to mechanical reasons the obvious solution—that of better mechanical installations—was not practised.

The proper proportion between line insulation and apparatus insulation has received too little consideration in the past. The authors bring up this point. Obviously it is less serious to have a line flashover than a bushing flashover or insulation puncture. During the past two years the Westinghouse Company together with the operating companies, has conducted surge investigations with the klydonograph on a great many power systems. During these investigations, we have conducted tests on 66-kv. lines having line insulation ranging from pin type, or three 10-in. disks to ten 10-in. disks. In spite of the ground wire, we shall always encounter a certain number of flashovers due to direct strokes and the highest induced strokes. More attention should be given this matter so that apparatus is not subjected to these higher potentials by over-insulating the line. On the other hand too low a value of insulation permits an excessive number of flashovers at a voltage lower than necessary and too low to permit the operation of lightning arresters.

There is a point in this question which though evident might bear mentioning. The proportional protection from flashovers afforded by a ground wire is far greater than that indicated by the reduction in surge voltages. If the number of surges between various voltages over a long period are plotted against voltage and a curve drawn through the points a curve is obtained resembling a probability curve as shown in Fig. 2.

If the full line represents the number of surges of various voltages on a particular line without a ground wire, a curve of the surges encountered on the same line with a ground wire

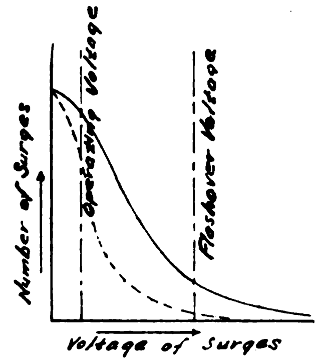

Fig. 2

would be displaced by the amount of the reduction accomplished by the ground wire, giving the dotted line. A vertical line may be drawn at the impluse-flashover voltage of the line in question. The flashovers of the line are caused only by the surges lying to the right of this vertical line. It is clearly seen that the flashover region under the dotted line is less than the flashover region under the full line by more than the percentage reduction.

Our tests with the klydonograph checks the authors' experience in that the highest potentials from lightning were always on the highest conductor and the lowest on the bottom conductor.

There were two points brought out in the discussion towards which I might be able to contribute. The question was asked as to whether flashovers were encountered at some distance from the lightning stroke, indicating a higher potential at some distance from the source. In our experience with the klydonograph, we have never encountered this situation except in the case of a flashover on an isolated-neutral system. We have encountered surges of the order of one million volts and at a distance of 50 mi. no potential greater than normal line potential was recorded. Where the lightning caused a flashover on an isolated-neutral line an over-voltage would be recorded at all stations no matter how long the line. This, however, was due to the acting ground set up by the flashover.

Another question brought up was whether or not the upper conductors afforded protection to the conductors beneath them. From the theory of the ground wire this is not possible except where the upper conductors flashover. The only protection afforded by the ground wire is due to the fact that its charge dissipates to ground with the discharge of the cloud and the

presence of a conductor remaining at ground potential reduces the potential induced on the neighboring conductors. The only way in which the upper conductors could shield the lower conductors is by discharging their charge to ground either by means of the flashover or by lightning arresters.

V. Karapetoff: In considering the influence of the ground wire, it is necessary to distinguish between its effect in reducing the over-voltage and the over-charge. These two effects are expressed numerically by different ratios. Consider the simplest case of a single conductor without any ground wire, with a cloud above charged positively. Then you have a negative bound charge on the wire, with the positive charge conducted to the ground through leakage. When a lightning flash takes place, the bound charge becomes free, so that the protective equipment is subjected, first of all, to an over-voltage, and secondly, there is a definite bound charge which has to be conducted to the ground, say, through a lightning arrestor.

Now consider a ground wire near the conductor. Certain equations may be established for the bound charge, etc. A solution of these equations gives the over-potential to which the line wire is subjected immediately after the stroke of lightning, and also the value of the charge released on this wire as a result of this stroke. The new values of over-voltage and of released charge may be compared with those obtained before, without the ground wire.

As a result of some computations which I have had an opportunity of performing lately, I find the ratio of the two over-voltages to be somewhat different from that of the two charges. Depending upon what you are interested in, that is, whether it is the maximum instantaneous over-voltage or the discharge capacity of the protective equipment (which is bound with the magnitude of the charge and not of the voltage), your judgment about the protective value of the ground wire will be different. My computations, unfortunately, have been made only for this simple combination. It would be desirable to continue these computations so as to include, say, three or six line conductors and a ground wire.

Herman Halperin: In my work as chairman of the A. I. E. E. Subcommittee on Lightning Arresters during the past year, it appeared that the members of the subcommittee and other engineers had many opinions as to the means of coping with lightning disturbances on high-voltage lines, especially those operating between 66 kv. and 154 kv.; but there were little definite data of operating experience, which is the final criterion, to show just what was accomplished by certain types of protection or methods of diminishing the magnitude of lightning voltages. The subcommittee members felt that more operating companies should gather complete data regarding the lightning on their lines, analyze the data, and submit papers along the lines of the one submitted by the authors today. Their paper is especially timely, as it concerns a voltage on which there is considerable discussion. I am sure that the industry will look forward to another paper in two years to compare the coming two years' experience of the authors with ground wires with the last two years, when ground wires were not used on certain lines.

In the future investigations of the authors, it might be well to obtain some data as to the magnitude of transient voltages on their lines, by means of a recording device such as the klydonograph. These data, when correlated with the operating experiences, will give a more definite idea of the effectiveness of the various designs in coping with lightning on their lines.

M. L. Sindeband: Mr. Cox mentioned the problem of insulation. In this paper, we mentioned the matter of over-insulating the transmission line and the bad effect this would have on the equipment in the substations resulting, as it would, in pushing the high voltage from the line into the stations. Of course, the ground wire would leave the transmission-line insulation unchanged but by cutting down the induced voltage it would have a particularly beneficial effect on the substation equipment since, as a general rule, the oil switches and transformers are not insulated as highly as the transmission line.

When we first started this problem and considered the idea of adding more insulators, the manufacturers of equipment objected since they argued that if the insulation of the line is going to be boosted, the insulation of the equipment should be boosted at the same time and they were afraid that this would lead to large expense. If that were done,—that is, if the line insulation were raised,—it does not necessarily mean that the equipment insulation has to be raised likewise since the station and substation equipment has, as a general rule, the benefit of a lightning arrester but the moment you go into that you enter into another controversy—namely, the lightning arrester—and there is almost as much disagreement about that as there is about the ground wire.

Mr. Vincent asked what particular feature of the rings governed their design. We experimented with the design of the rings only in so far as the clearing of lightning flashovers and 60-cycle flashovers were concerned. The wet proposition was not considered at all.

Now as to the table listing the troubles: On our original table sent in to the Institute we had some marks indicating which were under rain conditions and which under purely lightning conditions. Unfortunately, they were left out in printing. However, as we recall it, practically all of these troubles occured during rain periods, that is, they were a combination of rain and lightning.

Fig. 18 is a 60-cycle dry flashover test.

In conclusion, I wish to state that I believe that the operating companies should contribute their bit in helping the manufacturers of equipment with this problem, because certainly the manufacturing companies do spend a great deal of time and money for this purpose.

AUTOMATIC AND SUPERVISORY CONTROL OF HYDROELECTRIC STATIONS

(Smith)

Niagara Falls, N. Y., May 28, 1926

W. H. Gerrie: It may be of interest to relate some operating experiences in connection with two such plants as Mr. Smith has described. The plants I refer to are on the Central Ontario System of the Hydro-Electric Power Commission and consist of three generators per plant, the capacity of the units in the one being 2000 kv-a. and in the other 1400 kv-a. Excitation is supplied by direct-connected exciters and control by one regulator of the vibrating type in each plant. The plants are located on a navigable stream, the levels of which are required to be maintained within very close limits. Both plants are controlled from one point and the operator in charge has to operate in addition the plant where he is located, which has a capacity of 9000 kv-a.

The following satisfactory points have been observed up to the present:

(1) The reliability of the sequence relays.

(2) The saving in time of bringing on generators by the self-synchronizing method.

(3) The apparent reliability of the supervisory equipment.

In connection with the second point it is interesting to note that we are obtaining satisfactory results with the self-synchronizing method on generators that are not equipped with damper windings, but which have solid field poles. This is in part contradictory to the statement contained in Mr. Smith's paper.

Our experience so far has shown that we have had more troubles due to dirty contacts and sticking supervisory relays than we have had with the sequence relays. While their operation has given a fair degree of satisfaction, the troubles we have experienced point to the necessity of having a specially trained man available to analyze and eliminate these troubles with the least possible delay.

Some of the points on which we are rather skeptical at present are as follows:

(1) The economy of this system of control where less than four plants are so operated in the same territory.

(2) Whether the governors will perform satisfactorily enough to insure reliable operation after they have been in service for several years.

(3) Whether the method of controlling excitation by one regulator should be encouraged where several direct-connected exciters in the one plant are used.

(4) The proper method of obtaining battery-charging supply.

(5) Whether the remote meters as they at present exist are sufficiently reliable for satisfactory operation and for system operating records.

Elaborating on these, I might say that it is desirable to have an attendant available at each plant for ordinary cleaning who can be called out in cases of emergency. Also it is desirable to have a specially trained man for ordinary inspection who, in case of trouble on the supervisory or sequence relays, can locate and remove the trouble with the least possible delay. Under normal conditions this man should be able to handle four or five plants. Where only one or two plants are in service, the cost of his time together with the carrying charges on the additional capital cost of the plants does not leave sufficient margin to say definitely that the remote-control plant is justifiable. The same is true of the governors. These devices should have expert inspection and adjustment and this is not always available on small systems.

We have had considerable difficulty in obtaining balanced reactive loads with balanced kw. loads between generators in the one plant. This may become serious enough when operating at full kw. load to introduce excessive heating, causing the generator to be tripped off by thermal protection when it can least be spared. This trouble is directly attributable to the regulator operating under the above mentioned condition.

We have in use at these plants two systems for obtaining battery-charging supply, *viz:* (1) from the exciter system, and (2) from rectifiers. The first is impractical in that it cannot follow the ordinary system voltage variations between day and night conditions and between week-day and week-end conditions. The latter difficulty is particularly aggravated where a holiday follows a week-end. Also there is considerable inconvenience from blowing fuses on high excitation which, when it occurs, causes the battery to go on discharge. The rectifier has not as yet proved that it is reliable. It would appear that the most satisfactory results should be obtained from the motor-generator charger.

Two methods of remote metering in use are (1) current method and (2) impulse (condenser) method. While the latter method has given fair results, it is not without certain inherent defects the most serious of which is that variable control voltage will change the calibration. The time lag to the meter also is not a desirable feature when adjusting load on the plant. Extreme warm weather also affects the viscosity of the damping fluid to such an extent as to give an entirely different chart, although the actual frequency regulation may be the same. Also some of the condensers have become defective. Indications so far point to the current method as being the most satisfactory that we have experienced.

The operating company must thoroughly appreciate the manufacturer's difficulties in development in a new art such as this and be willing to cooperate in supplying operating data so that faulty applications may be weeded out. The manufacturer on the other hand must fully appreciate his responsibility in the development of a new art and wrong applications must not be permitted to get out into the field.

Another point that should be emphasized is the necessity for competent centralized supervision of such installations. The whole work should be under the supervision of a competent field engineer who is able to correlate all sections of the work.

It is also very important that manufacturers make a thorough analysis of system operating conditions before proceeding with any installation and the operating companies should lend all assistance possible in supplying the necessary operating data.

In Mr. Smith's paper I note that in section (G) he refers to shutting a unit down when the voltage drops to 80 per cent of normal for several seconds. In actual practise this works out as unnecessary protection and we may find the system dropping load on ordinary system surges.

Reference is also made to the use of annunciators for bringing to the attention of the attendant troubles of a serious nature. It cannot be emphasized too strongly that these annunciators should be very reliable. Also it has been my experience that the tendency is to have an insufficient supply of them.

Mr. Smith says that the multiple-unit station gives rise to no particular problem. I would like to draw attention, however, to the complications of such a system. It seems to me that the division of excitation is a real problem. Mr. Smith refers to one installation for the New England Power Company using direct-connected exciters and separate regulators. A description of the method of voltage control, in the light of the difficulties that I have already mentioned in using the one regulator, would be of interest.

Mr. Smith refers to the fact that in general the direct-connected exciter is by far the more desirable for automatic control. It might be of interest if Mr. Smith would elaborate on the various reasons for this statement. Also in applying this system of control to old stations which generally have the motor driven and turbine driven exciter, it might be of interest to know whether any problems of a particular nature would be introduced. It seems to me that the question of excitation unbalance between generators referred to above would be entirely eliminated with the one exciter, but it may be that other complications are introduced which make the direct-connected exciter preferable for automatic stations.

C. F. Publow: I would appreciate having Mr. Smith give details regarding the following functions which he notes automatic equipment is generally arranged for.

(1) Item "D": Protection against motoring the generator. We have found that owing to the changes in system frequency between the time a unit is shut down and started again, although of a very small order as will be shown later, yet when a unit is brought on it occasionally closes its gate tight and motors on the line until such time as the operator discovers the situation and corrects it. This in many instances would take upwards of at least a minute and I am interested in knowing what form of protection has been found suitable for such cases, as I believe this performance will be common to any system and more especially to some of the ones Mr. Smith refers to where the frequency varies upwards of five per cent.

(2) Item "F": Charging the battery. I would be interested to have Mr. Smith state definitely what method of battery charging he refers to. We have two methods (from rectifiers and from exciters where vibrating type regulators are used) neither of which has proved satisfactory.

I note Mr. Smith refers to using the exciter voltage for operating a speed device for placing a unit in service at approximately synchronous speed. How closely can this method be depended on to repeat itself? It would appear to have the disadvantage of having no protection for high exciter voltage, which would occur on overspeeds.

I was particularly interested in Mr. Smith's description of the connections used in mounting the protective equipment for the supervisory connections between stations, and I would appreciate a statement as to the functions of the various parts of this protection.

I would appreciate getting an expression of opinion on the following:

(1) The desirability of grounding the positive terminal of the

battery which supplies power to the automatic telephone type of supervisory equipment.

(2) The use of oil dash pots for controlling the governor during the initial starting period. This type of control has the disadvantage of (a) permitting "creeping" and (b) variations in its performance due to temperature changes.

In this connection I would like to ask if a motor connected to the governor stop control lever has ever been used. It appears to me that this device could readily be adapted for this work and overcome the two disadvantages noted above in an oil dash-pot control.

(3) The most desirable source of energy for the motor-driven governor fly-ball. Use has been made of potential transformers on the two stations on the Commission's system, but this supply is of no use in event of a machine pulling out of step. Slip rings connected to the exciter and mounted above the commutator would seem an ideal source of power supply for this important service if it can be obtained at a nominal cost.

(4) What would be considered a satisfactory value in ohms of a station ground in an average hydroelectric station, where remote supervisory installations are applicable.

Remote supervisory control to be successful is dependent on:

1. Reliable control circuits connecting the control and remote stations. These should remain intact except in cases of direct lightning strokes or where a high-voltage line falls on them and in such instances the protective equipment should function to limit the damage done to the point where the fault occurred.

2. A signal once started by the operator at the control point or automatically by the equipment at the remote station must repeat itself until the "answer back" or equivalent is received which de-energizes the repeating circuit; *i. e.*, indications must be correct, or by repetition warn the operator that trouble exists, and the design of the equipment should incorporate the feature that the equipment at the two ends will re-synchronize before repeating the code.

3. The equipment in its design must incorporate No. 2 above and be mechanically rugged enough to perform the service required of it with a minimum of maintenance.

4. Means should be provided which will permit canceling a supervisory signal where one has been put through and the automatic sequence has failed to complete its function at the remote stations. Under such circumstances the operator may be helpless and considerable damage may result before an attendant can be rushed to the remote station. This feature seems desirable in addition to the automatic sequence scheme being arranged to permit only one start, in event of trouble, unless the supervisory signal is repeated.

5. When there is a considerable number of indications, some are much more essential than others and it may be desirable to have incorporated in the supervisory scheme, means of giving these more essential signals precedence over the other. In all cases I believe it would be advisable to give order signals from the control station precedence over signals originating from the remote stations.

6. A high degree of maintenance care. This should be generally in one individual's charge who is fully familiar with the circuits and the operation of the equipment.

Automatic switching equipment can be made thoroughly reliable by adhering to the following points:

1. That the sequence scheme is well adapted for the work it must perform.

2. That suitable relays and corresponding equipment have been chosen which will always perform their function accurately whenever required and failing this will make the sequence inoperative.

3. That a proper assembly of this equipment has been carried out. This applies to their location and connecting with a view to their particular function from a safety standpoint and also with ease of maintenance. It would seem desirable that all contactors should be provided with positive wiping contacts which will assure good contact even though they are dirty.

4. That the equipment should be carefully adjusted by thoroughly competent men when installed, to perform their particular function so accurately that they may be depended on to "repeat" and that for the first few months this performance be carefully checked and an accurate record of it kept. This record will serve as a guide to the frequency of inspection required in the various parts later on. The speed device is an exceptionally important one to which the foregoing comment is particularly applicable.

5. Workmanship of a high order is required on the various devices used and in their assembly.

6. A competent maintenance man should be in charge of the equipment. It is essential in maintenance work to be observant of equipment the functioning of which will inherently vary with weather conditions, and in this connection I believe manufacturers should supply data on the performance of their equipment of this nature. This will materially assist the operating companies in making the needed adjustments and in this way they will be warned of the necessity of watching these points carefully. The dash-pot control of the governor for controlling the unit during the starting period is a good example of this type of device.

In the installation and initial operation of both supervisory and automatic equipment, too much care cannot be taken in accurately checking, point by point, every piece of equipment.

The following points should be given attention:

(1) Careful consideration should be given to the mechanical work where devices are attached to the generators in order to avoid their being damaged during disturbances.

(2) The brakes should be interlocked mechanically and electrically so that they cannot be applied with the unit connected to the system.

(3) Trip-free devices should be furnished if this feature is not incorporated in the sequence relays.

(4) The choice of air or oil brakes should be given serious consideration. We have oil brakes on all six units and so far it has been impossible to make them oil-tight.

(5) The inherent characteristics of each individual device should be thoroughly known in order that under the different ordinary conditions which will occur in the actual operation of station they will inherently correct for the variations from normal.

As stated in the foregoing, the supervisory control circuits connecting the control and remote stations must be practically invulnerable. These circuits may be affected whenever a disturbance occurs on the transmission lines, which they usually parallel, and unless special precautions are taken, the control circuits will be inoperative just at the time when they are most needed, and this from an operating standpoint is a very serious condition. For nearly a year and a half, serious troubles have been experienced by the Commission, on the control circuits to the two supervisory stations mentioned by Mr. Gerrie. By exhaustive testing and analysis, the inherent weakness has been located and by the installation of protective transformers, now being built, the supervisory circuit should be immune from all transmission line troubles, except a direct stroke of lightning or where a high-voltage line falls on the supervisory control circuit.

The stations in question are Ranney Falls the control point, Dam No. 8 and Dam No. 9. The distance from Ranney Falls to Dam No. 9 is approximately 1½ miles, and to Dam No. 8 is 3½ miles. They are connected by one 44-kv., 3-phase, 60-cycle line which feeds out of Ranney Falls and loops in to Dam No. 9 and Dam No. 8, and thence to Sidney Terminal Station some 20 mi. south, a line which forms part of a 44-kv. network of some 400 mi. of line and which is complicated by several loops. The supervisory connecting wires consist of standard paper-insulated, lead-covered telephone cable located on the same right-of-way as the 44-kv. line, but on a separate pole line at an average distance of 25 ft. from the

high-voltage line, a 20-pair cable between Ranney Falls and Dam No. 9 station and a 10-pair cable between Dam No. 9 and Dam No. 8 stations. Twelve conductors are required under the existing conditions for the control of each station and 66 different operations are performed besides the metering and water-level measurements at each station.

In each of the remote stations there are three generating units which with their respective step-up transformer constitute a unit. The generators in both stations are vertical, water-wheel driven units with direct-connected exciters. The units are of 1400-kv-a. capacity at Dam No. 9, and 2000-kv-a. capacity at Dam No. 8.

It may be of interest to note that the turbines in Dam No. 9 are of the propeller type and the generators are equipped with damper windings while at Dam No. 8 the water-wheels are of the Francis type of runner, and the generators are not equipped with damper windings. Self-synchronizing of the units is employed in both stations. This practise at Dam No. 8, from current literature, would appear as questionable practise, but results have proved it very successful. It should be noted, however, that the generators in this station have solid field poles.

Induction was first thought to be the trouble, but an analysis indicated that the burn-outs were much too severe to be caused by it under the existing conditions. It later was discovered that on account of the high-voltage neutral being grounded to the station ground at the control point, the lead covering of the supervisory cable was acting as a ground stabilizing conductor whenever faults occurred on the high-voltage transmission system with a flow of ground current. By removing the high-voltage neutral ground at the control point approximately 1000 ft. from the station, trouble of this nature was mitigated except where due to a lightning-arrester discharge or an insulator spillover at the control or either of the remote stations. The system is operating at present under this hazard with operators maintained in both the remote stations. The protective transformers referred to in the foregoing are designed to make the supervisory cable immune from these troubles.

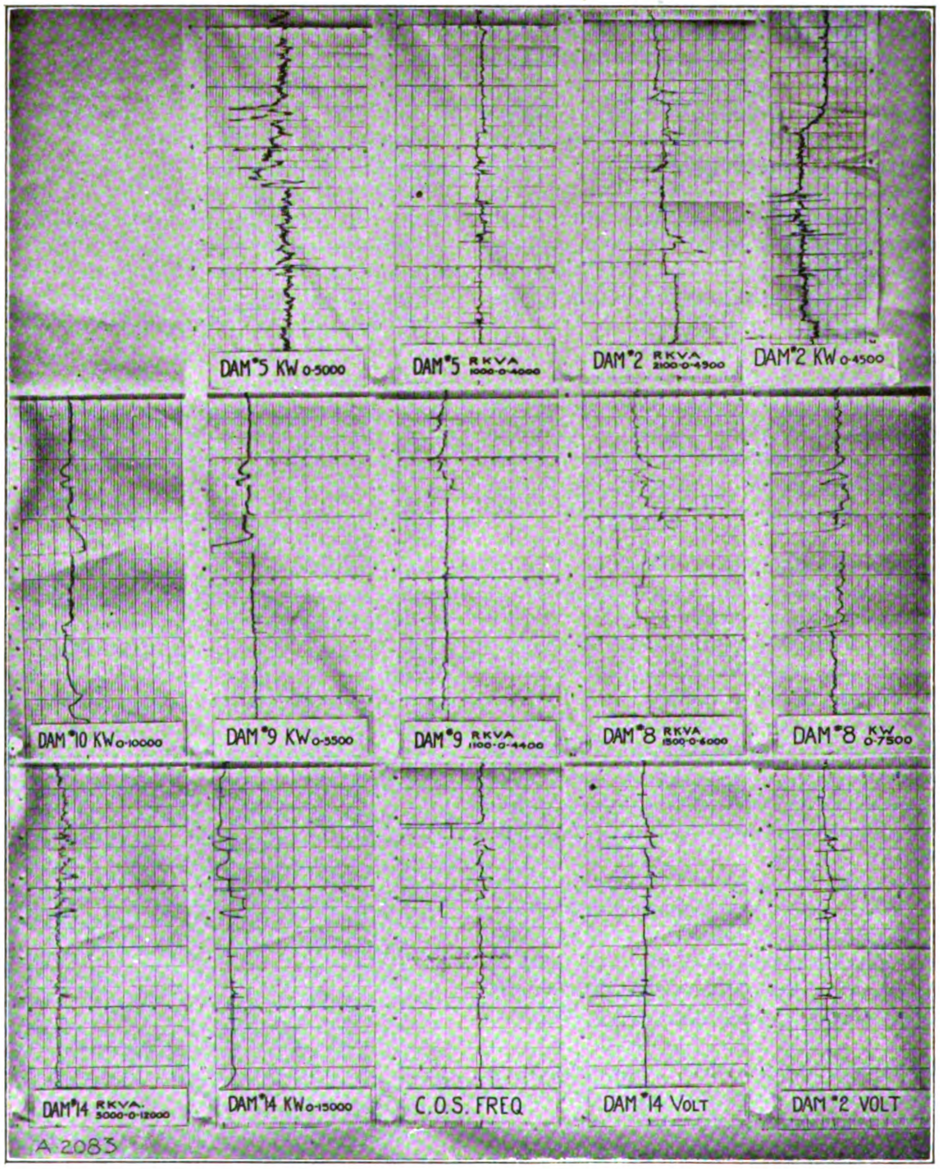

Fig. 1

For a period of approximately three months during the past winter, the supervisory control was not in operation. When again placed in service, very little trouble was experienced, and only a few cases of mechanical trouble have occurred in the past two months, a performance very creditable to the equipment.

Dependence is not yet placed in the control and operators are still on duty at the remote stations.

In attacking the problem of the installation of operation of the automatic and supervisory stations, an effort was made by the Commission quickly to acquaint its staff of engineers and operators who were to be directly responsible for the installation and operation of these stations with the details of their connections by preparing unit diagrams of correlated devices; *i. e.*, the automatic connection diagrams as supplied by the manufacturing companies were split up. A corresponding drawing of the governor was also prepared. These have been of untold value and still form a ready reference.

Fig. 1 shows a number of graphic meter charts taken during a period of several hours on the morning of September 18th, 1925, at which time there was a severe electrical storm over the entire system. Note how closely the frequency is regulated even during such a time. This group of charts forms a very interesting study of this system's operating characteristics.

Fig. 2 shows a number of oscillographs which form part of the test on the performance of these stations.

I feel that much more successful tests could be obtained now, as a decided improvement has been made in the regulator and governors and speed control adjustments since the tests referred to in the foregoing were conducted and these changes would vitally affect the performance of the equipment. The oscillographs shown refer only to Dam No. 9 station; those obtained for Dam No. 8 station were equally successful, the disturbances of course being considerably different due largely to the differences in design of both generators and turbines. It may be interesting to note that on a number of the oscillographs referred to, as many as five quantities are readily readable on a three-element oscillograph. For measuring speed on these, a chronograph method, similar to that used by Mr. J. A. Johnston but developed independently by the hydro engineers, was used with success.

A. G. Darling: The problem of self or automatic synchronizing has been very much discussed. I want merely to cite two cases of self synchronizing under very difficult conditions which have been successful.

One case was in a paper company which uses power to drive paper machines which require very close speed regulation. This particular case involved a 750-kw. steam turbine generator and an auxiliary 3000-kw. steam turbine generator. The first was non-condensing and was used to supply power directly to the paper machines while the second was put on the line when the power company did not have sufficient power available to furnish power for the balance of the mill. They were operated in parallel.

The operator in charge had great difficulty in bringing in the 3000-kw. machine by the usual method of exciting first and then synchronizing by a synchroscope without breaking the sheet on the paper machine.

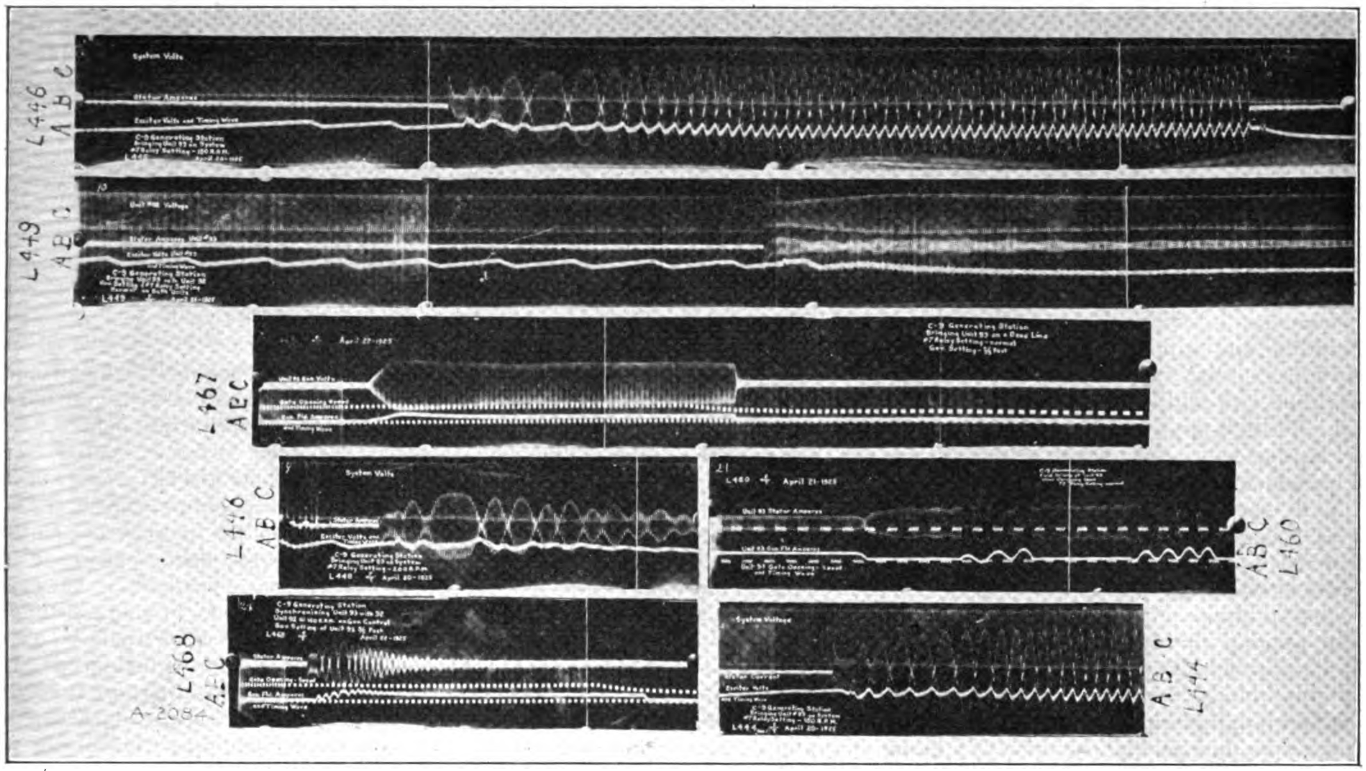

Fig. 2

He asked for advice on the point and it was suggested that he bring in the 3000-kw. unit by the self-synchronizing method, that is to say, put it on the 750-kw. turbine without its field being excited. His success after that was uniform. He did not have to depend on the operator's accuracy and his sheet was not broken when synchronizing the 3000-kw. machine.

The second case is of another paper company in the middle west which operated two steam-engine-driven paper machines. In addition to the paper machines, 200-h. p. synchronous motors were directly connected to the engines.

Initially these two motors were supplied from the power company in the vicinity without a great deal of success because the speed regulation of the power company system was too wide to permit paper being made consistently for 24 hrs. The paper company owned a hydroelectric development nearby and installed there three 2500-kw. units. One unit was on the line all day long and the other two units came on and went off as the water level increased and decreased during the day, so that there were two operations of synchronizing and two of coming off the line during every 24 hrs. These machines were put in parallel with

the 200-h. p. synchronous motors on the paper machine drive and were self synchronized.

The plant has been operating for two years, I believe, and they have had no difficulty with breaking the sheet of paper when the 2500-kw. units are put on in parallel with 200-h. p. motors.

F. V. Smith: Mr. Darling's experiences with the difficulties encountered with manual synchronizing and the success of self-synchronizing methods are interesting and bring out strongly the necessity for very accurate synchronizing in some cases. The average paper-mill operator cannot always be expected to hit the mark and it is apparent that if a machine is excited and thrown in out of phase it will produce more disturbance than if put on the line as an induction motor. With a reliable means of assuring proper phase relations as is done by the automatic synchronizer the disturbance would be reduced to practically zero.

Mr. Gerrie also has mentioned successful self-synchronizing with machines without dampers. This is sometimes a possibility and should always be tested out in case of old machines that are to be made automatic and are not provided with dampers. In certain cases with a large number of solid poles sufficient current will circulate in the pole faces to pull the machines into step. This is the exception rather than the rule, however.

Mr. Gerrie and Mr. Publow have brought up a number of points which will be covered in order.

As to the economy of supervisory control installations, every problem has to be treated separately. Proper inspection and maintenance is, of course, necessary but any operator capable of testing and adjusting relays should be able to handle the supervisory control without difficulty. There are many systems operating with only one or two plants and finding it quite economical. There is no reason why the governors should not function as satisfactorily after years of service as any other piece of equipment.

As to regulators, by far the most satisfactory arrangement is to have a separate regulator for each machine. Proper division of reactive current can then be secured without any difficulty by proper cross compensation; any instruction book on regulators will explain this connection.

In general, the battery should be charged from rectifiers. This is particularly true where a regulator is used on the exciter and the voltage varies over quite a range. The control for rectifiers is quite simple and most suitable for automatic stations. There is no fundamental objection to a motor generator except the additional expense and complication of control which is not in general felt to be justified.

The integrating type of remote metering should be perfectly accurate while the graphic type should be accurate within three per cent which is comparable with any graphic meter. The various types of metering schemes available have their application depending on the kind of indication required and the length and characteristics of the control circuit. In adjusting load the time lag in the meter should be no greater than that in the governor and gate mechanism and it is difficult to see that this is of any particular moment. Any operator would naturally wait for a few seconds after changing load before making another adjustment.

Both Mr. Gerrie and Mr. Publow refer to the failures of supervisory-control cable when faults occurred on the high-tension line owing to lack of foresight in locating the station grounds. It is to be hoped that this experience will prove of value to others.

The question as to the setting of low-voltage relays and the number of annunciators provided can always be adjusted to the satisfaction of all concerned.

As to the multiple-unit stations, where individual regulators and direct-connected exciters are used with rectifier control for the battery, the problem is not difficult to handle. The parallel operation of regulators has already been mentioned.

The direct-connected exciter is particularly advantageous because of the elimination of all starting or governor control for a separate motor-generator set or water-wheel exciter together with the protective apparatus that would have to be provided. The time of starting and getting on the line would also be delayed by the time necessary to start the exciter and another link would be added in the chain which should be made as simple as possible in all automatic stations.

Mr. Publow brings up a number of points that have already been covered. The shutting down of a generator due to high frequency on the system has not been encountered to any extent. It is difficult to say why it would not be satisfactory to set up the governor to the top frequency limit so that the automatic generator would tend to take load rather than shut down and then by means of supervisory control the load can be adjusted afterwards to suit.

The application in which exciter voltage is used to determine approximately synchronous speed is one in which the automatic generators are small in comparison with the whole system and accurate adjustment is not necessary as the current surge on closing the breaker is unimportant. This does not interfere with over-voltage protection of the exciter.

The arrangement of protective tubes has already been described in the paper; there is nothing further to add on this point.

Mr. Publow has listed a number of points on which successful supervisory control is dependent. I find myself in hearty agreement with these; they are all incorporated in the code type of supervisory control. Also automatic switching is in general in accordance with the factors mentioned.

As to the desirability of grounding the battery, it is found much more satisfactory to keep the battery circuit entirely isolated so as to prevent any faulty operation by accidental grounds.

Difficulties with the oil dash-pot for governor control have never been found to be of any importance and as far as is known it has never been felt necessary to use a motor mechanism.

The same feeling exists as to control for the governor motor; while it is open to objection at times the change suggested has never been felt warranted. There is no objection to it, however.

It is not possible to give a definite figure for ground resistance; that which would be satisfactory in some cases would be quite unsatisfactory in others. The essential point is that the ground resistance should be such that is is considerably less than the path provided through the supervisory circuit which can be determined for any particular case.

There is a last important point which must be considered and which has been mentioned by both discussors, and that is the relation of the manufacturer to the installation and operation of the equipment. While it is the duty of the manufacturer to furnish the apparatus with complete information, it is a question whether it is desirable that he should take care of all the installation and initial operation. As the operating company's men must ultimately take charge of everything and also correct troubles when they occur, there is no way for them to become better acquainted with the details than in the erection stage and the more they have to do with it the better; they will then feel enough confidence to go ahead when difficulties occur. Many operators feel that there is something mysterious about automatic control. There is no justification for this attitude and there is nothing in automatic and supervisory control that cannot be handled by intelligent operators without constant appeals to the manufacturer.

These tests were made on 1400-kv-a, 180-rev. per min. units driven by propeller-type turbines.

In L 446 it is interesting to note what a slight disturbance was noticeable in the system voltage when a unit was placed on the line and failed to "pull in" due to its slow speed. The machine was thrown on the system when it had a speed of 150 rev. per min. Curve *A* shows exciter voltage and timing wave. Curve *B* shows stator amperes. Curve *C* shows system voltage.

L 499 shows a unit synchronized with a duplicate unit carrying

no load and although an abrupt voltage disturbance occurred it was practically damped out in a second. Curve *A* shows exciter voltage on the unit being synchronized. Curve *B* shows stator amperes on the unit being synchronized. Curve *C* shows voltage of the running unit.

L 467 proves how smoothly and quickly an isolated unit can be placed in service on a system. Curve *A* shows field amperes and timing wave. Curve *B* shows gate opening and speed. Curve *C* shows generator voltage.

In L 448 where the unit failed to "pull in" due to overspeed, there will again be noted the slight voltage disturbance which occurred and also the peculiar alternately large and small stator-current disturbances. The machine was connected to the system when running at 200 rev. per min. Curve *A* shows exciter voltage and timing wave. Curve *B* shows stator current. Curve *C* shows system voltage.

A severe test of field failure under load is shown in L 460. Apparently there was no tendency for this unit to pull out of step at the load carried. Curve *A* shows gate opening, speed and timing wave. Curve *B* shows field current. Curve *C* shows stator current.

The test shown in L 468 was performed to illustrate the ability of a unit (No. 93) to pull into step with a duplicate unit (No. 92) running under no load at a reduced frequency. Unit No. 92 was running at 160 rev. per min. on governor control. The governor of No. 93 was set for highest speed. Curve *A* shows generator field amperes and timing wave. Curve *B* shows gate opening and speed. Curve *C* shows stator amperes.

L 444 shows the failure of a unit to pull into step when connected to the system while running at 150 rev. per min. Curve *A* shows exciter voltage and timing wave. Curve *B* shows stator current. Curve *C* shows system voltage. This, it should be noted, is a duplicate of L 446, but the initial disturbances are quite different.

STEEL-ENCLOSED POWER RECTIFIERS[1]

(MARTI)

NIAGARA FALLS, N. Y., MAY 27, 1926

R. H. Wheeler: Mr. Marti has been quite conservative in many statements in his paper. Progress in the development of the rectifier, together with its applications in commercial service, is going forward at a rapid rate. One thing that Mr. Marti did not bring out, and which from my angle is interesting, is that the rectifier is a piece of machinery which has the ability of being placed in practically any available space, rather than demanding a machine hall with ample provision for ventilation. The floor loadings required by the rectifier are less than 200 lb. per sq. ft., and permit of the rectifier being installed directly without special foundations.

I wish to confirm the statements of Mr. Marti as to the absence of noise. There are no reciprocating parts other than that of the vacuum pump which, when it is running, makes a chatter, but when one realizes that it is operated by a fractional h. p. motor, it is at once evident that the noise is not great and can easily be muffled by a cover if absolutely noiseless operation is desired.

Otto Naef: Mr. Marti mentioned that in order to obtain close d-c. regulation, special equipment must be added, and he quoted the interphase transformer, or absorption coil, as it is often called, as one of the means.

After considerable research, Brown Boveri has succeeded in bringing out a zig-zag-connected transformer winding which gives the same close regulation as is otherwise only obtained by the use of an interphase transformer. Because of the somewhat larger transformer required, this solution is not necessarily cheaper than the older method, but it has the advantage of greater simplicity.

1. A. I. E. E. JOURNAL, Sept. 1926, p. 832.

D. C. Prince: Mr. Marti refers to an ingenious seal as having made possible the successful steel-tank rectifier. The accompanying Fig. 1 shows one of these earliest types of steel rectifiers, built about 1908. The operation of these early rectifiers compared favorably with that of any of the newer types.

In saying that the quantitative relations on which rectifier design is based are well established, Mr. Marti doubtless refers

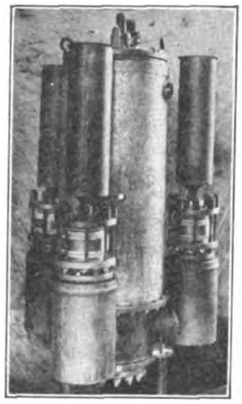

FIG. 1—EARLY TYPE OF STEEL-CLAD MERCURY-ARC RECTIFIER (1908)

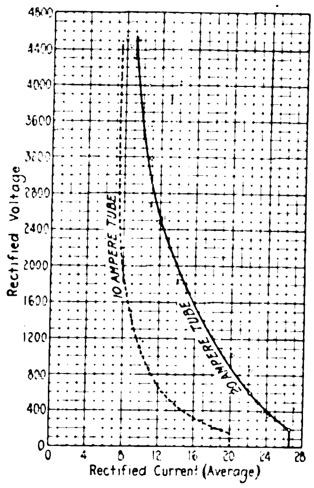

FIG. 2—VOLT-AMPERE CURVES MADE FROM GLASS RECTIFIER

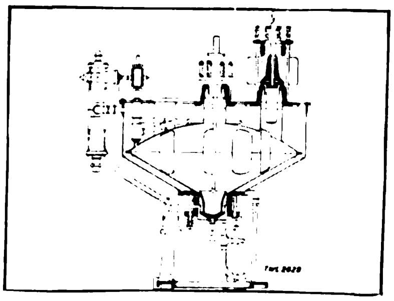

FIG. 3—A. E. G. TYPE OF RECTIFIER

to the circuit characteristics. As far as I am aware, no data for metal rectifiers have been published including reproducible curves between volts and amperes at which arc-back occurs, such as shown in Fig. 2 herewith. This curve was made from a glass rectifier.

The extent to which engineering opinion differs regarding the fundamentals of steel rectifier design is brought out by comparing the accompanying Fig. 3 with the Brown Boveri

rectifier shown in section in Mr. Marti's Fig. 10. It will be observed that the A. E. G. type has no arc guides and no condensing dome nor any elaborate anode hoods. The A. E. G. rectifiers are regarded as highly successful, and there are many installations. I understand that they have little if any seal trouble.

Even the figures accepted for some years for cathode drop have recently been overthrown[2]. The present figure is about 10 volts, part of which is consumed as latent heat of ionization of the mercury vapor. This part is responsible for most of the heating at the anodes where recombination occurs.

Too much cannot be said in praise of the paper by Messrs. Daellenbach and Gerecke referred to by Mr. Marti as the basis for his circuit theory. The part quoted by Mr. Marti, applying to regulation, is limited to the case of no resistance and reactance only in the individual anode leads. It is also limited to the case where not more than two anodes carry current simultaneously. The original paper by Messrs. Daellenbach and Gerecke is much more complete and will repay careful study, although the analytical methods pursued become rather involved for the more complicated cases met in practise. Their paper has been very useful in my work.

E. B. Shand: A number of years ago the Westinghouse Company did a great deal of work on steel-tank rectifiers, and a resumé of this was given by the late B. G. Lamme in the discussion of "Power Rectifiers" by Milliken, *Proc.* Assoc. Iron & Steel E. E., 1921, p. 645. In this work, we started using mercury seals with the steel tanks in 1908 and developed them in 1909 to the general type used at present by the Brown Boveri Company. In 1915 considerable amount of work was done on plastic sealing cements. Our experience at that time indicates that the tightest possible joints can be made by this means, although the application to commercial use presents an additional problem. At this time we were able to operate rectifiers of commercial size with these seals for periods of somewhat over a month, without pumping. Welded tanks were introduced in 1910.

I might add that the wire resistance gage for high vacuum, which is mentioned in Mr. Marti's paper (Figs. 16A and B), was developed during this work in 1916 or '17. I still have in the laboratory a gage of this sort which dates from the above period.

A single auxiliary anode was used for both starting and exciting of the rectifier. An external source of direct current was supplied to this anode. Small rectifiers are now available for the purpose of furnishing this power and which require no attention of any sort.

In connection with the bibliography, I believe that the interesting papers of M. Giroz[3] should be included.

In connection with the tabulated data on the sixth page of Mr. Marti's paper, I notice that the case of three single-phase transformers connected in star has not been included. In this case, the current ratios in the transformers secondaries and in the primary line are similar to the case of the delta-connected transformer with the balance coil.

It might be added that the balance coil or interphase transformer was developed in connection with the earlier work of the Westinghouse Company by Mr. C. L. Fortescue.

S. Q. Hayes: A point that may be of interest to a good many people is that the electrification of the railways in Japan now being carried out at 1500 volts direct-current has quite a large number of substations, and some of those substations have synchronous converters, some have motor converters, some have motor-generator sets, and some have mercury rectifiers; and they are operating the whole system together in parallel.

F. A. Faron: Mr. Marti infers in his paper that arc-backs occur during the bake-out or forming period. Are we to understand that arc-backs never occur during regular operation?

On the twelfth page Mr. Marti refers to the possibility of a rectifier starting to take peaks of such short duration that converter units would miss these peaks. What he says about starting may be true, but why should a machine be started to take care of such peaks? This is what the overload capacity of the machine is for. And if the load goes beyond this allowable limit, it is not usually a useful one and devices are provided to take care of limiting the output. With reference to regulation, it should be noted that it is possible, as brought out by Mr. Prince, to build rectifier equipment with practically flat d-c. voltage characteristics from low load to full load.

Mr. Marti indicates that traction loads are handled by converting equipment with drooping characteristics. This is not quite correct, for in 90 per cent of the traction substations in this country, compound-wound machines are used, having practically flat voltage characteristics from no load to full load.

Fig. 20 is apparently based on a maximum rated unit. Experience has shown that railway operators are not particularly interested in a maximum rating but in what the machine will do for a period of about two hours, which is the usual duration of peak service. This is fairly well brought out in Curve 21-*B*, on the same page. In comparison with Curve 20, it should be noted that a standard 500-kw. railway converter, for instance, would be rated 750 kw. for two hours and three times load for one minute.

Does Mr. Marti intend to convey that all equipment including rectifiers, transformers, auxiliary devices and switchboard for 600 volts take about the same space as complete converter equipments, or does he mean only the tanks? I am of the opinion that the complete installation of rectifiers, transformers, reactors, accessories, switchboard, etc., occupy more space than equivalent converter capacity for this voltage. I agree with Mr. Marti that, for higher voltages, the complete rectifier units require less space than converter units.

In traction work it is quite common to provide single-phase transformers which give the possibility of open-delta operation of converters in cases of emergency. This feature is not desirable in connection with a rectifier.

Under the subject of starting it should be noted that in automatic stations it is usually found more economical to remove the transformer from the line when the station is not in operation, to save the transformer excitation losses.

I have been unable to check the figures given under the heading *Efficiency*, as the converters offered by American manufacturers have higher efficiencies than those shown on the curves of Fig. 21A and actually cross the efficiency curve of the rectifier at about 600-kw. point, and show somewhat over one per cent higher efficiencies of the converter than Curve *A*, which reduces the hypothetical saving set forth by Mr. Marti.

I am fearful that "automatic control" is a rather abused and misunderstood term, but it should be understood as applying to a station wherein all functions of operation are performed without the aid of an attendant.

Certain functions necessary to the operation of a rectifier, which are absent with converter operations, must be properly incorporated in the control, and protection provided should the sequence of the device in operation be other than that intended.

There will be certain temporary shut-downs during operation which the control must take care of; such, for example, as low a-c. power supply, single-phase operation, overheating of the rectifier, failure of the exciting arc and overheating of the transformers.

Furthermore, such conditions as failure of cooling-water supply, continued arc-backs, heavy sustained overloads, etc., require that the equipment be shut down and locked out, and

2. Gunther-Schulze, *Engineering Progress*, Aug. 1925, (in English).

3. Les Redresseurs a Vapeur de Mercure, *Bulletin de la Societe Francaise des Electriciens*, June, 1924, p. 463.

Les Redresseurs a Vapeur de Mercure Grand Debit, *Revue Generale de l'Electricite*, Nov. 20, 1920, p. 721.

La Chute de Tension Inductive des Redresseurs a Vapeur de Mercure, *Revue Generale de l'Electricite*, Feb. 14 and 21, 1925, p. 253 and 303.

that the automatic control be designed to carry out these functions.

Incidentally, a very careful investigation has convinced me that there have been no rectifiers built which will not arc-back if the vapor-pressure conditions in the neighborhood of the anode are not correct.

Mr. Marti says: "For instance, a railroad equipped for using 600-volt direct current can be changed to 1200-volt direct current merely by changing the connections of the transformers and making no changes whatever in the rectifiers." It is one of the advantages of rectifiers to be able to use the same unit for higher voltages, provided it is suitably insulated;—but unfortunately the substation is only one thing that must be changed; in fact, changing the substation voltage, even where converters are used, is a relatively small expense compared to insulation of line, sectionalizing switches, motors, control, etc.

The substation of the average traction system in this country represents only an investment of about 20 per cent of the total investment in electrical apparatus and of this the converter and transformer represents about one-half, and it can readily be appreciated that changing the voltage at the substation is a small part of the total cost.

There have been cases in the past where it was as simple to arrange substations originally designed for 600 volts and which contained two or more machines to provide for 1200-volt operation, merely by insulating the base of one machine and connecting the units in series; in fact some of the first 1200-volt roads in this country contain substation equipments arranged in this way. I would therefore suggest qualification of this statement.

In another sentence of this paragraph attention is called to the rectifier being able to withstand "instantaneous currents of even three times the normal value." It should be noted that standard, 500-kw., synchronous converters for railway service are guaranteed to stand three times normal load for one minute.

From this discussion it might be assumed that I oppose rectifiers as against synchronous converters, but such is not the case. Rectifiers are a comparatively new type of apparatus in this country, and their operation will be watched with interest, for undoubtedly there are applications where rectifiers are desirable. There are some points in Mr. Marti's paper, however, with which I cannot agree.

Albrecht Naeter (communicated after adjournment): Having had the privilege of making an acceptance test of one of the early Brown Boveri rectifiers in the United States, the writer was very much interested in this article by Mr. Marti, for he found that in the early stages of operation, after the forming period of the electrodes of the particular set tested, considerable difficulty was encountered by the operating staff in maintaining a good vacuum. Frequently only a few minutes after a vacuum determination had been made by the MacLeod type of gage the vacuum would drop quickly to a value considered unsafe for continued full-load operation. Fortunately the development of the novel electric hot-wire vacuum gage, according to the paper under discussion, has helped to ameliorate this situation because of the further researches made possible through it. The writer feels that, from the standpoint of the operating personnel, the vacuum-gage indication should be a continuously recording one that is visible at all times. Naturally this would be taken care of through the automatic feature of the vacuum-pump set in complete automatic sets, provided the rectifier is kept out of service without an operator's attention when the vacuum is low.

The writer recognizes the advantages of rectifiers, and agrees heartily with their use for higher voltages such as are common in railway work. It seems that undue stress has been laid upon the relative merits of these rectifiers and synchronous converters. Mr. Marti points out in his paper that the best field of application of these rectifiers is that of higher voltages,—higher than those of the commercially practicable synchronous converters. If the efficiency curves in Fig. 21 had been plotted for 240-volt machines, instead of 600-volt, and for the same kilowatt rating, the rectifier would probably have been found at a disadvantage. The rectifier would have shown up still less favorably if the overall efficiency of a 3000- or 4000-kw. synchronous-converter set of 240 volts had been compared to that of the several rectifiers required for the same output. A number of years ago the technical press was full of articles on the relative merits of motor-generator sets and synchronous converters, on the assumption that was then accepted that these machines were equally applicable to the same field; but now it is recognized that each has its particular advantages that make its application desirable in certain cases.

Inasmuch as the author places emphasis on the merits of rectifiers, it would have been well, for the sake of completeness of the article, to summarize some of the disadvantages of rectifiers, particularly as compared to the converter, (since he carries out that comparison), such as low efficiency at 240 volts, limited maximum sizes now available, lack of neutral for three-wire systems, etc.

O. K. Marti: Referring to Mr. Prince's remarks regarding engineering opinion concerning the design of various types of rectifiers, I should like only to call attention to the fact that the Brown Boveri rectifier, a cross-section of which is shown in my paper in Fig. 10, outnumbers the A. E. G. type shown by Mr. Prince, in the proportion of ten to one, and it can be inferred from this fact that the eventual development will probably result in a type similar to the one shown in Fig. 10 in my paper.

With reference to Mr. Shand's discussion, it was interesting for me to note that two companies have followed, independent of each other, practically the same lines in developing the steel-enclosed rectifier. Regarding the two systems of ignition, it is certain that the a-c. system of ignition and excitation is far superior to the other system, since it does not require an auxiliary d-c. generating device.

I am obliged to Mr. Shand for the additional references for my bibliography and, at this opportunity, I should also like to mention a series of articles by Dr. Schaefer, published in the BBC Mitteilungen, 1919, Nos, 3, 5, 7, 8, and 9; incidentally, these articles discussed for the first time a method of compounding mercury-arc rectifiers similar in principle to the one on which Mr. Prince's paper is based.

To Mr. Faron's remarks, I should like to add that, under normal operating conditions, a rectifier will not back-fire, but there is no question that back-fires may occur under abnormal conditions, such as those caused by inadmissibly high overloads, poor vacuum due to leakage or the use of improper material in the manufacture of the rectifier.

Regarding starting, I wish to bring out the fact that a rectifier can be started in less than two seconds, being then immediately able to pick up load. This surely is an advantage over a rotary converter which requires about thirty seconds for starting, and therefore cannot take care of any load before that time. To a railroad company, for instance, it means a great deal to have no delays of trains caused by lack of power.

Referring to the over-compound characteristics of traction conversion devices, it would have been interesting if Mr. Faron would have mentioned not only the fact that 90 per cent of the installed synchronous converters have over-compound characteristics, but would also have stated what was the percentage of converters with such a characteristic ordered during the last year. He would probably have found that it was about 50 per cent. This would have given a true picture of the status of the matter. Moreover, it would have been interesting if he would also have given the relative advantages of the two characteristics for railway service. I, personally, cannot see any, but will state here some of the many advantages of a drooping characteristic. It is realized by most railway men that the latter characteristic

guarantees a far more flexible operation and a far better distribution of load between neighboring substations. This results in a better load factor, allows giving the same service with a lower station capacity, reduces the losses in the feeders, and does away, in most cases, with a load-resisting device. This last means nothing else than a complication of the system and a great waste of power as long as it is in operation.

As to the floor space needed by a rectifier, it is true that the actual floor space required by a 600-volt rectifier, with all its auxiliaries, is somewhat more than for a rotary converter of the same voltage and capacity. However, considering the smaller weight of the rectifier, it is possible to utilize the space available for the converting units more effectively,—for instance, by mounting the rectifier and its auxiliaries on different floors of a building. Moreover, for the same reason, a lighter foundation, and also a lighter building construction, can be used, so that both in the erection of new buildings and in the adaptation of old buildings to substation uses, a material gain is effected.

With reference to the efficiency curves shown in Fig. 21A of my paper, I should like to mention that they were derived from data published by American manufacturers, including the stray losses according to the A. I. E. E. Standards, given as one per cent of the output. The efficiency of the transformers was taken to be the same for both the rotary converters and the mercury-arc rectifiers.

Regarding the automatic control, Mr. Faron states that auxiliaries will have to take care of abnormal conditions; but this holds true also for rotary converters. I wish to point out again that the automatic control of a rectifier is much simpler than that of a rotary converter, as most of the operations necessary in starting a rotary converter,—such as step-changing, raising and lowering the brushes, polarity check, etc.—are absent in the starting of rectifiers, for which the total starting operation consists of the natural sequence of closing the a-c. breaker, the automatic ignition, and closing the d-c. breaker. Due to the valve action of the arc, the protection which Mr. Faron recommends is not needed for the usual a-c. voltage supply.

I fully agree with Mr. Naeter's statements, and I think he is more than right when he compares with the present conditions the state in which electrical engineers were when the rotary converter came into prominence to take the place of the well established motor generator. There is no question but that a rotary converter will in many cases have an advantage over a mercury-arc rectifier, just as a motor-generator set shows outstanding advantages over the rotary converter in certain applications.

MOTOR VEHICLE LIGHTING TESTS

An interesting series of lighting tests were conducted in connection with the meeting of the joint Steering Committee of the Illuminating Engineering Society and the Society of Automotive Engineers which was held during the recent convention of the S. A. E. at French Lick.

Seven cars were equipped with special test headlighting equipment consisting of two pairs of headlamps on each car giving a graduation of vertical and horizontal spreads of light over a wide range. Means were provided also for securing asymmetric distribution (low beam on the left and high beam on the right).

The demonstrations attracted considerable attention in that they showed the wide range available which could be made to conform to the state requirements while meeting the tastes of different car operators. A large number of persons participated and it is hoped that their comments will aid the committee materially in guiding future work.—From I. E. S. *Transaction*, July 1926.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

INSIDE-FROSTED LAMPS

A Discovery Promoting Efficient Light Production

Growing appreciation of the importance of good electric lighting during the decade between 1915 and 1925 led to much wider use of diffused light. Diffusion by enclosing the lamps in translucent glassware and adequate shades and by using other devices was a vague subject to the general public.

Consequently with the advent of the high-efficiency tungsten lamp, the manufacturers endeavored to conceal the bright filaments by etching or frosting the bulbs. Frosting on the outside of the bulb proved objectionable for two chief reasons. It was wasteful of light, offsetting, to a slight degree, the great progress made in increasing the light-producing efficiency of the filament. Also, outside-frosted lamps collected dust and dirt quickly, which could not easily be wiped off.

For many years lamp engineers realized that a lamp frosted on the inside, instead of on the outside, would be very desirable. It would not only present a smooth outside surface and be as easily cleaned as a clear lamp, but a lighter frosting would suffice, increasing the efficiency. The trouble with the idea was, that when a lamp bulb was frosted on the inside, it became as brittle as an egg shell. For twenty years engineers wrestled with this problem to no avail, until Marvin Pipkin, of the National Lamp Works of the General Electric Company solved the difficulty. The method is simple.

A strong solution of acid is first sprayed into the bulb, which etches it. In this condition the surface of the glass is made up of irregular little projections with many sharp angles. While the glass is still in this state it is extremely weak, and a slight pressure or bump is sufficient to shatter it. So far, the process is similar to former attempts at inside frosting. The difference lies in the strengthening process, which is the application of another acid solution, somewhat weaker than the first. This second treating rounds off the sharp edges and minute projections, giving the glass an appearance, under a powerful microscope, of being made up of tiny hemispheres. The bulb is now strong again,—just as strong as it was originally.

Superiority of the inside-frosted lamp over the outside-frosted, so far as light transmitting characteristics are concerned, also needs explanation. In the outside-frosted lamp, light from the filament travels through the gas or vacuum to the wall of the bulb, then through the glass, on the outer surface of which it meets the frost. Then, depending upon the direction of the plane of the particle of rough surfaces, the beam either passes on through the frosted surface as useful light or is reflected back through the glass layer. Each time the light passes through the glass, a certain amount of absorption takes place.

Diffusion of the light by the inside frost is obtained

by prismatic refraction with comparatively little loss. In fact, the inside frost allows an even greater portion of the light to pass through than does a similar frost on the outside of the lamp. This is due to the fact that the multiple internal reflections are not so numerous in the inside frosted lamp because the rough, interior surface does not reflect any considerable portion of the light back and forth inside the lamp, as happens with the outside-frosted lamp. Moreover, the relative absorption of the inside frost does not increase so rapidly with the life of the lamp as does that of other diffusing media.

For these reasons, then, the inside-frosted lamp is only about two per cent less efficient than a clear lamp, contrasted with a loss of efficiency of three to four times this much in the old style sand-frosted and sprayed lamps.

Another great benefit of the discovery of inside frosting is at once apparent when it is realized that now the manufacturers need only one type of lamp of each wattage instead of lamps with several different finishes. This is beneficial not only from the standpoint of economies resulting from the increased use of automatic machinery and the decreased investment in lamps lying idle in warehouses and on dealers' shelves, but also there is still greater benefit for the public in general. Since the inside-frosted lamps give practically as much light as clear lamps, they can be used to replace clear lamps for every ordinary use. This means that wherever, because of ignorance or carelessness, lamps are used without proper shades or glassware, the inside-frosted lamps will afford a certain degree of eyesight protection. Furthermore, wherever lamps are properly shaded, the inside frosting will eliminate sharp shadows and striations, with negligible loss of efficiency.

The invention of the inside-frosting process, of the same order of importance as the invention of gas-filled lamps and tipless lamp construction, is one more example of the value of systematic research, persistently pursued.

EUROPE ORGANIZES ITS LIGHTING ACTIVITIES

Within the last two or three years an increasingly greater amount of attention has been given in various European countries to the promotion of better lighting in factories, homes offices and the like. Lighting demonstrations, illumination courses, technical and advertising literature are all being pressed into service to carry the message of good lighting to the people of many foreign lands. A list of some of the European countries where this work is now being carried on intensively would include England, France, Germany, Italy, Austria, Sweden, Czechoslovakia, Belgium, Scotland and perhaps some others.

Holland has only recently organized an Illuminating Engineering Society which is supported by a number of able and prominent men.

Like some of the others, this new society has the following objects:

1. To educate the public in the art of illumination by lectures, demonstrations, publications and the like.
2. To demonstrate proper and practical ideas about lighting to pupils already in school.
3. To encourage the application of proper lighting in practise by giving information and advice to those who desire it.
4. To bring about new applications and improvements in lighting through the standardization of accessories and development work.

It is being organized to accomplish these things by means of permanent demonstration rooms, illuminating engineering and general educational service.

A lecture given by Mr. C. P. Jensen before the thirty-first Congress of the V. D. E. (Association of German Electrical Engineers) in June, at Wiesbaden dealt with the German Society of Lighting Economics from the point of view of the electrical organizations in Germany. It was a plea to them to unite in a cooperative movement for a broader understanding of lighting economics as a means of rendering a greater service to the users of light.

Once a suitable neutral basis for the cooperation of the electrotechnical industry has been created in the field of illuminating economics, there remains only the question of its practical influence on the broad masses of the light-consuming public with the view to increasing the service of this great electric lighting industry.

It is hoped that a growing demand for electric lighting service will be established and that through increased production and other advantages to be derived from better lighting, a great economic good will be accomplished.

Europe today, says Mr. Jensen, is setting out on a program of electrical standardization similiar to that which has meant so much to electrical progress in America. Plans are being made to standardize the voltages of lighting circuits and to decrease the number of lamp types.

These German activities received their impetus over a year ago with the opening at Berlin of the new "house of light" containing a group of lighting demonstration rooms. Since then some 50,000 people have been initiated there into the "mysteries" of good lighting. Furthermore, many well attended illumination courses have been given and these have helped to spread the idea of the advantages of better lighting.

TREND OF ELECTRIC LIGHTING

Significant are many of the trends shown in the annual report of the National Electric Light Association's Lamp Committee. In three years the average wattage of lamps consumed has risen from 55.6 to 57.6; the percentage of exactly 115-volt lamps has risen from 42.8 to 44.6. The Committee recommends that every member company have a "well organized Lighting Service Department," and that there be permanent lighting demonstration rooms in every city of the country.

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Pacific Coast Convention

SALT LAKE CITY, SEPTEMBER 6-10, 1926

"Excellent from a professional standpoint and highly enjoyable socially" was the verdict rendered, by the two hundred and fifty or more members and guests in attendance, upon the Annual Pacific Coast Convention held at the Hotel Utah, Salt Lake City, September 6-10.

The technical program included numerous high-grade papers covering a wide variety of topics, discussions contributed by members and guests were valuable, inspection trips to power plants and other places of engineering interest were well managed, and all the visitors were highly appreciative of the cordial hospitality extended by the Salt Lake City members and the ladies of their families.

Student Activities

The first event of the Convention was a Conference of Counselors and Student Branch Chairmen of the Pacific and North West Districts, on Monday morning, September 6. The Counselors present were: Henry H. Henline, Stanford University; J. Hugo Johnson, University of Idaho; T. C. McFarland, University of California; J. F. Merrill, University of Utah; F. O. McMillan, Oregon Agricultural College; S. G. Palmer, University of Nevada; George S. Smith, University of Washington; Royal W. Sorensen, California Institute of Technology; and J. A. Thaler, Montana State College.

The Student Chairmen present were: F. D. Crowther, Oregon Agricultural College; J. W. Cruse, University of Arizona; Chas. F. Dalziel, University of California; Thomas L. Gottier, California Institute of Technology; Clarence M. Murray, Jr., University of Washington; and Alfred V. Pering, Stanford University.

President Chesney, National Secretary Hutchinson, Vice-President Schoolfield and others interested were also in attendance.

Professor Merrill was elected Chairman of the Conference, and Professor Smith Secretary. There was an interesting and profitable discussion regarding various student activities and recommendations were adopted which will be transmitted to the Board of Directors.

Later in the week the Counselors of each of the two Districts met separately and organized as Committees on Student Activities for their respective Geographical Districts as follows:

Pacific District Committee: Chairman, Professor H. H. Henline, Stanford University; Secretary: Professor R. W. Sorensen, California Institute of Technology.

North West District Committee: Chairman: Professor J. A. Thaler, Montana State College; Secretary: Professor George S. Smith, University of Washington.

Opening Session

The first technical session was held on Monday afternoon and was called to order by Mr. C. R. Higson, Chairman of the Convention Committee, who greeted the members and guests and then presented George H. Dern, Governor of Utah, who delivered an excellent address of welcome. Chairman Higson then presented President Chesney as the presiding officer of the Convention, who in responding, congratulated the people of Utah upon having elected an engineer to the office of Governor.

President Chesney then delivered a brief address relating principally to research and standardization, in which he outlined certain major policies which he believed should be followed by the Institute.

He mentioned as examples of leaders in the research and development work in the electrical engineering field in this country, William Stanley, Nikola Tesla, Benjamin Lamme, and Chas. P. Steinmetz, giving a brief outline in each case of the contributions of these leaders. After reviewing briefly the work done upon standardization in the electrical field in this country, President Chesney continuing said:

"The American Institute of Electrical Engineers for the past twenty-five years, through its Standards Committee, has taken the initiative in the formulation of all the electrical standards of America, and its work is recognized as being authoritative throughout the entire world. Its procedure and its resulting standards during this period have been acceptable to the manufacturing and the consuming interests as well as to the general public. The industry has learned to value and depend upon the A. I. E. E. standards in commercial transactions covering matters of interest to all sections of the electrical industry. It has made no attempt to dictate to industry, but introduces standards on any particular line only when it is clear that all interested parties agree that the step is wise and desirable.

"In the Institute Standards Committee, or in its subcommittees, the manufacturer and purchaser and the general interests come together and develop the required standards in a way which has been generally satisfactory to all the interested sections of the industry. The electrical standards so issued have been identified with the name of the Institute, and its name should be continued in connection with them, and in the interest of simplicity and order it would appear that no other name was necessary. It should be remembered that the Institute as an organization has no interest other than one of public service, which duty the Institute has performed throughout the entire period of twenty-five years at its own expense. The Institute, therefore, in connection with the voluntary formulation of electrical standards, has assumed obligations during the past quarter of a century to the electrical industry and to the public which make it now impossible to discontinue the

present practise or lessen its responsibilities until a more simple and direct method has been devised and demonstrated."

The following papers and discussions were then presented:

The Space Charge that Surrounds a Conductor in Corona, by H. J. Ryan and J. S. Carroll, Stanford University. (Presented by Professor Carroll.) Discussion by Messrs. Harris J. Ryan, H. E. Mendenhall, F. O. McMillan and J. S. Carroll.

110-Kv. Transmission Line Construction of the Washington Water Power Co., by L. R. Gamble, Washington Water Power Co. (Presented by the author.) Discussion by Messrs. C. R. Higson, Harold Michener and the author.

A New 220-Kv. Transmission Line, by C. B. Carlson and H. Michener, Southern California Edison Co. (Presented by H. Michener.)

Effect of Unbalanced Tension in a Long-Span Transmission Line, by E. S. Healy and A. J. Wright, Electric Bond and Share Co. (Presented with lantern slides by Mr. Healy.) Discussion by Harold Michener.

Tuesday's Technical Session

The technical session on Tuesday morning was presided over by Vice-President Paul M. Downing, of San Francisco. The following papers were presented:

The Circle Diagram of a Transmission Network, by F. E. Terman, Stanford University. (Presented by the author.)

Calibration of Lichtenberg Figures, by K. B. McEachron, General Electric Company. (Presented by the author.) Discussion on the above two papers was presented by Messrs. J. Slepian and K. B. McEachron.

Stability Characteristics of Alternators, by O. E. Shirley, General Electric Company. (Presented by the author.)

Synchronizing Power in Synchronous Machines, by H. V. Putnam, Westinghouse Electric & Manufacturing Co. (Presented by the author.) Discussions followed by Messrs. David Hall, C. A. Nickle, F. E. Terman, H. V. Putnam, and O. E. Shirley.

At the afternoon session, Vice-President Downing presiding, the following papers were presented:

Vacuum-Switching Experiments at California Institute of Technology, by R. W. Sorensen and H. E. Mendenhall, California Institute of Technology. (Presented by R. W. Sorensen.) Discussion by Messrs. J. Slepian, D. C. Prince, H. E. Mendenhall and R. W. Sorensen.

Electrical Practise in Lead-Silver Mines in Utah, by Leonard Wilson, Consulting Engineer. (Presented by the author.)

Electricity and Coal Mining, by Daniel Harrington, Chief Safety Engineer, U. S. Bureau of Mines. (Presented by Mr. H. T. Plumb.) Discussion by Messrs. Paul Ransom, H. T. Plumb, D. C. McKeehan and Paul M. Downing; also a communication from F. L. Stone.

Engineering Education: Its History and Prospects, by H. H. Henline, Stanford University. (Presented by the author.) Discussion by Messrs. F. E. Terman, J. H. Johnson, George H. Smith, R. W. Sorensen, D. I. Cone, H. T. Plumb, D. C. Prince, H. Michener, K. B. Miller, F. O. McMillan, G. Ross Henninger, David Hall, Paul M. Downing and H. H. Henline; also a written discussion from L. R. Robinson.

Wednesday's Technical Session

Vice-President H. H. Schoolfield, of Portland, Oregon, presided at the session on Wednesday morning, and the following papers were presented:

Protection of Oil Tanks against Lightning, by F. W. Peek, Jr., General Electric Company. (Presented with motion pictures by the author.)

Fire Protection of A-C. Generators, by J. A. Johnson, Niagara Falls Power Co., and E. J. Burnham, General Electric Company. (Presented with lantern slides by E. J. Burnham.) Discussion on the above two papers was presented by Messrs. J. Slepian, R. W. Sorensen, D. I. Cone, B. F. Howard and F. W. Peek, Jr., and a written discussion from E. H. Freiburghouse.

Thursday's Technical Session

At the final technical session on Thursday morning, Vice-President Schoolfield presiding, the following papers were presented;

Variable Voltage Equipment for Electric Power Shovels, by R. W. McNeil, Westinghouse Electric & Manufacturing Co. (Presented by the author.) A written discussion was presented from R. S. Stevens.

Temperature of a Contact and Related Current-Interruption Problems, by Joseph Slepian, Westinghouse Electric & Manufacturing Co. (Presented by the author.)

Transcontinental Telephony, by O. B. Jacobs and H. H. Nance, American Telephone and Telegraph Co. (Presented by O. B. Jacobs.)

Controlling Insulation Difficulties in the Vicinity of Great Salt Lake, by B. F. Howard, Mountain States Telephone & Telegraph Co. (Presented with lantern slides by the author.) Discussion by Messrs. J. B. Johnson, K. B. Miller, A. S. Peters, W. C. Lee and B. F. Howard.

Carrier-Current Communication on Submarine Cables, by H. W. Hitchcock, Pacific Telephone and Telegraph Co. (Presented by the author.) Discussion by Messrs. J. E. Heller, K. B. Miller, and W. G. Rubel.

Entertainment Features

On Monday afternoon, practically all the members and guests in attendance participated in an excursion to the Saltair resort on the shores of the Great Salt Lake, where many enjoyed the unique experience of bathing in the lake which is noted for its great buoyancy. Dinner and dancing occupied the time of the visitors until a late hour.

The principal social event of the Convention occurred on Wednesday evening, at which time all the members and guests present attended a dinner in the Hotel Utah, at the conclusion of which greetings were extended by C. R. Higson, Chairman of the Convention Committee, who then presented President Chesney as the presiding officer of the evening. Distinguished guests present included Senator Reed Smoot, Mayor C. Clarence Neslen of Salt Lake City, and President Grant of the Church of the Latter Day Saints. A brief and exceedingly interesting address was delivered by Senator Smoot, after which followed the ceremonies in connection with the presentation of the Edison Medal to Dr. Harris J. Ryan, as described more fully elsewhere in this issue. During the dinner the guests were favored with music and singing by local talent.

The program of the week included many other enjoyable events, beginning with an organ recital in the celebrated Mormon Tabernacle at noon on Monday. There were various drives about the city and nearby canyons for the ladies, including luncheon at the Country Club on Tuesday, and at the Pinecrest Inn, at the head of Emigration Canyon, on Wednesday.

One of the principal events was an informal reception on Tuesday evening, the receiving line consisting of President and Mrs. Chesney, Dr. and Mrs. Harris J. Ryan, Vice-President and Mrs. Paul M. Downing, Vice President H. H. Schoolfield, National Secretary F. L. Hutchinson, Mr. and Mrs. C. R. Higson, Mr. and Mrs. B. C. J. Wheatlake, and Mr. and Mrs. H. T. Plumb. Following the reception, a highly interesting, illustrated lecture on Western Canyon Scenery was given by Randall L. Jones, after which dancing completed the evening's entertainment.

A Golf Tournament was conducted on Wednesday afternoon, the winners being Vice-President Paul M. Downing and the runner-up, P. A. Parry, of Salt Lake City. Prizes were presented to the winners by Chairman Wheatlake of the Utah Section at the closing Convention session. By winning the tournament, Vice-President Downing became the custodian of the John B. Fisken Cup, which is competed for each year at the Pacific Coast Convention.

Upon the adjournment of the final session on Thursday noon,

the members and guests were taken by busses for an excursion to Bingham Canyon and Magna, visiting the famous Mine and Mills of the Utah Copper Company, where the operations, including blasting, were of great interest to the visitors. A visit was also made to the underground workings of the Utah-Apex Mine.

On Friday there was an all-day excursion provided by the Utah Power and Light Company to the Company's new hydroelectric station at Cutler on the lower Bear River.

During the Convention, a Conference was held of the Vice-Presidents of the Pacific and North West Districts and the representatives of the Sections within those Districts, at which it was decided to recommend that next year's Pacific Coast Convention be held in the San Francisco territory at a date to be determined later.

In addition to the various scheduled events referred to above, there were many courtesies extended by the local members and ladies of their families. A Local Ladies' Committee, which was particularly active in providing for the comfort and pleasure of the visiting ladies, consisted of Mesdames Brundige, Clark, Hale, Higson, Moser, Plumb, Rowley, Salberg and Wheatlake.

At the final session of the Convention, a motion was adopted expressing the high appreciation of the visiting members and guests of the effective services of the Local Convention Committee in making and carrying out with gratifying success the plans for the various events of the Convention. The local members were: Messrs. C. R. Higson, Chairman, P. P. Ashworth, H. G. Baker, D. L. Brundige, H. W. Clark, R. J. Corfield, C. P. Kahler, J. A. Kahn, C. A. Malinowski, J. F. Merrill, H. T. Plumb, C. C. Pratt, Paul Ransom, John Salberg, M. M. Steck, H. B. Waters, and B. C. J. Wheatlake.

Edison Medal Presented to Harris J. Ryan

The most impressive feature of the Pacific Coast Convention was the presentation of the Edison Medal to Dr. Harris J. Ryan at the dinner on Wednesday evening, September 8, 1926.

President Chesney presided and announced that the members and guests were assembled to honor Harris J. Ryan, Past President of the Institute, to whom the Edison Medal for the year 1925 had been awarded. He then called upon National Secretary Hutchinson, who briefly outlined the origin and significance of the Edison Medal.

President Chesney then called upon Vice President Paul M. Downing, of San Francisco, who spoke of the work and achievements of Dr. Ryan, in part as follows:

We are here this evening to do honor to one whom we all respect, admire and love, a man whose accomplishments in the field of scientific research and engineering have pointed him out as one upon whom the American Institute of Electrical Engineers should confer this particular mark of distinction. To those of us from the far west this is a particularly happy occasion because for more than 20 years we have had the pleasure and the proud privilege of claiming Dr. Ryan and his charming wife as residents of our sunny state of California.

Born in Powell Valley, Pennsylvania, Dr. Ryan received his early education in Baltimore City College and Lebanon Valley College. Leaving the latter he entered Cornell in 1883, about the time that institution was inaugurating its electrical engineering course. After graduating from Cornell in 1887 he was for 2 years associated with J. G. White and D. C. Jackson then engaged in general engineering practise under the firm name of Western Engineering Company. In 1889 he returned to Cornell as instructor in charge of the electrical machinery laboratory. This change marked the turning point in his career in that he left the field of commercial engineering to enter that of scientific research. Advancement in his chosen line of work was rapid. In 1890 he was made assistant professor in electrical engineering at Cornell and in 1895, when only 29 years of age, he was honored by being appointed as professor in full charge of the electrical engineering department. He remained in that position until 1905 when the "kid" professor as he was then known accepted the call of Stanford University to take charge of the electrical engineering department of that institution, which position he still holds.

In reviewing Dr. Ryan's accomplishments one cannot help but be impressed by the clear foresight and unprejudiced manner in which he has approached every problem confronting him. Scientific investigation is by its very nature pioneer work. It differs from that of engineering in that the scientist must work away out in advance of the engineer. He must point out the way by blazing a trail along which the latter may follow perhaps years later and put to practical application the fundamentals that have been established by the scientist. It therefore follows that if a man is to be successful in scientific research work he must love his work, he must be a man of broad imagination, and he must have unlimited enthusiasm. Dr. Ryan answers all of these specifications.

Since 1889, Dr. Ryan has been a liberal contributor to technical literature, many of his papers having been presented before this Institute. In reviewing his work one cannot help but be impressed with the fact that unlike many others engaged on more or less highly technical research work, Dr. Ryan has devoted his time and attention very largely to the scientific study of problems that have great practical and economic value to the electrical industry. As substantial evidence of this we find that one of his earliest contributions to electrical progress was a paper describing the development and pointing out the advantages of using balancing coils, as they were then termed, designed to overcome field distortion and the shifting of the neutral point in direct-current machines, due to armature reactions. The first practical application of this principle was in the Thompson-Ryan generator which was the forerunner of the present day interpole type of construction now used almost universally in direct-current generators and motors. This one improvement alone has been of tremendous commercial value to the industry not only in the improved operation of d-c. equipment, but by its application, the size and weight of machines per unit of capacity has been materially reduced, thus reducing the price correspondingly.

But important as his studies in the field of direct current have been, those having to do with alternating current are of even greater importance. Looking back from our present position to the early 90's, it seems easy in the light of present day knowledge to imagine how a high voltage system might very easily have been brought into existence, but at that time the scientific world knew but little about alternating currents and less about high voltages. There were wide differences of opinion respecting the possibilities of developing and transmitting power over long distances and there were wider differences of opinion on the question of whether alternating current or direct current was best suited for transmission purposes.

It was in the laboratory at Cornell University that Professor Ryan began his studies in connection with the use of high voltages. Suitable equipment and facilities for carrying on his investigations were not available. Much of what he needed had to be built in the laboratory under his direction. Even at that time, when so little was known about high voltages, his foresight and wisdom in determining what the design and construction of such equipment should be were sound and it is interesting to know that the 90,000-volt dry insulated transformer built by him many years ago is still in service and is an important part of the Cornell laboratory equipment.

His paper on transformers presented before the Institute in 1889 is one of his outstanding accomplishments. It was received by the scientific world with an enthusiasm that immediately brought the author into the limelight of international fame.

No small part of the success attending the investigations covered by this paper is due to the development of the cathode ray wave indicator, or as it is now generally called the cathode ray oscillograph. Its development was more or less of an incident in connection with the solution of the bigger and more important problem being studied but it proved to be a most important factor in obtaining results that otherwise might not have been possible. It not only served a most useful purpose in connection with the work then in hand but during recent years it has found a broad field of usefulness in studying the high frequencies used in connection with the transmission of the human voice.

A few years after this paper was presented certain experiments conducted on certain lines operating in the Rocky Mountain region resulted in the announcement by transmission engineers that 40,000 volts was the limit for transmission lines and it was useless to attempt to go higher. Doubting the truth of this announcement, Dr. Ryan with a pioneer spirit born of that type of mind to which all attainment is but a challenge to further effort, definitely determined to prove that the use of much higher voltages was not only possible but entirely practical. His investigations and studies along this line continued until 1904 when he summarized the results in a paper presented before the Institute entitled, "The Conductivity of the Atmosphere at High Voltages." The fundamentals set forth in this paper were a distinct contribution to electrical science. By establishing the law of corona formation the problem of transmitting power at high voltage was materially simplified and the former theory that 40,000 volts was a maximum beyond which it was impractical or impossible to go was completely disproved.

During recent years Dr. Ryan has devoted a great deal of his time and attention to the study of insulation and insulators for use on high voltage lines. The results of his investigations covering the distribution of voltage across the different units making up a string of insulators and the best manner of equalizing same, the cause and effect of aging of porcelain, the causes of failures and flashovers of insulators and other similar work have been of inestimable value to the engineering fraternity in the design and successful operation of present day high-voltage lines. As a result of these investigations, insulator manufacturers have been able to improve the design and quality of their product to a point where today we find 220,000-volt transmission lines operating more satisfactorily in every respect than do those of lower voltages constructed at times when we knew less about insulators and insulation than we do now.

No one will question the fact that during the past 30 years, transmission

of electric power has been one of the very great, if not the greatest, factors contributing to the growth of material wealth and the relief of labor. That growth has been made possible in a very large measure by the splendid work that has been done and is today being done by Dr. Ryan and others in working out the highly complicated problems that have confronted the industry without the solution of which progress would have been greatly retarded.

In recognition of the importance and value of the work that has been done and as substantial indication of their desire to have it continue, a number of electrical companies, both manufacturing and central station, have contributed toward the establishment of a modern up-to-date high tension laboratory at the University where research work well in advance of the industry can be carried on. As a compliment to our honored past president and co-worker, this new laboratory, known as the Harris J. Ryan High Tension Laboratory, will forever stand a splendid monument to the untiring energy and ability of the man whose name it bears. So far as funds will permit the laboratory is well along toward completion but it is not yet fully equipped.

That the electrical industry is willing to recognize and accept its indebtedness to Dr. Ryan and the University, not only on account of the splendid work that has already been done but also on account of the broad liberal policy concerning future work, is evidenced by the generosity of the donors without whose financial assistance and support the ideals of Dr. Ryan and his co-workers could not have been realized.

But beyond all of his accomplishments in the field of scientific work we must not overlook other of his achievements that can be measured only in terms of human value. During the more than 30 years that Dr. Ryan has devoted to training the minds and habits of young men he has endeared himself to all with whom he has come in contact and in this brief resumé of Dr. Ryan's achievements as a scientist and a teacher, I could not properly conclude without paying a tribute to Mrs. Ryan. Along with Dr. Ryan she has always taken a parental interest in the work and welfare of their students. Their home has always been open and students have always been received with a hearty welcome.

At the conclusion of Mr. Downing's address, President Chesney presented the Medal and Certificate of Award to Dr. Ryan, who in response spoke in part as follows:

I appreciate profoundly the award of the Edison Medal and the opportunity that I have now had of receiving the certificate of award and the medal from the hands of those who have been my life-long friends and virtual co-workers functioning as the officers of the Institute.

At this extraordinary moment in my life my mind goes back to the beautiful and inspiring resolution that the Edison Medal Association made a part of its deed of trust to the American Institute of Electrical Engineers for the award of the Edison Medal which reads:

Whereas: it seems to the (Edison Medal) Association that the most effective means of accomplishing the object for which it was formed would be the establishment of an Edison Medal which should, during the centuries to come, serve as an honorable incentive to scientists, engineers, and artisans to obtain by their works the high standard of accomplishment set by the illustrious man whose name and features shall live while human intelligence continues to inhabit the world.

Its full significance will be born in upon us when we remember the things of incalcuable value in the world today that would be absent had there been no Edison. No man ever lived to be a finer example of the glory of work for the amelioration of the conditions under which mankind must live and be happy.

The Certificate of Award and the Edison Medal are received by me in a deep consciousness of their significance and most earnestly do I hope that I may continue to deserve them as long as life shall last.

It is eminently proper when a man has been awarded the Edison Medal by the American Institute of Electrical Engineers that he should be called upon to give an account of himself and that I now gladly do.

Forty-three years ago this fall I entered Cornell as a freshman to take up the curriculum in electrical engineering, that had just been established and for which students were being admitted for the first time. The electrical engineering laboratory of the University was little more than the electrical section of the Physics laboratory of that day. The little more just referred to was one direct-current generator invariably referred to as the Gramme dynamo that was built by Professor Wm. A. Anthony, the 1890-1 President of the Institute.

Professor Anthony visited France immediately after 1872 when Gramme had completed his direct-current generator, generally conceded to have been the first direct-current dynamo of an ample size to reveal its possibilities in the engineering industries. Professor Anthony visited Gramme, saw his generator, and on returning to Cornell immediately set about to construct a replica thereof. It was completed in 1874 and exhibited just a half century ago at the Centennial in Philadelphia. Curricula in electrical engineering at Columbia, Cornell and other universities were announced somewhat less than ten years after the Centennial.

Anthony's Gramme dynamo was given at Philadelphia an award of merit for its novelty and enterprise. It was placed in the historical exhibit at the Chicago International Exposition only 17 years later, and was given an award for its historical merit. I was a member of another section of the Chicago World's Fair jury and had nothing to do with the award of historical merit for "Anthony's Old Gramme." However, I shall never forget the deep impression that the award made upon me. Even then after only 17 years of progress in our country the dynamo had become one of the great implements of our civilization. The lesson of the extraordinary progress that the electrical sciences and arts were making, was inescapable.

I had up to the time of the Paris Exposition in 1889 encountered the then traditional attitude of mind that dwelt much upon the historical background of things from out of which one looked with anticipation of few out-and-out new expediencies and implements arriving at a slow rate as always.

But the extraordinary personal exhibit of Edison at the Paris Exposition of 1889 began to change all that sort of thing for me as it did for a host of others of my generation and the Chicago 1893 award to Anthony's Old Gramme finished the change of mind for me, as I know it must have for many others. From that time to this I have belonged to the group that with all the persistence and enthusiasm its individuals can muster has held steadily to the purpose of finding out about things from the depths of the unknown; of opening up new seams in the face of the rock that must be penetrated to know what is within and beyond.

Attitude of mind is an enormous factor of human progress—and progress there must be, so long as human beings will hold the option of changing this old world from what it is to what it ought to be.

In the fourth year of the Institute I began my work as a faculty man at my alma mater. I soon found the real meaning and value of the American Institute of Electrical Engineers to all in the electrical arts and sciences. I found that I was wholly unprepared to assist my students effectively to an understanding of things without end, encountered everywhere; particularly was this so as matters stood in that day, for the transformer in the alternating-current circuit and the armature reaction effects in the continuous current machine. The alternating-current system for economic incandescent lighting so well suited for the needs of the new rapidly growing American towns and cities had been introduced three years before, *i. e.*, in 1885-6 and its use was being extended rapidly.

With the aid of a friend of my student days, Ernest Merritt, past-president of the American Physical Society, I worked through the summer of 1889 upon the problem by systematic measurement upon a particular transformer in sufficient detail to meet our requirements for teaching. The work was done at Buffalo, New York, through the courtesy of C. R. Huntly, Executive, and H. H. Humphreys, Engineer, of a lighting company of that city. We selected for our specimen a 10-light, 2000/50-volt, 133-cycle transformer.

Through Dr. E. L. Nichols, past-president of the Institute, I was invited to present a paper based upon our work on the transformer and the results obtained. The paper was duly prepared and presented at the December, 1889, meeting of the Institute in New York City and was published in the Proceedings in January, 1890. Then to me the entirely unexpected thing happened. The paper interested most of the trained workers in the electrical industries everywhere. It was republished seventeen times in America and Europe including Russia. From that time to this I have had friends everywhere throughout the electrical and related industries who have always wished me well and were ready with their helpful cooperation at all times. It was to me in relation to the Institute a wonderful lesson in many ways, particularly in two:

I. The value of getting at the facts singly and in their aggregate relation concerning phenomena and equipments for which uses are being found in the industries.

II. The extraordinary value of the American Institute of Electrical Engineers to its individual members and the electrical industries they promulgate.

The direct-current dynamo was put forward by the Italian Paccinoti in 1864 and first developed for engineering duty as already stated by the Frenchman, Gramme, in 1872. Like every great implement upon which our civilization is today established and maintained, the direct-current dynamo arrived as a product of the minds and industry of Paccinoti and Gramme complete in a sense and highly useful, but little understood as to details and as to their relation to the aggregate result. The lack of adequate knowledge of such details individually and collectively was a great handicap in education and for the progress of the art. To understand this one needs only to go back to the many distortions of the rational forms of continuous current machines that were put forward in many illusory efforts to make improvements nearly forty years ago.

With the aid of my students we began in 1892 a series of studies of commutation and characteristic behavior in relation to the shape of poles, length of air-gap and related factors. The results clearly indicated the helpfulness of the pole-face winding and commutating pole as they are now known. We were not the only persons to discern these helpful results, though we did enjoy with others the privilege of pioneering in these things. The final approach to perfection of the continuous current machine was not feasible in "the late nineties." That approach has been quite dependent upon the arrival of a good working understanding of polyphase current circuits.

The continuous current machine in recent years has rounded out its first great cycle of development. When, in America, it will enter upon its obvious second cycle, or better, its second round on its spiral of evolution, cannot today be foreseen. It is assuredly worth while for some engineers to remember always the wealth of expediency now available for such second round of evolution of this form of generator or motor. Should long distance transmission of power ever demand the use of the constant continuous

current generator and motor, there will be found a veritable mine of discernible expediency for evolving its success.

A third of a century ago from a faculty man's point of view, that of helpfulness to his students, I began the study of high voltage phenomena by constructing an oil immersed 30,000-volt transformer. The first decisive experimental result with it was soon obtained. It "burned out", but why, one could not tell. The most significant thing about the tragedy was a large smoke bubble that came to the surface of the dark heavy oil that was generally used at this time for insulating transformers. That was in 1893. During the following year we rebuilt it, using air in lieu of oil for immersion so that if it burnt out again we could see the fire and perhaps learn something of the cause. We kept the same core and coils and rebuilt the transformer the sixth time in 1899, air immersed and to have an output of 10 kw. at 90,000 volts, 133 cycles. The major insulation between the high and low voltage circuits was made by the Corning, New York, Glass Works of refractory glass. Each of the 30 high voltage coils was equipped with a 6000-volt non-arcing spark arrester. After that the transformer rendered satisfactory service at my alma mater through many years. It is a trivial incident in the telling but it made a real beginning for me as a high voltage worker.

In 1897 we learned through the pioneer high voltage studies of past Presidents Chas. F. Scott and Ralph D. Mershon, that at 40,000 volts, more or less dependent upon a variety of obscure factors, the electric current would escape into the atmosphere and a serious waste of power would in consequence occur.

The success of the long distance transmissions of power in the far west and from Niagara Falls to Buffalo caused a large division of the electrical engineers to set out upon the route that led to the establishment of the modern power industry. This division was directed on the right and left by the economic guidance of Kelvin and Sprague. The former asserted that the transmission of power is accomplished most economically when the existence and lost costs of the transmission conductor are equal. The latter asserted that economy in electrical power transmission varied directly as the voltage and inversely as the distance.

The discovery of Scott and Mershon that at a comparatively low voltage electric power would escape from the power transmission line sent a strong mental shock to this power division. As a faculty man greatly interested in the welfare of students preparing for service in the power division, I felt the shock keenly. For the cause of those students there was but one thing to do and that was to get at all the material facts as quickly as possible and then to study them for strategy in action. By February 1904, we had some of the facts and their relations well enough in hand to present a paper to the Institute that was received everywhere by the power division in such a whole-hearted manner of appreciation that I could not do otherwise than hope to have the privilege of being its permanent recruit.

I must interrupt this narrative in regard to my contacts as a faculty man with those who are establishing the power industry to say that through brief but highly appreciated years I have seen and enjoyed detached services in the large division of communication. In so doing I cooperated with those of my students who established the arc converter system of continuous wave radio telegraphy at home and abroad. My war work in the Supersonica Laboratory of the National Research Council, the purpose of which was aid of the allies in the perfection of the echo method for submarine defence, netted an experience in mechanical radio that has been highly valuable because of the many uses I have found for the same in my work with students. Thus it has been that I have learned abundantly in both the power and communication divisions of the electrical industries how enormously welcome a faculty man is to ask the privilege of camaraderie if he will but play the game right-mindedly. He must remember that he is a faculty man at all times and see to it that he is acting as such and that he is not acting to replace an engineer on the firing line of practise.

Dr. Ryan then showed some interesting lantern views of the new 2,000,000-volt laboratory at Stanford University, where further high voltage researches will be conducted.

The ceremonies ended with a brief address by Mr. H. T. Plum concluding with the following sentiment addressed to Dr. Ryan: "For your achievements as teacher, engineer and scientist, WE HONOR YOU! For your sincerity, devotion, humility and service, WE LOVE YOU!"

Regional Meeting in New York

NOVEMBER 11, 12, 1926

The two-day regional meeting to be held in New York City on November 11 and 12 will have three very instructive technical sessions and other features of much interest. The technical papers will cover the subjects of a-c. distribution networks, illumination and communication. There will be a lecture by a well-known speaker on the evening of November 11. A number of inspection trips are arranged for the afternoon of the same day. In order to allow for informal association of members, buffet luncheons will be held if possible on each day of the meeting. Also, a dinner is being planned for Thursday, November 11.

Headquarters for the meeting will be Engineering Societies Building, 33 West 39th Street, New York, where all events will be held with the exception of the dinner.

Further announcements will be mailed to all members in territory surrounding New York. It is urged that all who will attend notify Institute headquarters in advance by means of the card which will accompany the announcement in order that estimates may be made of the attendance, particularly at the luncheons and the dinner.

The following tentative program will give the general information on the meeting, though it is possible that some changes will be made later.

The general committee in charge of the meeting is as follows: H. A. Kidder, Chairman; O. B. Blackwell, H. V. Bozell, W. A. Del Mar, G. L. Knight, E. B. Meyer and G. H. Stickney.

TENTATIVE PROGRAM OF NEW YORK REGIONAL MEETING NOVEMBER 11 AND 12, 1926

THURSDAY MORNING—DISTRIBUTION SESSION

Recent Progress in Distribution Practise, J. F. Fairman and R. C. Rifenburg, Brooklyn Edison Company.

Combined Light and Power Systems for A-C. Secondary Networks, H. Richter, Westinghouse Electric & Mfg. Co.

Evolution of the Automatic Network Relay, J. S. Parsons, Westinghouse Electric & Mfg. Co.

Operating Requirements of the Automatic Network Relay, W. R. Bullard, Electric Bond & Share Company.

A-C. Network Relay Characteristics, D. K. Blake, General Electric Company.

THURSDAY NOON

Buffet Luncheon.

THURSDAY AFTERNOON

Inspection Trips.

THURSDAY EVENING

Dinner

Lecture by Prominent Scientist.

FRIDAY MORNING—ILLUMINATION SESSION

Remote Control of Multiple Street-Lighting Systems, W. S. Dempsey, New York Edison Company.

Lighting of Railway Classification Yards, G. T. Johnson, New York, New Haven & Hartford R. R.

The Induction Lamp, A New Source of Visible and Ultra Violet Radiation, T. E. Foulke, Cooper-Hewitt Electric Company.

FRIDAY NOON

Buffet Luncheon.

FRIDAY AFTERNOON—COMMUNICATION SESSION

Frequency Measurements with the Cathode-Ray Oscillograph, F. J. Rasmussen, Bell Telephone Laboratories, Inc.

A Shielded Bridge for Inductive-Impedance Measurements, W. J. Shackelton, Bell Telephone Laboratories, Inc.

Radio Broadcast Coverage of City Areas, L. S. Espenschied, American Telephone and Telegraph Company.

New York Section Meeting October 8

LECTURE ON FLAMES OF ATOMIC HYDROGEN

On the evening of Friday, October 8, 1926, the members of the New York Section will have the pleasure of hearing Dr. Irving Langmuir of the Research Laboratories, General Electric Company, describe "Atomic Hydrogen Arc Welding," recently developed by him. Dr. Langmuir's work, originating some fifteen years ago in a theoretical investigation of the heat loss of tungsten filaments of incandescent lamps in a hydrogen atmosphere, has now been applied in a different field—the development of a new method of welding. In brief, a stream of hydrogen is passed between two electrodes, the heat of the arc breaking up the hydrogen molecules into atoms. These combine again a short distance in front of the arc with the liberation of an enor-

mous amount of heat. Much higher temperatures are obtained than with usual welding methods and welding can be accomplished without oxidation and without fluxes. Dr. Langmuir's talk will be illustrated by extremely interesting slides and motion pictures.

The meeting will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, N. Y., at 8.15 p. m. on October 8, 1926. A cordial invitation to attend is extended by the New York Section to all interested in the subject.

New York Electrical Society's First Meeting to be on "The Vitaphone"

On the evening of Wednesday, October 27, 1926, the New York Electrical Society will hold the first meeting of the year 1926-27. In line with the practise of the society to give to engineers and to the public reliable information on the most recent developments in the engineering and scientific fields, the meeting of October 27 will be devoted to "The Vitaphone." Much has appeared in the press relative to the recent application of this development on the New York stage. The complete story of the principles, development and operation of the vitaphone will be outlined to the members of the society and their friends in a popular talk by E. B. Craft, executive vice-president, Bell Telephone Laboratories, Inc. Following Mr. Craft, the president of the Vitaphone Corporation, Mr. Walter Rich, will speak on educational and other possibilities. There will follow actual demonstrations of the vitaphone with the reproduction of selections by famous stars. The meeting will be held in the Auditorium of the Engineering Societies Bldg., 33 West 39th St., New York, N. Y. at 8.15 p. m. on Wednesday, October 27, 1926. A cordial invitation is extended to members of the A. I. E. E. and others interested to be present as guests of the New York Electrical Society.

Philadelphia Convention of Civil Engineers

The official program for the Philadelphia Convention of the American Society of Civil Engineers, Oct. 4-9, 1926 gives details of the various treats in store for those who attend. Seldom has the Society been privileged to present a more imposing schedule.

Salient Features of Power and Mechanical Show

Fifth National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y.

Opening December 6 and continuing through December 11, 1926; will open at 12 noon each day and close at 10:30 p. m.

The Exposition performs the service of a great clearing house of latest information about important developments in power and mechanical engineering, as regards heat and power generating apparatus, hoisting and conveying equipment, power transmission equipment, machine tools, refrigerating machinery and heating and ventilating machinery.

The American Society of Mechanical Engineers will hold its Annual Meeting in the Engineering Societies Building, 29 West 39th Street, from December 6-9. The meeting of the American Society of Refrigerating Engineers will be held at the Hotel Astor from December 7-9.

In the conduct of the Exposition the management will be assisted by an Advisory Board of outstanding consulting engineers and officers from The American Society of Mechanical Engineers, the American Society of Refrigerating Engineers, the American Society of Heating and Ventilating Engineers, the National Electric Light Association and the National Association of Stationary Engineers.

Electrochemists to Discuss Electric Furnace Refractories

The American Electrochemical Society will hold its fiftieth national meeting, at Hotel Washington, Washington, D. C., October 7, 8 and 9. An elaborate program has been arranged by the local committee and preparations are being made for an unusually large attendance.

Electrical engineers will be particularly interested in the Symposium scheduled for Thursday morning, October 8th, at Hotel Washington. The symposium will be in charge of Dr. H. W. Gillett, of the Bureau of Standards, an engineer of world-wide reputation and an inventor of electric furnaces and other electrical devices. The symposium topic is "Materials for Extreme Conditions in the Electrochemical Industries."

The first paper of the symposium is by Dr. H. J. French, Senior Metallurgist, Bureau of Standards, who will discuss the principal characteristics and typical applications of metals used industrially to resist high temperatures or corrosion. Dr. J. G. Thompson will report the findings of the Fixed Nitrogen Research Laboratory at Washington and will offer recommendations as to the best materials for the nitrogen fixation industry.

The Carborundum Company, of Niagara Falls, have, during the last five years, carried out extensive tests on thermal insulation of electric furnaces and these tests will be reported on by Dr. M. L. Hartmann and Mr. O. B. Westmont. Mr. F. A. J. FitzGerald, the well-known electric furnace engineer of Niagara Falls, will present a communication on recrystallized carborundum, or silicon carbide.

The second half will be devoted to the refractory problem for the induction furnace which has been a more difficult one than the similar problem for the electric arc furnace. Mr. Max Unger, of the General Electric Co., Pittsfield works, inventor of the General Electric Induction Furnace, will describe at length his researches that led up to the solving of this very difficult refractory problem.

The Friday morning session will be devoted to papers on Electrodeposition. Mr. G. Prescott Fuller, engineer of the new Electrolytic Iron Plant at Niagara Falls, will describe the new process and product.

"Voltage Studies in Copper Refining Cells" is the title of a paper by Colin G. Fink and C. A. Philippi. A paper of special interest is that by J. D. Edwards and C. S. Taylor on "The Electrical Resistivity of Aluminum-Calcium Alloys." The last session of the meeting, Saturday morning, will be devoted to organic electrochemistry.

Among the social features of the program is a visit to the Government Laboratories. On Thursday evening there will be an informal dinner at which Prof. W. D. Bancroft, of Cornell University, will discourse on "The Ramifications of a Research Problem." The formal address of the convention will be delivered by Dr. Chas. Greeley Abbot, Director of the Smithsonian Observatory, at the National Academy of Sciences on Friday evening, October 8th. The title of Dr. Abbot's address is "Solar Radiation."

At this same meeting, Honorary Membership in the American Electrochemical Society will be officially bestowed on Dr. Edward Weston, internationally known for his standard cell.

Fall Meeting of American Welding Society

One of the largest Welding Expositions will be held in connection with the Fall Meeting of the American Welding Society, Buffalo, N. Y., November 17, 18 and 19, 1926. This Exposition will show new developments in welding apparatus and supplies, and a unique feature will be an exhibit of a large variety of welded products. The Exhibit will open the day preceding the Annual Fall Meeting of the Society. Indications are that several thousand people will be in attendance at the various technical sessions, inspection trips, committee meetings and exhibits, in-

cluding representatives from all parts of the United States and Canada.

Technical sessions include authoritative papers and discussions on "The Design and Development of Welding Apparatus," "Organization of Welding on the Railroads;" "Welding of Locomotive Parts;" "Welding Science in the Engineering Curriculum of Universities;" and "Arc Welding in a Gaseous Atmosphere."

An inspection trip has been arranged to Niagara Falls, and members of the society and their guests will view the Falls from the American side with a short inspection trip through the Niagara Falls Power House. This will be followed by a buffet supper on the Canadian side and then a special illumination of the Falls will be shown, returning to Buffalo late in the evening.

Bituminous Coal Conference

The Conference on Bituminous Coal to be held at the Carnegie Institute of Technology in Pittsburgh has been definitely scheduled for November 15 to November 19, 1926, according to an announcement from the institution.

The purpose of the meeting, according to Dr. Thomas S. Baker, president of the Carnegie Institute of Technology, is to bring together the men of all countries who have done notable work in the study of more scientific and rational utilization of soft coal. Listed for discussion are such questions as the manufacture of substitutes for gasoline from coal; the complete gasification of coal; high temperature and low temperature carbonization; by-products; smokeless fuel; pulverized coal; hydro-electric power versus steam power, etc.

Among the members of the Advisory Board assisting in the development of the conference plans are Andrew W. Mellon, Secretary of the United States Treasury; John Hays Hammond, engineer and inventor; Otto H. Kahn, banker; Charles M. Schwab, steel manufacturer; Samuel Insull, public utility leader; E. M. Herr, president of the Westinghouse Electric and Manufacturing Company; and Dr. Frank B. Jewett, vice-president of the American Telephone and Telegraph Company, and director of research of the Bell Telephone Research Laboratories.

Standardization of Voltages Will Be a Winter Convention Topic

The standardization of voltages, and particularly of high voltages, has received much attention from the electrical industry for the last two years. Various organizations have been studying this question and, as a result, a group of central-station operating engineers, members of consulting and management organizations, electrical manufacturers and European engineers has arranged for the presentation of papers on this subject at the coming Winter Convention of the A. I. E. E., February 7-10, 1927. The committee on arrangements, of which B. G. Jamieson is chairman, has prepared the following announcement of its plans.

First, from a review made by the Apparatus Committee of the N. E. L. A., it appears that the standard voltages for transformers established in 1922 are not well adapted to meet the present conditions and less than half of all the power transformers above 200 kv-a. are being ordered in line with these standards.

Second, the increasing number of interconnections which are taking place has focused attention on the subject of uniformity of voltages, particularly in the high-pressure field.

The study by the Electrical Apparatus Committee of the N. E. L. A., which included the data received from operating companies in answer to a questionnaire, indicated that a revision of the 1922 transformer-voltage standards must take into account not only the present operating voltage of systems, but the voltage ratings of generators, oil circuit breakers and other electrical equipment connected on the same system, and finally, the utilization voltage.

In order to focus the attention of the industry on this subject and arrive at some concrete recommendations, it is proposed to devote one of the regular sessions of the Winter Convention to the discussion of this subject. The papers presented at this meeting will cover the points of view of different groups in the electrical industry as well as the different requirements of the field served in different localities. The subject is of such far-reaching importance that foreign engineers will be brought into the discussion and present their view as they see it in their countries; and the electrical manufacturers will present their view as to the effect of equipment on production if new standardization can be made along this line.

A tabulation was published in the N. E. L. A. Bulletin for September setting forth a proposed set of standard voltages for systems, generators, transformers, motors, and other electrical apparatus, all interdependent and fitting together in such a way that, with system voltages and apparatus voltages selected according to the proposed standards, a system will work under any reasonable condition of load and voltage drop. This was published as a foreword to the discussion of the Winter Convention.

It is hoped that all engineers interested in this problem will be prepared to enter into the discussion at the Winter Convention, and if they will advise Institute headquarters, advance copies of the papers will be sent to them prior to the meeting.

National Electrical Manufacturers Association

The creation of a National Electrical Manufacturers Association, consisting of 270 leading electrical interests, has been announced following the merging of the Electric Power Club, the Associated Manufacturers of Electrical Supplies and the Electrical Manufacturers Council. Gerard Swope, President of the General Electric Company and Fellow of the Institute, has been elected President of the new association, with James William Perry, Treasurer. Mr. Perry is also a Member of the Institute.

The general purpose of the new association is to advance the art and reliability of electrical equipment; specifically, to further the interests of makers of electric apparatus and supplies, engineering safety, transportation and other industrial problems; to promote the possible standardization of electrical apparatus by the collection and dissemination of information of value to members of the electrical profession and to the public; to appear for legislative movements, before governmental bureaus and to create a spirit of wide cooperation for the betterment of electrical developments.

Election of Officers of the A. I. E. E.

The actions specified in the Institute's Constitution and By-laws relative to the organization of a National Nominating Committee are being taken, and the meeting of the National Nominating Committee for the nomination of officers to be voted upon at the election in the Spring of 1927 will be held between November 15 and December 15. All suggestions for the consideration of the National Nominating Committee must be received by the Secretary of the Committee at Institute headquarters, New York, not later than November 15.

The sections of the Constitution and By-laws governing these matters are quoted below:

CONSTITUTION

28. There shall be constituted each year a National Nominating Committee consisting of one representative of each geographical district, elected by its Executive Committee, and other members chosen by and from the Board of Directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the By-laws; The National Secretary of the INSTITUTE shall be the secretary of the National Nominating Committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as Vice-President of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The National Nominating Committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The National Nominating Committee shall name on or before December 15 of each year, one or more candidates for President, Treasurer and the proper number of Managers, and shall include in its ticket such candidates for Vice-Presidents as have been named by the nominating committees of the respective geographical districts, if received by the National Nominating Committee when and as provided in the By-laws; otherwise the National Nominating Committee shall nominate one or more candidates for Vice-President(s) from the district(s) concerned.

BY-LAWS

Sec. 21. During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 1st of that year the Executive Committee of each District must select a member of that District to serve as a member of the National Nominating Committee and shall, by November 1st, notify the Secretary of the National Nominating Committee of the name of the member selected.

During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 15th of that year a nomination for a Vice-President from that District, made by the District Executive Committee, must be in the hands of the Secretary of the National Nominating Committee.

Between October 1st and November 15th of each year, the Board of Directors shall choose five of its members to serve on the National Nominating Committee and shall notify the Secretary of that Committee of the names so selected, and shall also notify the five members selected.

The Secretary of the National Nominating Committee shall give the fifteen members so selected not less than ten days' notice of the first meeting of the committee, which shall be held not later than December 15th. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the National Nominating Committee must be received by the Secretary of the committee by November 15th. The nominations as made by the National Nominating Committee shall be published in the January issue of the A. I. E. E. Journal, or otherwise mailed to the Institute membership during the month of January.

F. L. Hutchinson,
National Secretary

George Westinghouse Memorial Committee Appointed

A committee chosen from among executives of the Westinghouse corporations has been named to represent the enterprises founded by George Westinghouse in the work of erecting a memorial to him in Schenley Park, Pittsburgh, Pa. to perpetuate esteem for his life and work.

The committee consists of A. L. Humphreys, president of the Westinghouse Airbrake Company, chairman; E. M. Herr, president of the Westinghouse Electric and Manufacturing Company; F. A. Merrick, vice president of the Westinghouse Electric and Manufacturing Company, and John F. Miller of the Westinghouse Airbrake Company, vice chairman.

AMERICAN ENGINEERING COUNCIL

MEETING OF ADMINISTRATIVE BOARD

The Administrative Board of the American Engineering Council will meet at Ithaca, N. Y., November 11 and 12. Reports will be received from numerous committees which have been active during the summer. Among the topics in the large agenda which is being prepared are safety and production, registration of engineers, government reorganization, and jurisdictional strikes in the building industry. Dean Dexter S. Kimball of Cornell University, the president of the Council, will preside.

NATIONAL SURVEY TOWARD INDUSTRIAL SAFETY

Charles W. Lytle, Director of Industrial Cooperation of the Engineering College at New York University, has been appointed to direct field investigations in New York as a part of a nation-wide survey by the American Engineering Council, which seeks to check the growing number of industrial accidents in this country.

Two thousand industrial plants will be investigated by the engineers under the direction of a main committee headed by A. W. Berresford of Detroit, Past president of the Institute, with a view, according to the President of the Council, Dean Dexter S. Kimball of Cornell University, of getting to the bottom of the whole problem of accident prevention.

Industrial Accidents Discussed

The thirteenth annual meeting of the International Association of Industrial Accident Boards and Commissions will be held at Hartford, Conn., September 14-15, it was announced September 8 by the Bureau of Labor Statistics. The association is made up of State and city organizations' representatives.

Ethelbert Stewart, United States Commissioner of Labor, will attend as representative of the Department of Labor. He also is secretary-treasurer of the association, the sessions of which will be held in the hall of the House of Representatives, in the State Capitol at Hartford.

The meetings will be addressed by many of the leading authorities on industrial accident prevention. Special attention will be given to medical problems that may be made to assist industrial workers.

Would Standardize Motor Vehicles for Government

Announcement of an inquiry into the possibility of standardizing motor propelled vehicles for use by the Government was made in the annual report of the Federal Specifications Board. The work will be started by a preliminary technical committee.

The committee was instructed to study the question of motor-vehicle standardization from the standpoint of saving in replacement and repair as well as the utilitarian possibilities of a standard machine being used by every branch of the Government.

In addition to this committee, others were created to study standard specifications for such things as foundry equipments and supplies, machinery and commercial wire. The report also disclosed that 114 master specifications for Government supplies were promulgated during the last fiscal year.

PERSONAL MENTION

M. Merwin Eells has resigned from his position as research engineer for the Western Coil and Electrical Company of Racine, Wisconsin, to become chief engineer of the Buckwalter Radio Corporation of Chicago.

A. Barnett Green, formerly of Murrie & Co., Appraisal Engineers and the Electrical Division of the New York Municipal Railway Corporation, has opened an office in the Marbridge Building, 1328 Broadway, New York City for the editing of engineering matter, compiling of data and the writing of advertising copy.

Doctor Edward Weston, Past President and Charter Member of the Institute, will have Honorary Membership in American Electrochemical Society bestowed upon him at their October 8th meeting, Hotel Washington, Washington, D. C. Doctor Weston, in 1875, established in Newark, N. J., the first factory in America devoted exclusively to dynamo electric machines. He is also the inventor of the Weston Measuring Instruments and holds several patents on electric lighting and other electrical devices.

Burch Foraker, for many years with the New York Telephone Company, and ultimately serving it as General Manager, has recently removed to Detroit to become President of the

Michigan Bell Telephone Company, as successor to the late Judge Franz C. Kuhn.

George M. Bates, who has been Manager of the Central Station Division of the Westinghouse Electric & Mfg. Co., Boston, Mass., has been chosen as District Manager of the new Boston office opened by the American Brown Boveri Electric Corporation. Mr. Bates had been with the Westinghouse Company since 1898.

Yasudiro Sakai, Consulting Engineer and Member of the Institute, announces the opening of a new office in Room 465, Marunouchi Bldg., Tokio, Japan. Mr. Sakai is a patent expert and is specially equipped to handle applications for Japanese "Letters Patent" and trade mark registrations.

Carl George Schluederberg, previously assistant to the manager, Supply & Merchandising Depts. of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., has been appointed General Manager of the George Cutter Company, South Bend, Ind. Mr. Schluederberg is a member of the N. E. L. A., the American Chemical Society, the American Electrochemical Society and the American Institute of Electrical Engineers.

Edward E. Hill, who has for some time been assistant superintendent in the Meter Dept. of the New York Edison has been advanced to Manager of the Meter Dept. Mr. Hill has been a member of the Institute since 1916 and is at present vice-chairman of the National Meter Committee, Engineering Division of the National Light Association as well as chairman of their Engineering Division of the Metropolitan New York Section.

Obituary

Charles Hampton Bedell, born Dec. 18, 1861, Lynn Co., Ia., died at his home, New London, Conn., Sept. 2, 1926.

In 1888 he became head of the Research Laboratory of the Electro Dynamic Co. of Philadelphia, and remained with them in that capacity until 1909. He then joined the Electric Boat Co., Groton, Conn., with whom he was up to the time of his death. In 1887 he received the degrees of B. S. and A. M. from Haverford College also taking one years electrical course at John Hopkins University.

Mr. Bedell joined the Institute in 1903.

James Warren McCrosky, 57 years old, died in Pasadena, California, July 20, 1926. From 1896 to 1902 he was engaged in engineering work in Argentina, where he designed, constructed and operated the first commercial electric railways and the first hydroelectric plant in that country. From 1902 to 1914, he was in London with J. G. White & Company, Ltd., doing engineering work and negotiating contracts. During the World War he served as one of the six members of the Contraband Committee of the War Trade Board. After the War he spent five years with the Bankers Trust Company, as manager of the Foreign Trade Department, retiring from business in 1924. He was a Fellow of the American Institute of Electrical Engineers, a member of the Engineers Club of New York and the Bankers Club of America, and of the Pan-American Society.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (AUGUST 1-31, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

Aerostatics.

By Edward P. Warner. N. Y., Ronald Press Co., 1926. (Ronald aeronautic library). 112 pp., diagrs., 9 x 6 in., cloth. $3.25.

A textbook based upon the first part of a course in the theory of airship design given at the Massachusetts Institute of Technology.

Aircraft Power Plants.

By Edward T. Jones and others. N. Y., Ronald Press Co., 1926. (Ronald aeronautic library). 208 pp., illus., diagrs., 9 x 6 in., cloth. $4.25.

This book is not intended so much for those engaged in building or operating engines, as for designers of aircraft, who need to know something of the characteristics of the power plants in order to adapt them to the structures they design, and for pilots who need knowledge of the engine to operate their craft successfully. The book discusses the various types of heat engines from a thermodynamic point of view, pointing out the advantages and disadvantages of each and the factors that affect performance. Propellers are treated in the same fashion. The concluding section treats of water ballast recovery.

Calculus.

By Herman W. March and Henry C. Wolff. 2nd edition. N. Y., McGraw-Hill Book Co., 1926. 398 pp., 7 x 5 in., cloth. $2.50.

An elementary textbook for beginners who are students of science or technology. The authors have endeavored, while developing the fundamental processes of the calculus, to place the emphasis upon the mode of thought and to show how this mode of thought fits naturally into the expression and derivation of scientific laws and of natural concepts. This method of presentation will lead the student, they hope, to continue to apply these fundamental modes of thinking throughout his career, even though he may forget the details of the subject.

Conquests of Engineering.

By Cyril Hall. Lond., Blackie & Son, Ltd., [1926]. 288 pp., illus., 8 x 5 in., cloth. 3s 6d.

Bridges, tunnels, canals, lighthouses and docks are the works discussed in this popular account of civil engineering. The author writes in interesting fashion of the way in which these works are designed and built and tells the story of some famous examples. Intended for the general reader.

DIESEL ENGINES: Marine—Locomotive—Stationary.

By David Louis Jones. N. Y., Norman W. Henley Publ. Co., 1926. 565 + 39 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

A manual for operators of Diesel engines, prepared by the instructor in the Diesel engine department of the U. S. Navy Submarine School. Keeping in mind the class for which he writes, the author devotes but little time to theoretical principles, thermodynamic considerations, etc., but gives most of his attention to the actual construction and the operation of the various parts of commercial engines, to advice on operation and to descriptions of typical engines. The book should be helpful to all in charge of Diesel power plants.

ELEKTRISCHE SCHALTVORGANGE.

By Reinhold Rüdenberg. 2nd edition. Berlin, Julius Springer, 1926. 510 pp., illus., diagrs., 10 x 7 in., cloth. 24 r. m.

An exhaustive discussion of the phenomena that accompany switching operations and of the disturbances that they cause in heavy-current lines. Dr. Rüdenberg, who is chief electrician of the Siemens-Schuckertwerke, takes the various kinds of circuits, one by one, and the switching operations to which each may be subjected, and deals fully with the mathematical theory of the phenomena that occur.

This edition is much the same as the first, but small errors have been corrected, the bibliography completed through 1925 and an index added.

DIE FERNSPRECHANLAGEN MIT WAHLER-BETRIEB.

By Fritz Lubberger. 3rd edition. Mün. u. Ber., R. Oldenbourg, 1926. 277 pp., plates, 10 x 7 in., paper. 11,-mk.

A systematic discussion of the problems involved in the construction of an automatic telephone system, the possible methods of solving them and the advantages and disadvantages of these various possibilities. The discussion is limited to technical phases of the subject, economic questions being left for a separate treatment. The six leading commercial systems are described in detail.

LES FILTRES ELECTRIQUES.

By Piere David. Paris, Gauthier-Villars et cie., 1926. 129 pp., diagrs., tables, 10 x 7 in., paper. 25 fr.

The first part of this treatise endeavors to recapitulate, in a new way, the essential points of the theory of electric filters. His work is intended especially to make available to French electricians the results obtained by American investigators, particularly those connected with the Bell system. The second part treats of practical matters. In it the theoretical results are grouped so as to facilitate practical application of filters to various purposes.

HANDBOOK OF NON-FERROUS METALLURGY.

By Donald M. Liddell, Editor-in-Chief. N. Y., McGraw-Hill Book Co., 1926. 2 vols., illus., diagrs., tables, 9 x 6 in., cloth. $12.00.

This handbook will be valued by engineers and metallurgists who wish a concise account of modern metallurgical methods, as well as by students. Each topic has been handled by an author acquainted with it through experience.

The first volume treats of processes and materials that are common to all metallurgical operations. It contains chapters on crushing and grinding, sampling, screening, classification, concentration, dewatering, fuels, refractories, briquetting, power plants, plant materials, plant layout and electric furnaces. In volume two a chapter is devoted to the metallurgy of each metal.

HYDROLOGY AND GROUND WATER.

By J. M. Lacey. Lond., Crosby Lockwood & Son, 1926. 159 pp., diagrs., 9 x 6 in., cloth. 12s 6d.

The want of a comprehensive work on hydrology, ground water and surface flow, has induced the author to compile this work. It is intended to aid engineers engaged in schemes for water works, irrigation or drainage.

INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY.

Prepared under the auspices of the International Research Council and the National Academy of Sciences by the National Research Council of the United States of America. 1st edit. N. Y., McGraw-Hill Bk. Co., 1926. 415 pp., diagrs., 11 x 9 in., cloth. $60.

This book, the result of the cooperative work of many specialists, gives the values for physical and chemical constants which they have selected as the "best" values, from the great mass of determinations recorded in scientific and technical literature before the year 1924. It selects, in each case, the value that appears most worthy of credence and makes it available readily.

The need for such a reference book has long been obvious. The seeker after data, who has usually been confronted by several values, with no means of criticizing their relative accuracy, will be much relieved to have a selected figure which has the stamp of authority. The book is a necessity to every laboratory and scientific library.

In a sense, the work supplements the "International Annual Tables of Constants." It removes the necessity of examining all the volumes of the latter in most cases, by giving immediately the prepared value.

KRAN- UND TRANSPORTANLAGEN FUR HUTTEN-, HAFEN-, WERFT-, UND WERKSTATTBETRIEBE.

By C. Michenfelder. 2nd edition. Berlin, Julius Springer, 1926. 683 pp., illus., diagrs., 11 x 8 in., boards, 67, 50 mk.

An extensive descriptive treatise on modern hoisting and conveying machinery, particularly as used in smelters, rolling-mills, shipyards and harbors. The work is intended to assist in the selection of equipment rather than to aid in design and therefore the text follows the course of operations in these various industries, explaining the problem of transportation at each operation and the ways by which it can be met. The book is a useful detailed description of current German practise, illustrated with many photographs of machines and installations.

MATHEMATICS FOR ENGINEERS.

By Raymond W. Dull. N. Y., McGraw-Hill Book Co., 1926. 780 pp., 8 x 5 in.. cloth. $5.00.

The two sources to which the engineer turns for mathematical aid are the engineer's handbook and the mathematical textbook. The first of these, Mr. Dull says, is too concise and incomplete to be satisfactory; the second is not well adapted to use for quick reference.

The present book, prepared by a practising engineer, appears to be primarily intended as a convenient work of reference and as a means for reviewing various topics. The entire range of mathematics ordinarily used in engineering is traversed, the examples are worked out with greater fulness than usual and the text is arranged to facilitate ready understanding of each question. Graphical solutions are included and a considerable treatment of absolute and relative errors is given.

NORTH MANCHURIA AND THE CHINESE EASTERN RAILWAY.

By I. A. Mihailoff, editor. Harbin, China, Chinese Eastern Railway, 1924. 454 pp., illus., maps, 12 x 9 in., fabrikoid. Price not quoted.

A systematic account of industrial conditions in North Manchuria, prepared by the Economic Bureau of the Chinese Eastern Railway. Data are given on agriculture and forests, on the trade in grain, cattle, lumber and coal, on milling and manufacturing, on banking, currency, etc. Ways of communication, especially the Chinese Eastern Railway, are described. The book contains many photographs.

ON THE METALLURGY OF IRON AND STEEL.

By F. T. Sisco, Bengt Kjerrman and Birger Egeberg. Amer. Soc. Steel Treating, Cleveland, Ohio. 1926. 193 pp., illus; $1 paper cover, $2 cloth binding.

This book is a reprint of three papers presented before the American Society for Steel Treating recently, which attracted so much attention that there was a demand for their separate publication. Mr. Sisco's discussion of the metallurgy of iron and steel constitutes nearly seven-eighths of the book; Dr. Kjerrman contributes 10 pages on Swedish steel practise and Dr. Egeberg adds 5 pages on electric steel melting. The reprint will be extremely useful to any one who wishes a brief, clear, and accurate statement of the general features of iron and steel metallurgy, especially to both technical and non-technical employees of steel companies who wish to obtain a better understanding of the business they are engaged in.

PHOTOTOPOGRAPHY; a Manual of Photographic Surveying Methods.

By Arthur Lovat Higgins. Cambridge, University Press, 1926. 130 pp., illus., diagrs., plates, 8 x 5 in., cloth. $2.40. (Gift of Macmillan Co., N. Y.)

The author has attempted to outline the essential principles of the operations of some of the best-known exponents of the photographic method and thus to produce a practical manual for surveyors and students.

PORTS AND TERMINAL FACILITIES.

By Roy S. MacElwee. 2nd ed., enl. N. Y., McGraw-Hill Book Co., 1926. 446 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

The new edition of this work is actually, the author says, a new book, containing less than fifteen per cent of the original work. That portion of the older edition which dealt with the upbuilding of traffic through competitive ocean gateways now appears as a separate work entitled "Port Development," while the volume before us discusses the construction and equipment of ports.

The book first discusses general matters, the characteristics of well coordinated seaports and wharf design. Equipment and arrangements for general cargo wharves and warehouses are described in detail, after which attention is given to passenger terminals and facilities for handling ore, coal, liquids and grain in bulk. The concluding chapter discusses industrial harbor development.

LE PROBLEME ACTUEL DU CONDENSEUR A SURFACE.

By A. Delas. Paris, Revue Industrielle, 1926. 22 pp., illus., 8 x 5 in., paper. 5 fr.

Describes the results of recent researches which have increased the efficiency of surface condensers by rearrangement of the condenser tubes. These rearrangements have made it possible, at the Gennevilliers power plant, to suppress one-fourth of the tubes in certain of its condensers.

PROPRIETES PHYSIQUES DES VAPEURS DE PETROLE ET LES LOIS DE LEUR ECOULEMENT.

By Jean Rey. Paris, Dunod, 1925. 251 pp., diagrs., plates, tables, 9 x 6 in., paper. 8,50 Fr.

The author has found it necessary, in connection with his professional work, to undertake an extensive investigation of the physical properties of kerosene. In this memoir he presents the results of his researches.

In part one the numerical values he has obtained are used to determine approximately the law of variation, with the temperature or pressure, of the physical properties of kerosene: vapor tension, heat of vaporization, liquid density, specific heat, etc. The second part describes the apparatus used in the researches, and the application of the burners invented by the author to boilers and lighthouses.

RADIOACTIVITY.

By George Hevesy and Fritz Paneth; trans. by Robert W. Lawson. Lond. & N. Y., Oxford Univ. Press, 1926. 252 pp., illus., diagrs., tables, 9 x 6 in., cloth. 15 s.

Hevesy and Paneth's Radioactivity first appeared in the German language in 1923. Translations into Russian and Hungarian were published in 1924 and 1925, and now comes the present English version. This last is not a literal translation of the original work, but is essentially a new edition, for the authors have incorporated in it the results of scientific advances since the German edition appeared and have extended the bibliographic references up to 1925.

The book differs from the majority of those on the subject by being intended specifically for use as a textbook, a work which will give those having no preliminary knowledge of radioactivity an insight into the science at first hand. The subject matter is arranged from the didactic point of view, somewhat as is done in textbooks of physics and chemistry, the historical development of the subject being separated and outlined late in the book.

RATIO CHART IN BUSINESS.

By Percy A. Bivins. N. Y., Codex Book Co., 1926. 177 pp., charts, 8 x 6 in., cloth. $3.00.

A clear, detailed description of the methods of making ratio or logarithmic charts and thorough explanation of many of its applications in industry and business. The author treats the subject in simple language, readily understood by those unfamiliar with the subject, and the book should do much to popularize this valuable method.

LES RESERVES D'ENERGIE.

By M. Rigaud. Paris, Gauthier-Villars & cie., [1926]. 295 pp., 8 x 5 in., paper. 30 fr.

Discusses, from a broad viewpoint, the possible sources of energy and present utilization of them. Beginning with the kinetic energy of the earth and the utilization of tidal power, the author then considers the internal energy of the earth. Radient energy from the sun is discussed, with its indirect utilization by winds and direct utilization by falling water. Turning then to mineral fuels, the winning and use of coal and oil are treated.

SCIENCE OF FLIGHT AND ITS PRACTICAL APPLICATION, Vol. 1; Airships and Kite Balloons.

By P. H. Sumner. Lond., Crosby Lockwood & Son, 1926. 168 pp., illus., diagrs., tables, 9 x 6 in., cloth. 16s.

After an introductory chapter on the British air policy, Captain Sumner takes up successively the principles of aerostatics, the general construction of the dirigible, the airship in flight, the types of airships and their performances, and kite balloons. The book, which is the first of two volumes on the general subject of flight, is devoted to buoyant airships. It is based on the author's long experience in airship construction in the Air Ministry.

TABLES ANNUELLES DE CONSTANTES ET DONNEES NUMERIQUES DE CHIMIE, DE PHYSIQUE ET DE TECHNOLOGIE. Vol. 5, pt. 2, 1917-1922.

Publiées sous le patronage de l'Union de Chimie pure et appliqué. Paris, Gauthier-Villars et cie, Cambridge, Eng., Cambridge University Press; Chicago, Univ. of Chicago Press. 1926. 1130 pp., 11 x 9 in., cloth. $25.00 (pts. 1 and 2).

A new volume of this indispensable collection of chemical and physical data, containing tables showing those recorded during the years 1917-1921.

With the publication of this volume, the interruption caused by the war has been made up. A volume covering the years 1924 and 1925 will probably appear early next year, and it is the hope of the Committee soon to make the publication again an annual.

THERMODYNAMICS AND CHEMISTRY.

By F. H. Macdougall. 2nd edition. N. Y., John Wiley & Sons, 1926. 414 pp., tables, 9 x 6 in., cloth. $5.50.

A textbook for advanced students of chemistry, which aims to give an accurate, logical and sufficiently rigorous exposition of thermodynamics, with numerous examples of the application of the principles to their work. The new edition is enlarged and partly rewritten.

THEORY AND PRACTISE OF RADIO FREQUENCY MEASUREMENTS.

By E. B. Moullin. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1926. 278 pp., diagrs., tables, 9 x 6 in., cloth. 25 s.

The author has aimed to write a work that will serve as a handbook for use and reference on the laboratory table while measurements are in progress. It will also be usable as a textbook for advanced students.

The subjects covered are the measurement of potential difference, current, frequency, resistance, capacity, inductance, antenna characteristics, and the intensity of radiated fields. The book is based on the experience of the author and the isolated papers scattered through the scientific journals. It is, the author believes, the first book devoted entirely to the subject.

TRANSPORT AVIATION.

By Archibald Black. N. Y., Simmons-Boardman Pub. Co., 1926. 245 pp., illus., tables, 9 x 6 in., cloth. $3.00.

A discussion of the various problems connected with commercial aviation. The author describes present developments here and abroad and studies the possibilities of the airplane as a means of transportation. He discusses the influence of design upon the cost of operation, general requirements of airplanes for commercial use, the design of passenger and freight airplanes, airways, landing fields and the organization of air lines. Cost data are scattered through the book.

UBER DIE WAHL EINES GASWERKSOFENSYSTEMS.

By L. Litinsky. Halle (Saale), William Knapp, 1926. 29 pp., illus., 10 x 7 in., paper. 1,50 r. m.

In selecting the generators for a gas works the problem is to choose the type that will produce gas at the lowest cost per cubic foot, but many factors enter into the decision as to what constitutes the most economical equipment. The present pamphlet analyzes the various alternatives before the designer and points out the relative merits of each.

L'UNION D'ELECTRICITE.

By H. Bres. Paris, Revue Industrielle, 1926. 63 pp., illus., 8 x 5 in., paper, 10 fr.

A pamphlet describing recent additions to the Gennevilliers power station of the Union d'Electricité and installations of new machinery in its Vitry plant. The additions are 50,000-kw. turboalternators, pulverized-coal boiler plants and numerous other improvements on a large scale.

Past Section and Branch Meetings

SECTION MEETINGS

Atlanta

Annual Dinner. The following officers were elected: Chairman, C. E. Bennett; Vice-Chairman, E. H. Bailey; Secretary-Treasurer, W. F. Oliver. July 30. Attendance 55.

Kansas City

Electric Domestic Refrigeration, by B. J. George, Kansas City Power & Light Co., and

Flickering of Lights by a Sixty-Cycle Generator, by S. M. DeCamp, General Electric Co. June 7. Attendance 27.

Mexico

Talk by Gustavo Trevino, Mexican Telephone and Telegraph Co., upon the work his company is doing in Mexico. July 1. Attendance 25.

Oklahoma

Rural Electrification, by Edwin Kurtz, Oklahoma A. & M. College;

What the Employer Expects of a Young Engineer, by Frank Meyer, Oklahoma Gas and Electric Co., and

First Aid to the Injured, by N. I. Sommers. The following officers were elected: Chairman, E. R. Page; Vice-Chairman, Edwin Kurtz; Secretary-Treasurer, C. C. Stewart. May 26. Attendance 90.

Philadelphia

Electrical Features of the New Richmond Generating Station, by R. A. Hentz, Philadelphia Electric Co. Illustrated with slides. Inspection trip to the Generating Station. May 10. Attendance 172.

Dinner Meeting. The following officers were elected: Chairman, L. J. Costa; Secretary, R. H. Silbert; Treasurer, E. C. Drew. A short talk was given by Mr. William McClellan on the problems confronting the electrical industry today. June 14. Attendance 85.

Portland

Get-Together Meeting. Joint with National Electric Light Association, American Society of Mechanical Engineers and American Society of Mining and Metallurgical Engineers. June 19. Attendance 212.

St. Louis

Introduction of Machine Switching Telephony in St. Louis, by J. H. Landwehr, Southwestern Bell Telephone Co. The following officers were elected: Chairman, Walter Millan; Secretary, L. N. Van Hook. May 19. Attendance 128.

Utah

Business Meeting. The following officers were elected: Chairman, B. C. V. Wheatlake; Secretary-Treasurer, D. L. Brundige. August 6. Attendance 25.

BRANCH MEETINGS

University of California

Business Meeting. August 25. Attendance 31.

Ohio Northern University

Business Meeting. September 9. Attendance 36.

Rutgers University

Business and Social Meeting. The following officers were elected: Chairman, E. C. Siddons; Vice-Chairman, Frank Chalten; Secretary-Treasurer, W. H. Bohlke. May 10. Attendance 31.

University of Southern California

Business Meeting. May 13. Attendance 25.

Business Meeting. The following officers were elected: Chairman, Karl Raife; Vice-Chairman, Lester Weisser; Secretary, Elwood Smith; Treasurer, Willard Bausman. May 20.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL ENGINEER, with three or four years' experience in design of electrical layouts for generating and substations for positions in engineering department of public utility. Apply by letter. Location, South. X-644-C-S.

DIRECT CURRENT MACHINE DESIGNER, experienced, for medium industrial sizes. Apply by letter stating technical training, experience, age and salary expected. Opportunity. Location, Pennsylvania. X-658-C-S.

BOILER ROOM ENGINEER, for new public utility station in South, operating high-pressure boilers. Must have oil-burning experience and be capable supervising operation and maintenance. Apply by letter giving full details of experience, and salary expected. Headquarters, New York City. X-695.

ILLUMINATING ENGINEER, capable supervising design and production of floodlighting units, searchlights and other illuminating equipment. Also with ability to make layouts and installation recommendations on special floodlighting work. Apply by letter stating age,

education, experience, salary desired. Headquarters, Philadelphia. X-738-C.

ELECTRICAL DESIGN ENGINEER, on large direct current machines having at least five years' design experience; experience in steel mill applications of direct current motors is desirable. Apply by letter, giving full particulars concerning age, technical education, design experience, references, salary expected, and date when available. Apply by letter. Location, Pennsylvania. X-819-C.

ELECTRICAL AND MECHANICAL ENGINEER, preferably graduate, under 40, experienced in design and manufacture of switches, fuses, panel boards, receptacles, and similar electrical accessories, as general assistant to chief engineer of concern producing such devices. Should be willing and able to work at the board and handle small as well as big jobs. Opportunities. Apply by letter. Location, East. X-628.

MEN AVAILABLE

ELECTRICAL ENGINEER, 31, married, desires position with a manufacturing or engineering concern. Several years' laboratory experience in development work. Recently production manager for non-electrical firm. Now available. New Jersey, Pennsylvania, or Middlewest preferred. C-1798.

RECENT GRADUATE IN ELECTRICAL ENGINEERING desires position with large concern. Had two years' experience installing central office telephone equipment. Prefers position along experimental and research lines. C-1813-8-C-3.

PLANT ENGINEER, 33, married, thorough training in taking responsibility and handling of men. Thirteen years' experience on mechanical and electrical maintenance, construction and installation work in steel mills, blast furnaces, zinc spelters, acid plant, textile plants and small parts manufacture. New York State Professional Engineer's License. Available at once. Location, Eastern United States (small town preferred). B-5026.

GRADUATE ELECTRICAL ENGINEER wishes connection with large power company or consulting firm. Two years' general test experience with large manufacturing company, one year station test with large metropolitan power and light company, two years general engineering with large metropolitan power company specializing in problems involving relay work and general system protection. B-7797.

ENGINEER CHARGE OF PLANT, for manufacturing concern with future prospects of branch superintendency sought by graduate E. E., 32, married. Nine years' experience including hydro plant preliminaries, design with field installations, construction and maintenance of lines transformers, substation A-C. and D-C., trolley, automatic control, pumps, fans, compressors and hoists, night school teaching. Now employed, but available on short notice. C-1828.

DISTRIBUTION ENGINEER, technical graduate, 33, married, several years' electrical and mechanical test experience in power stations, four years' distribution experience with large public utility in East. Desires position in distribution engineering, or sales engineering in distribution field. Location, East. Available one month. Salary $260. B-1410.

ELECTRICAL ENGINEER, 36, professionally licensed in the States of New York, New Jersey and Pennsylvania, with sixteen years' experience covering design, construction, supervising, estimating, contracting, sales, consultant and executive, desires to locate where opportunity is available. B-6985.

ELECTRICAL ENGINEER, 26, married, technical graduate, four years' experience test supervision with a-c. public utility, one year's experience teaching, executive, statistician, organizer. Desires position with progressive organization offering reasonable advancement for conscientious, energetic worker. C-1346.

UTILITY ELECTRICAL ENGINEER, ten years' experience in design of power stations and substations. Past two years in responsible charge of important projects for one of the countries largest systems, covering every phase of the work. Desires position with utility or holding company in or near New York City. Minimum salary $350 a month. B-7809.

ELECTRICAL ENGINEER, with twenty years' practical experience in industry and utility, desires position of responsibility in a growing organization with modern business policies. Research and developmental department on small electro-mechanical apparatus desired, meters and instruments a specialty. At present employed in charge of laboratory. C-1867.

JUNIOR SALES ENGINEER, technical school graduate, good appearance and personality. Experience; two years electrical maintenance, one year signal system work, one year industrial motor inspection for public utilities, one year electrical estimating and drafting for electrical contractors. Age 30, single. Available now. Salary open. Location, East. B-7920

COLLEGE GRADUATE, '25 in E. E., desires position where he can acquire experience either in appraisal or construction work. Available two weeks. Location, New York. C-512.

ELECTRICAL ENGINEER desires executive position with progressive company. Has had twenty years' experience in the manufacture, operation, repair, maintenance of electrical machinery and equipment, such as power plants, steel mill drives, street railway, mining equipment. For the past eleven years has had full charge of repairs, machine work, maintenance all electrical equipment for large steel plant. Location immaterial if salary is right. C-1879.

ELECTRICAL ENGINEER, 35, single, ten years' experience in the design and construction of generating stations, substations. Transmission lines, underground systems with large public utility concerns, and five years with large electrical manufacturer in heavy plant sales and contract department, estimating, tendering and technical correspondence. Desires position as sales engineer United States or abroad. Available two weeks' notice. C-1827.

ENGINEER, experienced in the design, manufacture and application of switching equipment, desires permanent position with operating company or sales organization. Age 31, married. C-1886.

ELECTRICAL ENGINEER, 27, single, technical graduate, four years' experience installation, testing, research, and manufacturing supervision. Desires position, preferably in New York, with advancement opportunity. B-7270.

CANADIAN, electrical engineering education, expert photographer, experience in electrical contracting, theatrical lighting and marine engineering, some knowledge of photo-electricity, desires position. Age 23, unmarried. Available immediately. Location immaterial. C-1906.

RECEIVER, recently discharged wishes connection with public utility. Eighteen years' experience in management, operation and control of hydroelectric properties and general public utility business. Position of business management preferred rather than technical engineering B-6686.

TECHNICAL GRADUATE IN E. E., 29 years of age with three years' experience on central station electrical tests, distribution system estimates, pole line construction, two years on telephone apparatus inspection and circuit tests, two years on electric railways, development, tests and design of car equipment. Knows Spanish. Locate anywhere. C-1889.

ELECTRICAL ENGINEER, three years sales, electrical equipment, seven years construction, power house and substation steam and electric, four years valuation and cost accounting. Married. Location preferred, New York. C-68.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street, New York.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Lincoln Bouillou, 731 21st Avenue W., Seattle, Wash.
2.—W. A. R. Brown, Radio Corp. of America, 33 W. 42nd St. New York, N. Y.
3.—A. F. Buckley, 211 Sherman Ave., New York, N. Y.
4.—John C. Fretz, N. Y. & Queens Elec. Lt & Pr. Co., Long Island City, N. Y.
5.—William F. Gilman, Belgrade Lakes, Maine.
6.—S. G. Guth, 419 Hampton Ave., Wilkinsburg, Pa.
7.—Edward C. Hanson, Box 59, Pinelawn, N. Y.
8.—A. Hirth, 519 Lincoln Place, Brooklyn, N. Y.
9.—M. E. Jonson, 133 Ardsley Road, Schenectady, N. Y.
10.—Eric Kjellgren, 145 13th Street, Milwaukee, Wisc.
11.—Otto W. Lawrence, Avenue E., Bound Brook, N. J.
12.—D. F. McConnell, 402 N. Highland Ave., Pittsburgh, Pa.
13.—Jack Nile, 378 Bayden Ave., Hilton, N. J.
14.—J. P. Ortiz, N. Y. Edison Co., 23rd St & 4th Ave., New York, N. Y.
15.—I. T. Roberts, 2355 Prairie Ave., Evanston, Ill.
16.—Orville B. Weeks, 305 Martense St., Brooklyn, N. Y.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED SEPTEMBER 24, 1926

*BASS, OSWALD BURTON, 2nd Electrician, "Empress of Australia," Canadian Pacific Steamships, Ltd., Vancouver; res., Victoria, B. C., Can.

BERTHOLD, WOLF, Draftsman, New York Rapid Transit Corp., 85 Clinton St., Brooklyn, N. Y.

BEYRODT, KURT, Electrician, Bond Service Repair Co., 42 Bond St., New York, N. Y.

BROWN, JESTON FOSTER, Elec. Engg. Student, Tri-State College, Angola, Ind.

BRUMMAL, JACK S., Switchman, Kansas City Telephone Co., Kansas City, Mo.

*BRICKER, GEORGE WALTER, Jr., Public Utility Accountant, H. C. Hopson, Inc., 61 Broadway, New York; res., Brooklyn, N. Y.

BURKHARDT, GEORGE EDWARD, Laboratory Engineer, General Railway Signal Co., West Ave., Rochester, N. Y.

CHAPMAN, HENRY NORMANTON, Jr., Asst. Foreman, Engg. Dept., Woodward & Tierman Printing Co., 1519 Tower Grove Ave., St. Louis, Mo.

COOK, H. C., Electrical Superintendent, Day & Zimmermann, Inc., Saxton, Pa.

COOKE, LEIGHTON B., Electrical Engineer, Bell Telephone Laboratories, 463 West St., New York, N. Y.

COTTIER, JOHN PERCIVAL, Borough Electrical Engineer, Ohakune Borough Council, Mire St., Ohakune, N. Z.

COVINGTON, PRESTON M., Supt., Electric Light & Water Department, Red Springs, N. C.

DeCONLY, JULIAN COGGSALL, Consulting Engineer, 315 Bank of Italy Bldg., Los Angeles, Calif.

DEJONG, FRANZ, Supt. of Testing Division, Riegos y Fuerza del Ebro, S. A., Plaza Cataluna No. 2, Barcelona, Spain.

DENNEY, L. JOHN, Maintenance Engineer, Engg. Dept., Bell Telephone Co. of Penn., 416 7th Ave., Pittsburgh, Pa.

DOBERCK, WILLIAM A., Chief, Electrical Construction Dept., Andersen Meyer & Co., Ltd., Shanghai, China.

DOYLE, JOHN THOMAS, Engineer in charge, Westport Stockton Coal Co., Ngakawau, Westport, N. Z.

DUNLAP, BERT, Division Maintenance, Ozark Pipe Line, Ponca City, Okla.

ELWORD, AURIOL, Smoke Tested, Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C., Can.

EYTON, JOHN, Service Dept., Canadian Westinghouse Co., Ltd., 512 William St., Montreal, Que., Can.

GARDNER, WILLIAM, Plant Dept., New York Telephone Co., 227 E. 30th St., New York, N. Y.

GERST, PAUL ERNEST, Electrical Draftsman, Engg. Dept., Commonwealth Edison Co. 72 W. Adams St., Chicago, Ill.

HARRIS, CLAIR ASHLEY, General Foreman, Bureau of Reclamation, Emmett, Idaho.

HEARD, WILLIAM LAUREN, Telephone Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., East Orange, N. J.

HILL, LEON ALBERT, Fieldman, Pacific Tel. & Tel. Co., 165 S. Howard St., Spokane, Wash.

JORDAN, ESSEX F., City Electrical Inspector, City of Roanoke, 401 Anchor Bldg., Roanoke, Va.

KALE, PURUSHOTTAM B., Managing Director, The Central Provinces Engineering Co., Ltd., Nagpur & Jubbulpore, Mount Road, Nagpur, India.

KEGL, ZOLTAN JOSEF, Asst. to Manager, York Insulated Wire Works of General Electric Co., York, Pa.

KENT, HARRY GORDON, Power Sales Engineer, Binghamton Light, Heat & Power Co., Binghamton, N. Y.

KIRSCH, MYER JACK, Experimental Engineer, Petroleum Heat & Power Co., Stamford, Conn.

KOTHAWALA, KERSHASP R., Electrical Engineer, Kishangarh State, Kishangarh, Rajputana, India.

LEMMON, JAMES ABEL, Sales Engineer, Diehl Mfg. Co., Elizabeth, N. J.

LENEHAN, CHARLES V., Deputy Asst. Supt. The New York Edison Co., 44 W. 27th St., New York, N. Y.

LOPEZ, CHARLES EDWARD, Chief, Electrical Dept., Cia. Huanchaca de Bolivia, Pulacayo, Bolivia, S. Amer.

LESSMANN, GERHARD, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

MARRISON, WARREN ALVIN, Laboratory Engineer, Bell Telephone Laboratories, 463 West St., New York, N. Y.

McKENZIE, MALCOLM THOMAS, Meter Foreman, Savannah Electric & Power Co., Cor. Bay & Whitaker Sts., Savannah, Ga.

MESSENGER, THEODORE IVES, Application Engineer, Monitor Controller Co., 7016 Euclid Ave., Cleveland, Ohio.

MONTGOMERY, DOUGLAS, Electrical Engineer, Cia. Mexicana Luz y Fuerza Motriz, Mexico, D. F., Mex.; *for mail*, Pasadena, Calif.

MOORE, HARRY ALBERT, Park Utah Consolidated Mines Co., Park City, Utah

MORI, HIDE, Engineer, Dept. of Communication, Bureau of Electricity, Tokio, Japan.

MOULTON, FRED EARL, Electrician & Lineman, Clyde River Power Co., Main St., Richford, Vt.

NORDHAUS, Charles H., Engineer, Grigsby-Grunow-Hinds Co., 4450 Armitage Ave., Chicago, Ill.

ODERMATT, ARNOLD, Engg. Dept., American Brown Boveri Electric Corp., Camden, N. J.

PADDOCK, WILLIAM GEORGE, Electrical Engineer, Lucknow Municipal Water Works, Aish Bagh, Lucknow, U. P., India.

PARKER, WILLIAM A. H., Sales Engineer, West Gloucestershire Power Co., Ltd., 21 Eastgate St., Gloucester, England.

*SANDERS, WILLIAM FERRELL, Electrical Engineer, Tallassee Power Co., Badin, N. C.

SANTA-MARIA, DOMINGO, Engineer of Direction, de Servicios Electricos, Santo Domingo 1220, Santiago, Chile, So. Amer.

SIEMERS, FREDERIC W., 9610 38th Ave., Corona, N. Y.

SMITH, CLIFTON EDWARD, Electrical Engineer, J. Livingston & Co., 70 E. 45th St., New York, N. Y.

SMITH, GEORGE J., Designer, Binghamton Light, Heat & Power Co., 172 Washington St., Binghamton, N. Y.

SWEET, JAMES W., Operating Engineer, Virginia Public Service Co., Ronceverti, W. Va.

TANTON, FREDERICK WILLIAM, Operator, Power Dept., Newfoundland Power & Paper Co., Deer Lake, Newfoundland; *for mail*, Charlottetown, P. E. I., Can.

TASKER, HOMER G., Engineer, The Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco, Calif.

TEVONIAN, HAGOP PUZANT, Designer, Brooklyn Edison Co., Pearl & Johnson Sts., Brooklyn, N. Y.

TUCKERMAN, LUCIEN POMEROY, Research Engineer, De Forest Radio Co., Central Ave. & Franklin St., Jersey City, N. J.; res., Brooklyn, N. Y.

WINTERS, GLENN H., Electrical Draftsman Sargent & Lundy, Inc., 72 W. Adams St., Chicago, Ill.

Total 57.

*Formerly Enrolled Students.

ASSOCIATES REELECTED SEPTEMBER 24, 1926

BROOME, GEORGE WILEY, Electrical Designer, Stevens & Wood, Inc., 120 Broadway, New York, N. Y.

WEISS, HENRY E., Local Manager, Allis-Chalmers Mfg. Co., 915 Kearns Bldg., Salt Lake City, Utah.

ASSOCIATE REINSTATED SEPTEMBER 24, 1926

MARION, FREDERICK R., Communication Engineer, N. Y. N. H. & H. R. R. Co., New Haven, Conn.

MEMBERS ELECTED SEPTEMBER 24, 1926

HUNTINGTON, SCOTT ALLEN, Plant Engineer, The Syracuse Lighting Co., Inc., 421 Warren St., Syracuse, N. Y.

JANSSON, GUSTAV EMANUEL, General Engineer, Condit Electrical Mfg. Co., 1344 Hyde Park Ave., Boston; *for mail*, Wollaston, Mass.

JEANNIN, HARRY WALLACE, Vice-President of Engg., The Jeannin Electric Co., Toledo, Ohio.

JENNENS, WALTER SAMUEL, Electrical Engineer, Ohio Brass Co., Mansfield, Ohio.

LAPIROFF-SCOBLO, M., Professor of Elec. Engg., Government Electro-Technical Institute, Gorohvsakaya 23, U. S. S. R. Moscow, Russia.

WELLER, GEORGE LOUIS, Telephone Engineer, The Chesapeake & Potomac Telephone Co. & Associated Companies, 725, 13th St., N. W., Washington, D. C.

FELLOW ELECTED SEPTEMBER 24, 1926

MELSOM, SYDNEY WILLIAM, Head of Research Dept., Callendars Cable Co., Belvidere, Kent; res., London, Eng.

TRANSFERRED TO GRADE OF FELLOW SEPTEMBER 24, 1926

BOLSER, M. O., Assistant Electrical Engineer, Department of Water & Power, City of Los Angeles, Calif.

CRAFT, EDWARD B., Executive Vice-President, Bell Telephone Laboratories, New York, N. Y.

KELLEY, WILL G., Asst. Engineer of Distribution, Commonwealth Edison Co., Chicago, Ill.

MACCUTCHEON, A. M., Engineering Vice-President, Reliance Electric & Engineering Co., Cleveland, Ohio.

ORSETTICH, ROBERT, Chief Engineer, Wilton Works of General Electric Co., Birmingham, England.

POWELL, ALVIN L., Manager, Engineering Dept., Edison Lamp Works, Harrison, N. J.

SILVER, ARTHUR E., Consulting Electrical Engineer, Electric Bond & Share Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER SEPTEMBER 24, 1926

AMBROSE, FREDERIC B., Engineer, Duquesne Light Co., Pittsburgh, Pa.

BENHAM, C. F., Asst. to General Supt., Great Western Power Co., San Francisco, Calif.

BLACKWELL, EDWARD S., Asst. Supt. of Construction, Div. of Construction & Engineering, Stone & Webster, Inc., Pinehurst, Wash.

BOSTWICK, THOMAS J., Chief Electrical Engineer, Aluminum Company of America, Pittsburgh, Pa.

BURGER, EMMETT E., Electrical Engineer, General Electric Co., Schenectady, N. Y.

CHUBBUCK, L. B., Electrical Engineer, Canadian Westinghouse Co., Hamilton, Ont., Can.

COLE, GUERNEY H., Section Engineer, M. & P. Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

CURTIS, EDWARD C., Chief Engineer, Cia Cubana de Electricidad, Inc., Havana, Cuba.

DACE, FRED E., Head, Department of Electricity, Bradley Polytechnic Institute, Peoria, Ill.

DOERSCHUK, HERBERT M., Electrical Supt., Aluminum Co. of America, Niagara Falls, N. Y.

FINNEY, ALFRED C., Consulting Engineer, (Switchboard Practice), General Electric Co., Schenectady, N. Y.

FOGLER, WILLIAM A., Laboratories Supt., Philadelphia Electric Co., Philadelphia, Pa.

GARDNER, STERLING M., President & Chief Engineer, Gardner Electric Mfg. Co., Emeryville, Calif.

GIBBS, JESSE B., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.

GLANCY, ROBERT C., Chief Engineer, Eastern Bell Telephone Co. of Pennsylvania, Philadelphia, Pa.

GRAY, FRED J., Transmission Engineer, Upstate Territory, New York Telephone Co., Albany, N. Y.

HALPERIN, HERMAN, Engineer, Commonwealth Edison Co., Chicago, Ill.

HENNINGSEN, EARLE S., Electrical Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.

HOLLAND, WAYMAN A., Electrical Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

JOHNS, ALBERT N., Consulting Engineer, Los Angeles, Calif.

JOHNSON, CLARENCE N., General Engineer, Westinghouse Electric & Mfg. Co., Philadelphia, Pa.

KARKER, EARL C., Instructor in Electrical Engineering, Mechanics Institute, Rochester, N. Y.

KELMAN, J. N., President & Manager, Kelman Electric & Mfg. Co., Los Angeles, Calif.

KERR, HENRY H., Supt., Electric Operating Dept., Public Service Company of Colorado, Denver, Colo.

KIDDER, JAMES W., Supervising Engineer, New England Tel. & Tel. Co., Boston, Mass.

LUKE, GEORGE E., Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

LUTZ, ROBERT A., Electrical Engineer, Utilities Power & Light Corp., Chicago, Ill.

MARR, GEORGE M., Manager, Marine Sales, Charles Cory & Son, Inc., New York, N. Y.

MAYER, J. H., Equipment Engineer, Postal Telegraph Cable Co., New York, N. Y.

McCLAIN, JOHN R., Materials & Process Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

McNEELY, JOHN K., Research Professor of Electrical Engineering, Iowa State College, Ames, Iowa.

MILLER, GEORGE M., Supt., Electric Distribution & Construction, Louisville Gas & Electric Co., Louisville, Ky.

NIGH, EDSON R., Supt., Light & Power, Puget Sound Power & Light Co., Bremerton, Wash.

NORRIS, FERRIS W., Asst. Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.

PETERS, ALFRED S., Valuation Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.

PRAGST, ERNEST W., Electrical Engineer, General Electric Co., Schenectady, N. Y.

REYNOLDS, WILLIAM H., Foreman of Elec. Maintenance of Erie Works, General Electric Co., Erie, Pa.

RICE, CHESTER W., Research Engineer, General Electric Co., Schenectady, N. Y.

RIGGS, ALBERT C., Supt., Light & Power, Puget Sound Power & Light Co., Bellingham, Wash.

SEIBEL, CHARLES F., JR., Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

SMITH, GLEN H., Engineer, Outside Construction, Department of Lighting, City of Seattle, Wash.

SMITH, J. BRODIE, Vice-President & General Manager, Manchester Traction, Light & Power Co., Manchester, N. H.

SNOW, WILBER C., Industrial Power Salesman, Lighting Department, City of Seattle, Wash.

SPRARAGEN, WILLIAM, Secretary, Division of Engineering and Industrial Research, National Research Council, New York, N. Y.

SWOBODA, ADOLPH R., Apparatus Development Engineer, Bell Telephone Laboratories, New York, N. Y.

TREAT, ROBERT, Section Head, Central Station Engg. Dept., General Electric Co., Schenectady, N. Y.

TRUMBULL, ARTHUR J., Assistant Engineer, Distribution Department, Brooklyn Edison Co., Inc., Brooklyn, N. Y.

WAITE, LESLIE O., Engineer, Stone & Webster, Inc., Boston, Mass.

WALLIS, CHARLES R., Sales Engineer, General Electric Co., Seattle, Wash.

WALTHER, JOHN T., Professor of Electrical Engineering, Municipal University of Akron, Akron, Ohio.

WARD, RALPH B., Chief, Electrical Bureau, Newark, N. J.

WATKINS, SAMUEL S., Electrical Engineer, Gibbs & Hill, New York, N. Y.

WIESEMAN, ROBERT W., Special Designing Engineer, A. C. Engg. Dept., General Electric Co., Schenectady, N. Y.

WILSON, HARRY R., Central Station Engineering Dept., General Electric Co., Schenectady, N. Y.

WOOD, EDWIN D., Electrical Operating Engineer, Louisville Gas & Electric Co., Louisville, Ky.

WOODS, GEORGE M., General Engineering, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

WOODSON, J. C., Manager, Industrial Heating Engineering Dept., Westinghouse Electric & Mfg. Co., Mansfield, Ohio.

YERXA, RUSSELL A., Electrical Supt., Dwight P. Robinson & Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1926.

Almgren, E. W., Almgren Bros. & Lindberg, Tiger, Colo.

Andree, J. W., (Member), So. California Edison Co., Los Angeles, Calif.

Bailey, G. S., Great Western Power Co., San Francisco, Calif.

Bailey, R. E., (Member), Utah Power & Light Co., Park City, Utah

Banks, W. H., New York Edison Co., New York, N. Y.

Bell, W., Pine Hill Coal Co., Minersville, Pa.

Berg, J. E., Victor X-Ray Corp., Chicago, Ill.

Bernt, A. C., General Electric Co., Bloomfield, N. J.

Burbank, J. D., Niagara Lockport & Ontario Power Co., Buffalo, N. Y.

Chesnut, F. T., Gibbs & Hill Co., New York, N. Y.

Corrin, J. G., Pittsburgh Transformer Co., San Francisco, Calif.

Cowart, J. E., Thomas E. Murray & Co., New York, N. Y.

Dakin, F., General Electric Co., Pittsfield, Mass.

Dart, S. C., Oakland Motor Car Co., Pontiac, Mich.

Dempster, J. J., Canadian Westinghouse Co., Ltd., Hamilton, Ont., Can.

Doxey, F. S., General Electric Co., Schenectady, N. Y.

Eckardt, E. M., N. Y. Rapid Transit Corp., Brooklyn, N. Y.

Ein, S., Illinois Steel Co., South Chicago, Ill.

Ernst, J. P., New York Telephone Co., New York, N. Y.

Green, D. C., (Member), Utah Power & Light Co., Salt Lake City, Utah.

Grondahl, L. O., Union Switch & Signal Co., Swissvale, Pa.
(Applicant for re-election.)

Hale, J. A., (Member), Utah Power & Light Co., Salt Lake City, Utah

Hammond, T. A., General Electric Co., Pittsfield, Mass.

Hawkes, C. J., (Member), The Electric Storage Battery Co., Seattle, Wash.

Hoffmann, H. J., Stone & Webster, Inc., Boston, Mass.

Jones, A. L., Utah Power & Light Co., Salt Lake City, Utah

Keath, H. B., (Member), Wagner Electric Corp., St. Louis, Mo.

Kundert, A., The New York Edison Co., New York, N. Y.

Libecap, R. E., Superior Electric Co., Dallas, Texas

Lindell, K. S. I., Schweitzer & Conrad, Inc., Chicago, Ill.

Lockwood, E. L., Newport News & Hampton Ry., Gas & Electric Co., Hampton, Va.

McCartney, C. E., Southern Cities Power Co., Chattanooga, Tenn.

Niederer, E., Curtis Mfg. Co., St. Louis, Mo.

Norris, W. J., New York Rapid Transit Co., New York, N. Y.

Owens, S., Bureau of Safety, Chicago, Ill.

Parker, J. B., Saskatchewan Government Telephones, Regina, Sask., Can.

Pecha, A. F., Electrical Testing Laboratories, New York, N. Y.

Perlewitz, J. M., Graybar Electric Co., Salt Lake City, Utah
(Applicant for re-election.)

Phillips, A., Electrical Testing Laboratories, New York, N. Y.

Pontius, P. A., Westinghouse Elec. & Mfg. Co., Homewood, Pa.
Prior, F. O., (Member), Midwest Refining Co., Casper, Wyo.
Reinstidt, J. W., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Remscheid, E. J., General Electric Co., Schenectady, N. Y.
Robinson, J. P., Kerite Insulated Wire & Cable Co., San Francisco, Calif.
Rooney, F. H., (Member) Columbia Steel Corp., Provo, Utah
Save, G. A., New York Edison Co., New York, N. Y.
Schoberth, G., New York Edison Co., New York, N. Y.
Scurrah, W., Canadian Marconi Co., Montreal, Que., Can.
Seyler, P. K., Mountain States Tel. & Tel. Co., Salt Lake City, Utah
Sharp, S. M., Minnesota Power & Light Co., Duluth, Minn.
Simpson, J. C., Bell Telephone Co. of Canada, Montreal, Que., Can.
Smith, W. B., Lapp Insulator Co., Los Angeles, Calif.
Steindorf, H. A., Riter Conley Construction Co., St. Louis, Mo.
Szenes, A., New York Edison Co., New York, N. Y.
Vaughan, F. F., (Member), Phoenix Utility Co., Miami, Fla.
Watters, R. A., with Dr. H. B. Spencer (X-Ray Laboratory), Lynchburg, Va.
Weitmann, O., Sloan & Chace, Inc., Newark, N. J.
Werth, J. R., (Fellow), Appalachian Electric Power Co., Lynchburg, Va.
Whittaker, C. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. (Applicant for re-election.)
Wiack, J. W., Western Electric Co., Inc., New York, N. Y.
Wills, F. P., Adirondack Power & Light Co., Ltd., Schenectady, N. Y.
Yarling, F. C., Louisville Gas & Elec. Co., Louisville, Ky.
Total 62

Foreign

Banwet, D. N., Public Works Dept., Punjab, India
Cutten, W. L., Palmerston North Borough Council, Palmerston North, N. Z.
Hill, W., Oorgaum, Kolar Gold Fields, South India
Hofmann, A. Cl., G. Rohland & Co., Berlin-Charlottenburg, Germany
Kameda, M., Tokyo Electric Light Co., Demkika, Tokyo Dento Kabushi Kaisha, Tokyo, Japan
Rendell, E. F., (Member), The Victoria Falls & Transvaal Power Co., Ltd., Cleveland, Transvaal, So. Africa
Setty, K. S., Chengalvaroya Naikers Tech. Institute, Vepery, Madras, India
Uren, T. L., Malvern Electric Power Board, Christchurch, N. Z.
Velasco, A. P., Sorocagana Railway, Sao Paulo, Brazil, So. Amer.
Watkin, H., Nottingham Corp., Nottingham, Eng.
Total 10

STUDENTS ENROLLED

Hayes, R. A. H., McGill University
Huggler, G. Clarence, Pennsylvania State College
Johnson, George Carl, Northeastern University
Leonard, Richard J., Northeastern University
Mueller, Rudolf B., Univ. of Wisconsin
Peters, Jack B., Mass. Inst. of Technology
Total 6

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F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
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P. H. Powell, Canterbury College, Christchurch, New Zealand.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

A. I. E. E. COMMITTEES

(A list of the personnel of Institute committees may be found in the September issue of the Journal.)

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Technical Activities, A. G. Pierce

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Instruments and Measurements, A. E. Knowlton
Applications to Iron and Steel Production, A. G. Pierce
Production and Application of Light, Preston S. Millar
Applications to Marine Work, G. A. Pierce
Applications to Mining Work, W. H. Lesser
General Power Applications, A. M. MacCutcheon
Power Generation, H. W. Eales
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Transportation,

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(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the Journal.)

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American Bureau of Welding
American Committee of Electrolysis
American Engineering Council
American Engineering Standards Committee
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Committee on Elimination of Fatigue, Society of Industrial Engineers
Engineering Foundation Board
John Fritz Medal Board of Award
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Joint Committee on Welded Rail Joints
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National Fire Waste Council
National Museum of Engineering and Industry, Board of Trustees
National Research Council, Engineering Division
National Safety Council, Electrical Committee of Engineering Section
The Newcomen Society
Radio Advisory Committee, Bureau of Standards
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U. S. National Committee of the International Electrotechnical Commission
U. S. National Committee of the International Illumination Commission
Washington Award, Commission of

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Boston	Hartley Rowe	W. H. Colburn, 39 Boylston St., Boston, Mass.
Chicago	K. A. Auty	William Wurth, 1634 Peoples Gas Bldg., Michigan Ave. at Adams St., Chicago, Ill.
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Columbus	A. W. Janowitz	E. A. Williams, 231 N. Fifth St., Columbus, Ohio
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Denver	W. H. Edmunds	R. B. Bonney, Telephone Bldg., P. O. Box 960, Denver, Colo.
Detroit-Ann Arbor	Harold Cole	F. H. Riddie, Champion Porcelain Co., Detroit, Mich.
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Kansas City	R. L. Baldwin	S. M. De Camp, 510 Dwight Bldg., Kansas City, Mo.
Lehigh Valley	W. E. Lloyd, Jr.	G. W. Brooks, Pennsylvania Power & Light Co., 8th & Hamilton Sts., Allentown, Pa.
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Milwaukee	H.L.VanValkenberg	R. G. Lockett, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	S. B. Hood	M. E. Todd, University of Minnesota, Minneapolis, Minn.
Nebraska	C. W. Minard	N. W. Kingsley, 1303 Telephone Bldg., Omaha, Nebr.
New York	E. B. Meyer	O. B. Blackwell, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.
Niagara Frontier	H. B. Alverson	A. W. Underhill, Jr., 606 Lafayette Bldg., Buffalo, N. Y.
Oklahoma	E. R. Page	C. C. Stewart, Oklahoma Gas & Electric Co., Norman, Okla.
Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
Philadelphia	Louis J. Costa	R. H. Silbert, 2301 Market St., Philadelphia, Pa.
Pittsburgh	W. C. Goodwin	D. M. Simons, Standard Underground Cable Co., Cor. 17th & Pike Sts., Pittsburgh, Pa.
Pittsfield	E. F. Gehrkens	C. H. Kline, General Electric Co., Pittsfield, Mass.
Portland, Ore.	J. C. Henkle	J. E. Yates, Gasco Bldg., Portland, Ore.
Providence	Edwin E. Nelson	F. W. Smith, Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
Rochester	Earl C. Karker	Wade H. Reichard, General Ry. Signal Co., Rochester, N. Y.
St. Louis	W. H. Millan	L. N. Van Hook, 3869 Park Ave., St. Louis, Mo.
San Francisco	D. I. Cone	A. G. Jones, 807 Rialto Bldg., San Francisco, Calif.
Saskatchewan	S. R. Parker	W. P. Brattle, Dept of Telephones, Telephone Bldg., Regina, Sask.
Schenectady	R. E. Doherty	R. F. Franklin, Room 301, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	C. E. Mong	C. R. Wallis, 609 Colman Bldg., P. O. Box 1858, Seattle, Wash.
Sharon	H. L. Cole	L. E. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	Richard McKay	James B. Fisken, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	L. F. Curtis	J. Frank Murray, United Electric Light Co., 251 Wilbraham Ave., Springfield, Mass.
Syracuse	C. E. Dorr	F. E. Verdin, 615 City Bank Bldg., Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	M. B. Hastings	F. F. Ambuhl, Toronto Hydro-Electric System, 226 Yonge St., Toronto, Ontario
Urbana	J. T. Tykociner	L. B. Archer, 301 Electrical Engineering Lab., University of Illinois, Urbana, Ill.
Utah	B. C. J. Wheatlake	D. L. Brundige, Utah Power & Light Co., Box 1790, Salt Lake City, Utah
Vancouver	R. L. Hall	C. W. Colvin, B. C. Electric Railway Co., 425 Carrall St., Vancouver, B. C.
Washington, D. C.	C. A. Robinson	D. S. Wegg, Dept. of Commerce, Room 817, Pennsylvania Ave., at 19th St., N. W., Washton, D. C.
Worcester	C. F. Hood	F. B. Crosby, Morgan Construction Co., 15 Belmont St., Worcester, Mass.
Total 51		

LIST OF BRANCHES

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Alabama Polytechnic Institute, Auburn, Ala	J. D. Stewart	I. L. Knox	W. W. Hill
Alabama, University of, University, Ala	C.E. Rankin	Sewell St. John	
Arizona, University of, Tucson, Ariz	J. W. Cruse		Paul Cloke
Arkansas, University of, Fayetteville, Ark	Carroll Walsh	W. H. Mann	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	M. T. Goetz	C. W. Schramm	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	F. Wanpel	Joseph Heller	Robin Beach
Bucknell University, Lewisburg, Pa	A. Fogelsanger	J. D. Johnson	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	Thomas L. Gottier	Alan E. Capon	R. W. Sorensen
California, University of, Berkeley, Calif	C. F. Dalziel	R. S. Briggs	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	J. R. Power	R. O. Perrine	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. A. Baldwin	A. B. Anderson	H. B. Dates
Catholic University of America, Washington, D. C	B. J. Kroeger	J. E. O'Brien	T. J. MacKavanaugh
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Clarkson College of Technology, Potsdam, N. Y	W. R. MacGregor	L. G. Carney	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	B. V. Martin	W. H. Sudlow	S. R. Rhodes
Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, University of, Boulder, Colo	A. D. Thomas	J. A. Setter	W. C. DuVall
Cooper Union, New York, N. Y	F. H. Miller	H. T. Wilhelm	Norman L. Towle
Denver, University of, Denver, Colo	Harold Henson	Allea Ohlson	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	H. D. Baker	R. S. Eininger, Jr.	E. O. Lange
Florida, University of, Gainesville, Fla	O. B. Turbyfill	R. Theo. Lundy	J. M. Weil
Georgia School of Technology, Atlanta, Ga	W. M. McGraw	F. L. Kaestle	E. S. Hannaford
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Iowa, University of, Iowa City, Iowa	L. Dimond	A. C. Boeke	A. H. Ford
Kansas State College, Manhattan, Kans	A. M. Young	John Yost	C. E. Reid
Kansas, University of, Lawrence, Kans	W. L. Immer	H. R. Hilkey	G. C. Shaad
Kentucky, University of, Lexington, Ky	J. A. Weingartner	C. E. Albert	
Lafayette College, Easton, Pa	A. H. Gabert	F. G. Keim	Morland King
Lehigh University, S. Bethlehem, Pa	F. G. Kear	J. H. Shuhart	J. L. Beaver
Lewis Institute, Chicago, Ill	O. D. Westerberg	R. G. Raymond	F. A. Rogers
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Yale University, New Haven, Conn.	W. W. Parker	J. W. Hinkley	Charles F. Scott

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Recording Voltmeters.—Catalog 1502, 24 pp. Voltmeter Section, describes a complete line of Bristol's recording voltmeters, together with price list. The Bristol Company, Waterbury, Conn.

Testing of Automobile Lamps.—Bulletin 105, 16 pp. Describes the testing and approval of automobile headlamps and tail lamps, with rules and specifications. Includes a list of approved electric headlighting devices. The Electrical Testing Laboratories, 80th Street & East End Avenue, New York.

New Prices for Century Motors.—The Century Electric Company, St. Louis, Mo., has issued new price lists of its repulsion start, induction, single-phase, and squirrel cage induction polyphase motors, effective September 13, 1926. Stocks are maintained at 29 points in the United States and more than 50 elsewhere.

Alternating Current Instruments.—Bulletin 150, 4 pp. Describes Roller-Smith Type HTA portable ammeters, milli-ammeters, voltmeters, and Type HA a-c. single-phase and d-c. wattmeters. **Direct Current Instruments.**—Bulletin 110, 8 pp. Describes Roller-Smith Type HTD portable ammeters, milli-ammeters, voltmeters, milli-voltmeters and volt-ammeters. The Roller-Smith Company, 12 Park Place, New York.

Insulators and Trolley Equipment.—Catalog 20, 945 pages, includes a complete list of all O-B porcelain insulators, trolley and line materials, rail bonds, car equipment and mining materials.

All of the material pertaining to porcelain insulators and hardware, 472 pages, is also being distributed in a separate binding, known as the Insulator Section. This binding is for the convenience of those interested in high tension material only. The books are indexed and have numerous convenient cross-references. The Ohio Brass Company, Mansfield, Ohio.

Lighting Data.—A series of interesting bulletins on illumination and lamps. Bulletin 108B, 24 pp., describes the lighting of offices and drafting rooms; Bulletin LD-114C, 40 pp., explains the theory and characteristics of Mazda lamps; Bulletin LD-117C, 36 pp., is on the calculation of lighting installations (predetermining the illumination); Bulletin LD-134A, 32 pp., refers to the lighting of the metal working industries; Bulletin LD-141A, 48 pp., covers motor car, garage, and display room lighting. It includes the automobile lighting laws of all of the states. Edison Lamp Works of General Electric Company, Harrison, N. J.

NOTES OF THE INDUSTRY

Ferranti, Limited, Establish Branch in New York.—Announcement has been made by Ferranti, Ltd. of Hollinwood, England, that a branch office has been established at 130 West 42nd Street, New York, and that the name of the American branch will be Ferranti, Incorporated.

New Branch Office for Bristol Company.—The Bristol Company, Waterbury, Conn., manufacturers of recording electrical instruments, has opened a branch sales and service office in the U. S. National Bank Building, Denver, Colo., H. T. Weeks, representative, in charge.

Timken Appoints C. H. Johnson.—The Timken Roller Bearing Company, Canton, Ohio, announces that C. H. Johnson has been appointed engineer of the service department. He will have direct charge of installation of Timken bearings in automotive and industrial applications.

Copperweld Steel Company Appoints Representative.—C. J. Spindler of the Valuation and Rate Department of the Illinois Power and Light Corporation with headquarters in Chicago, has accepted a position as representative of "Copperweld" with the Steel Sales Corporation. Mr. Spindler's territory will consist of Illinois, Wisconsin and Michigan.

Manufacturers' Agency Established at San Francisco.—Thomas A. Fawell has recently organized a manufacturers' sales agency at 40 Sansome Street, San Francisco. He now represents Kohlenite Products, Inc., New York, brushes for electrical machinery, and the Martindale Electric Company, Cleveland, motor maintenance equipment, stones, slotters, etc.

Kuhlman Electric Company Opens Branch at Atlanta.—The Kuhlman Electric Company, Bay City, Michigan, manufacturers of power, distribution and street lighting transformers, has announced the opening of a direct factory branch in Atlanta, Ga., located at 411 Glenn Building, Ernest K. Higginbottom in charge. Mr. Higginbottom has represented the Kuhlman Company throughout the southeast during the past two years.

The Jas. R. Kearney Corporation Adds to Staff.—The Jas. R. Kearney Corporation, St. Louis, Mo., announces that the following men have recently joined the organization: Walter A. Heinrich, as chief engineer; Mr. Heinrich was formerly connected with the W. N. Matthews Corporation as electrical engineer. Elon J. DeRight, special sales engineer; Mr. DeRight, until recently, was superintendent of high line construction of the Kansas City Light and Power Company. James R. Kearney, Jr. as advertising manager and secretary; Mr. Kearney is a recent graduate of the University of Missouri. Hal C. Fiske, as assistant designing engineer; Mr. Fiske was formerly connected with the sales organization of the J. E. Sumpter Company, Minneapolis. J. C. Friedrichs, as engineer; Mr. Friedrichs was formerly with the Western Engineering Company, St. Louis, Mo.

Record Breaking Turbine-Generators Being Built by the G-E Company.—The General Electric Company has announced that it will supply the equipment referred to below:

The Edison Electric Illuminating Company, Boston, is to install a 63,000 kw., single-cylinder turbine-generator. This machine will be the largest single-cylinder turbine in the world.

The Southern California Edison Company is to install two tandem-compound turbines, rated at 94,000 kw. at 90 per cent power factor or 105,000 kw. at unity power factor. These will be the largest tandem-compound turbines ever built.

The State Line Generating Company is to install a 208,000 kw. cross-compound turbine-generator in its new generating station on the shore of Lake Michigan. The ultimate capacity of the station is to be 1,000,000 kv., and the turbine-generator now building is the largest of any type yet projected.

Westinghouse Reorganizes Engineering Department.—Reorganization of the General Engineering Department of the Westinghouse Electric and Manufacturing Company has been announced by H. W. Cope, assistant director of engineering.

The reorganization has necessitated the re-allocation of several engineers, four being elevated to managers of engineering. These are F. C. Hanker, manager of Central Station Engineering; S. B. Cooper, manager of Railway Engineering; G. E. Stoltz, manager of Industrial Engineering and W. E. Thau, manager of Marine Engineering. S. A. Staege, formerly section engineer in charge of the paper mill section, has been appointed industrial engineer giving particular attention to the paper mill industry.

Among the other appointments, also announced by Mr. Cope, are: Central Station Engineering—C. A. Powel, R. D. Evans, and C. A. Butcher; Railway Engineering—H. K. Smith, G. M. Woods, and A. H. Candee; Industrial Engineering—E. M. Bouton, C. W. Drake, C. T. Guildford, C. H. Matthews, O. Needham, J. W. Speer, W. W. Spratt, and E. B. Dawson.

The appointment of N. W. Storer as consulting railway engineer in charge of the group handling of Diesel-electric locomotives and rail cars has also been announced.

JOURNAL OF THE A·I·E·E·

NOVEMBER 1926

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PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

New York Regional Meeting, New York, N. Y., Nov. 11-12

Winter Convention, New York, N. Y., Feb. 7-10

MEETINGS OF OTHER SOCIETIES

American Welding Society, Buffalo, N. Y., Nov. 16-19

American Physical Sceiety, Chicago, Ill., Nov. 26-27

The American Society of Mechanical Engineeers, New York, N. Y., Dec. 6-9

First National Exposition of Power and Mechanical Engineering, Grand Central Palace, New York, N. Y., Dec. 6-11

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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Vol. XLV NOVEMBER, 1926 Number 11

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A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any change in business connections.

Current Electrical Articles Published by Other Societies

Journal of Franklin Institute, September 1926

Inductance of Overhead Transmission Lines with Unequal Spacing of Wires, by A. Still

National Electric Light Ass'n. Bulletin, September 1926

A Proposed Set of Voltage Standards for A-C. Electrical Systems and Equipment, by the Electrical Apparatus Committee

Electric Power in Agriculture, by L. R. Nash

Rural Electrification and the Canadian Hydro, by E. A. Stewart

Safety Precautions in a 150,000-H. P. Hydroelectric Station, by R. D. Shaub

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLV NOVEMBER, 1926 **Number 11**

Student Activities in the A. I. E. E.

The prospects for better and more effective work by the Student Branches have been greatly increased during the past year by the appointment of faculty members as official Counselors, authorized by the Board of Directors a year ago. The Counselors, now eighty-seven in number, are ex-officio members of the Student Branches Committee and as a consequence the work during the year has centered chiefly on providing machinery for coordinating the efforts of the enlarged membership.

In general the plan in process of development may be outlined as follows:

1. A committee of Student Activities consisting of the Counselors, District Vice-president and Secretary to be organized in each District, with one of the Counselors as Chairman; the principal function of these committees will be to coordinate student activities in their respective districts.

2. That each District Student Activities Committee select each year one of its Counselor members as official delegate to an annual meeting of the Student Branches Committee during the Summer Convention of the Institute.

As part of the above outlined plan for the purpose of fostering and developing branch activity, the Sections delegates conference in joint meeting with the Committee on Student Branches at White Sulphur Springs, Va., during the Spring Convention of the Institute on May 21, after full discussion, took favorable action on the following recommendations to be submitted to the Board of Directors:

(a) The payment from the Treasury of the Institute for travel expenses (at the usual rate of 10 cents per mile one way) for branch counselors and incoming chairmen of branches for one annual district meeting.

(b) Similar payment of travel expenses of one district branch representative, selected by the Student Activities Committee of each district, to an annual national meeting held in conjunction with the Sections Delegates' Conference at the annual Summer Convention.

It is understood that the above is applicable only to those districts where permanent Student Activities Committees of Counselors, district Vice-president and Secretary have been effected.

In accord with the above general plan very successful meetings have been held during the year at several regional conventions. Student Activities Committees have been organized as follows:

District No. 1, Boston, May 7, A. H. Timbie, Chairman. District No. 2, Cleveland, March 9, H. B. Dates, Chairman. District No. 5, Madison, May 7, C. M. Janskey, Chairman. District No. 8, Salt Lake City, Sept. 6, H. H. Henline, Chairman. District No. 9, Salt Lake City, Sept. 6, J. A. Thaler, Chairman.

Three very successful conventions of electrical engineering students were also held last spring at Boston, New York and Swarthmore College, Pa.

While the organization of Student Activities Committees and the meetings held during the several district conventions have received most attention, the general problem of increasing the effectiveness of the Student Branches has been approached from many directions. Among the suggestions discussed at the White Sulphur Springs Convention the following may be of special interest:

1. Recognition of Student Branch activities by the faculty as an essential factor in the work of electrical engineering students.
2. More frequent visits from A. I. E. E. officials.
3. Better cooperation between Branches and nearby Sections. Joint meetings, exchange of programs, etc.
4. Presentation of papers by students at regional meetings of the Institute.
5. Printing of more student papers either as a special section in the A. I. E. E. JOURNAL or otherwise.

The several suggestions listed above, especially numbers four and five, should be fully discussed by all Student Activities Committees in order that definite action may be taken at the meeting of the Student Branches Committee during the next Summer Convention of the Institute.

Another part in the year's work has been to assist in the drafting of the revised set of By-laws for Branches recently submitted to and approved by the Board of Directors.

During the past year the Student Branches Committee has submitted to the Board of Directors favorable recommendation on applications for the establishment of Student Branches at the following institutions:

1. Stevens Institute of Technology, 2. Worcester Polytechnic Institute, 3. University of Wyoming, 4. Washington and Lee University, 5. Ohio University, 6. Princeton University, 7. University of New Hampshire, 8. Louisiana State University, 9. Akron Municipal University, 10. College of Engineering of the Newark Technical School, 11. University of Santa Clara.

The status of general student Engineering Societies seeking affiliation with the Institute has been carefully considered and on May 21 definitely determined by the Board of Directors with the adoption of the following By-law:

"SEC. 59A. An established student engineering society in a university or technical school of recognized standing may, upon application of its officers and a member of the Institute connected with the school, and the approval of the Board of Directors, become associated with the Institute. Members of such associated student engineering society may have the same privileges as enrolled Students of the Institute and will be governed by the same requirements."

In adopting this By-law, it was definitely understood by the Board that in recognizing general student engineering societies in this way, no financial support from the Institute treasury is contemplated, but that students who are members of such societies and who desire to subscribe to the JOURNAL at $3.00 per year, which is the same amount as paid by Enrolled Students of the Institute, may have this privilege; and also, the names of such affiliated organizations will be printed together with the list of Student Branches. In other words, the principal purpose of the By-law is to indicate clearly that the Institute is ready to cooperate with general student engineering societies in those institutions in which it is not deemed desirable, for one reason or another, to organize a separate Student Branch of the Institute.

C. E. MAGNUSSON,
Chairman, Student Branches Committee.

Some Leaders of the A. I E. E.

Arthur William Berresford, thirty-third president of the Institute (1920-1921), was born in Brooklyn, New York, in the year 1872. After the completion of his grade school education, he entered the Brooklyn Polytechnic Institute to prepare for his professional career and was graduated with the class of 1892. He then entered as Senior at Cornell University, graduating in 1893 with the degree of M. E. in Electricity.

From 1893 to 1896 Mr. Berresford engaged in the varied line of occupation inevitable to the beginner of any profession, his preliminary experience ranging in scope from work in the car barns of the Brooklyn City Railway Company—overhauling motors, and ground-hand on trolley-line construction work, drafting, wiring and installation—to the fields of sales and invention. In 1896 he was placed in charge of the testing and design work of the Ward-Leonard Electric Company and from that time until 1923 he was closely identified with electric motor control.

In 1898, in company with two associates, he bought over the Iron Clad Rheostat Company which, under the new name of the Iron Clad Resistance Company, they restored to a sound basis in two years time and sold it to The Cutler-Hammer Mfg. Co., which is today one of the representative heads in the field of motor control. Entering this company's engineering department in 1900, Mr. Berresford, within a period of 23 years, became successively superintendent, general manager and vice-president. His contributions to the profession have been largely from a managerial point of view, in encouraging and instructing many of the men who have achieved great things for the advancement of the electrical science. During the period of his service with The Cutler-Hammer Mfg. Co., many intricate devices were evolved, lending material betterment to modern steel mill equipment and production, hoisting and conveying machinery, electrically operated printing presses, modern electric elevator service and innumerable special control problems requiring a high order of engineering ability.

During the war period, Mr. Berresford was chairman of the General War Service Committee of the Electrical Manufacturing Industry and is now past-president of the Electrical Manufacturers Club and Associated Manufacturers of Electrical Supplies. He is also a member of the National Industrial Conference Board, The American Society of Mechanical Engineers, the Society of Naval Architects and Marine Engineers, the National Electric Light Association, Society for the Promotion of Engineering Education, Sigma Psi, Milwaukee and University Clubs of Chicago and Milwaukee, the Town Club, Country Club and Mohawk Clubs of Schenectady, the Engineers Club, New York Athletic Club and Chemists Club of New York. Mr. Berresford became an Associate of the Institute in 1894, was transferred to the grade of Member in 1906 and to the grade of Fellow in 1914. He was a Manager of the Institute from 1909-12, a Vice President from 1912-14 and President from 1920-21. He also served upon numerous important committees of the Institute, including the Executive, Sections, Public Policy, Meetings and Papers and Edison Medal Committees. He has represented the Institute upon the John Fritz Medal Board of Award and the American Engineering Council, and at the present time is a Vice-President of the latter organization.

He is now engaged in the field of electrical refrigeration as executive vice-president of the Nizer Corporation, of Detroit, one of the three units recently merged to form the Electric Refrigeration Corporation.

A system of budgeting the A. I. E. E. papers for the coming year was inaugurated by the Meetings and Papers Committee last year which has proved most satisfactory in limiting the amount of material accepted for JOURNAL publication to the number of pages available, without exceeding the appropriation allowed for this purpose. In previous years, in order to keep within the appropriation, it became necessary to abridge very drastically quite a number of papers; this year, by virtue of the budget system, we are able to publish all accepted papers either in full or with eight page abridgements as prescribed by the Publication Committee. A similar budget has been prepared for next year.

Transmission Features of Transcontinental Telephony

BY H. H. NANCE[1] and O. B. JACOBS[1]

Member, A. I. E. E. — Associate, A. I. E. E.

***Synopsis.**—In this paper, the various steps in the establishment of the existing network of transcontinental type circuits and the transmission design considerations are reviewed. The discussion covers the communication channels obtained from transcontinental type facilities and the bands of frequencies employed, and includes carrier-current systems, telephone repeaters and signaling systems. Mention is made of special uses of transcontinental telephone circuits, such as the transmission of program material for broadcasting and the transmission of pictures. Finally, the maintenance methods required to keep the system at full efficiency are outlined.*

IN view of the fact that this convention is being held in Salt Lake City and that the original transcontinental telephone line connects this point with Pacific Coast points and the eastern part of the country including points on the Atlantic Coast, it was suggested to the authors that it would be of interest to present a discussion of the transmission features of transcontinental telephony at this time.

Since considerable information on this subject has been covered by previous papers presented before the Institute, this discussion will be confined to a resumé of the transcontinental type facilities provided for coast-to-coast telephone service and some of the general transmission considerations which are important factors in determining the design of these facilities.

The opening of the first transcontinental line in 1915, between New York and San Francisco, marked a new era in long distance telephony, as this was the first achievement of successful telephone transmission over distances materially in excess of 2000 mi. and demonstrated clearly the practicability of meeting the transmission requirements for a nation-wide telephone service. Previous to that time, New York to Denver represented about the maximum distance for telephone connections and the transmission obtained would not be considered any too good as judged by the standards of today. The circuits for the New York-Denver service had been constructed of copper wire, 165 mils in diameter (435 lb. per mile), and were loaded with 250-milhenry coils spaced about eight miles apart. Repeaters, or amplifiers, however, were not used since methods for applying them to loaded lines, as well as for their use at more than one point in a connnection, had not been developed to a practical extent at that time.

By the time the new line west of Denver was constructed, telephone repeaters of new design and improvements in their application to telephone circuits had been developed so that the difficulty of operating in tandem and also over loaded lines had been overcome. Included in these improvements, which were applied to the new line and also to the existing line from New York to Denver, were new loading coils of a more stable design, very accurately spaced, in order to provide uniform impedance characteristics and balancing networks of simple design for use at repeater points to match or simulate the impedance of the line. The repeaters were located about 500 mi. apart so that on a New York-San Francisco connection, six repeaters were normally in the circuit. The transmission loss in a connection of this kind was about half that in a former New York-Denver connection and about the same as that in a former New York-Chicago connection.

Many new developments have been applied to the transcontinental circuits since the first of these were placed in service and also to other similar circuits throughout the country, which have resulted in a better quality of transmission, including increased over-all volume efficiency[2]. Briefly, the outstanding features of the improved circuits are that they are non-loaded and that the repeaters and the associated equipment have improved transmission characteristics. With the non-loaded circuits, increased speed of propagation and smoother lines are obtained and consequently they can be operated to give better volume without increased echo effect. At the same time, transmission is further improved due to the better attenuation-frequency characteristics. Variations in line attenuation with weather conditions also are considerably reduced.

The transmission improvements in the repeaters and associated equipment consist chiefly of better transmission-frequency and impedance-frequency characteristics, which, together with improved balancing networks, contribute toward better quality of transmission not only from the standpoint of naturalness but also from that of volume efficiency. Due to the higher attenuation of non-loaded lines as compared with loaded lines, a larger number of repeaters is required on a long non-loaded circuit than on a loaded circuit of similar length and therefore the importance of the improvements in the repeaters is correspondingly greater.

Three telephone circuits were provided by the first transcontinental facilities, which consisted of four wires

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1. Both of the American Telephone and Telegraph Co., New York City.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

2. *Telephone Transmission Over Long Distances*, by H. S. Osborne, TRANS. A. I. E. E., Vol. XLII, 1923, p. 984.

arranged for phantom operation. The circuit layout was planned to provide direct circuits between strategic points along the line to facilitate connections to other trunk routes as well as the handling of the message traffic between large cities on this route. The longest direct circuit set up was a Chicago-San Francisco circuit. There were also direct circuits from New York to Chicago, Chicago to Denver, Denver to San Francisco, Denver to Salt Lake City, Salt Lake City to San Francisco, etc.

For several years these facilities were sufficient to handle the long telephone message traffic connecting the country east of the Rocky Mountains with that to the west, but by 1923 the increase in traffic requirements made it advisable to provide additional facilities. After careful consideration of all factors, it was decided to provide these partly over the direct route between Chicago and Denver and thence over a new route to the south through El Paso and west through Tucson and Phoenix, Ariz. to Los Angeles. A second route from Chicago via Kansas City to Denver was already in existence, so by providing a new route west of Denver, two separate routes were made available from eastern points to the Pacific Coast. This was particularly desirable from the standpoint of service protection, and furthermore, there was an appreciable volume of traffic to Los Angeles and surrounding territory for which it was desirable to provide direct circuits. Toll circuits were already available between San Francisco and Los Angeles so that in times of trouble on either the central or the southern route, the other could be used for connections to both the northern and southern sections of the Pacific Coast.

Following the construction of the line from Denver to Los Angeles, the next steps were to provide trunk routes between New Orleans and Dallas and Dallas and El Paso which connect to other similar routes at New Orleans and Dallas, and to the Denver-Los Angeles route at El Paso. The line across Texas was completed in 1925 and at the present time transcontinental telephone connections may be established over an all southern route.

As a result of further increase in transcontinental traffic requirements, particularly to points in Washington and Oregon now reached over the central route by switching at San Francisco to circuits north along the coast, there is being constructed a direct northern route from Chicago through Minneapolis, Fargo, Bismarck, Billings, Helena, and Spokane, to Seattle. When completed, this will provide a third separate and distinct transcontinental route and will further insure the continuity of telephone service between the east and far west.

There are many other important routes throughout the country carrying circuits of the transcontinental type, as indicated on Fig. 1. Some of the longest direct circuits radiating from Chicago reach to San Francisco, Los Angeles, Denver, Dallas, Atlanta, Washington, New York and Boston, while circuits of similar class radiating from New York terminate in Minneapolis, Milwaukee, St. Louis, Kansas City, New Orleans, Atlanta, West Palm Beach and Havana. Other circuits of corresponding type[3] connect San Francisco with Portland, Salt Lake City, Denver and Los Angeles, while Los Angeles has direct circuits to El Paso and Dallas.

Telephone circuits having repeaters at several intermediate points may be compared to a series of power transmission lines, each one of which receives power from the originating point or a repeater and delivers power to another repeater or to the terminal. In contrast to power transmission lines, however, the sections of a repeatered telephone circuit and the associated equipment are designed with the object of causing power of a complicated nature to be reproduced in form at a distant point, and the fact that none of the original power reaches the far terminal is of no concern since in any event it would be useful only as a means of transmitting intelligible sounds while it would have no appreciable value purely from the power standpoint.

While the application of telephone repeaters to long telephone circuits improves their over-all transmission efficiency, the efficiency from a power transmission standpoint is zero, since none of the original energy passes through a repeater point. It is fortunate that the energy losses do not involve large amounts of power and therefore do not represent an appreciable economic loss from the power standpoint.

In the early days of the telephone, the only method of improving the volume efficiency of a telephone line was to increase the amount of copper; that is, to use wires of larger diameter. The use of metals of higher conductivity than copper was clearly prohibitive because of the cost. But additional increments in copper result in less and less improvement in efficiency so that wire larger than 165 mils in diameter was not used to any important extent.

With the invention and development of the loading coil and its application to open wire lines, it became possible to operate at a higher voltage with a consequent reduction in line losses. With this method, however, leakage losses in wet weather are greatly increased, resulting in considerable variation in efficiency.

The development of efficient amplifying devices and of circuit arrangements for applying them to two-way circuits provided the means for increasing the transmission volume efficiencies of long telephone circuits to a much greater extent than the older methods. Without telephone repeaters but with other parts of a long telephone circuit unchanged, the delivery at the receiving end of the amount of power ordinarily obtained would require startlingly large amounts of power at other points in the circuit. For example, in the case of a San Francisco-New York connection, the amount

3. *Applications of Long Distance Telephony on the Pacific Coast*, by H. W. Hitchcock, TRANS. A. I. E. E., Vol. XLII, 1923, p. 1071.

of power ordinarily applied at San Francisco would be required near Harrisburg, Pa. All of the power introduced ordinarily at all points in the line would be required at a point near Pittsburg. Power sufficient to light two 20-c. p. incandescent lamps would be necessary near Chicago, while the power of a five-kw. radio station would be required near Omaha. The requirements continue to rise rapidly until, near Rawlins, Wyo., a 50,000-kw. generator would have to deliver its entire rated capacity to the circuit, while at San Francisco, something in the order of the estimated total world production of mechanical and electrical power would be needed.

Let us suppose, however, that a 50,000-kw. generator delivered its entire output to the circuit at San Francisco, and overlook, for the moment, what would happen to the line if any such amount of energy were applied. The power received at New York would be of the order of one five-hundredth of a microwatt, which would have to flow for about 25,000 years in order to equal the energy required to light a 25-watt lamp for one minute.

From this it is evident that the economic solution of the problem of very long distance telephony does not lie in the application of large amounts of power at the circuit terminals, but rather in the use of amplifiers located at suitable intervals along the line.

In the design of telephone circuits, it is necessary to consider the three transmission essentials for easy and natural conversation. These are volume, accurate reproduction, and freedom from disturbance. The factors which tend to impair these qualities are attenuation, distortion and noise. In addition, cross-talk must be so low as to preclude appreciable overhearing of speech over other circuits.

Fortunately it is not necessary, nor even desirable, that all of the energy reaching a telephone transmitter be delivered by the receiver at the other end of the circuit, and the characteristics of the hearing mechanism of the human ear are such that very slight amounts of distortion and noise do not materially affect the intelligibility of received speech energy when the latter is of reasonable magnitude. In designing long telephone circuits the engineer thus has a small range within which to work as regards each of the essential factors for satisfactory transmission.

The attenuation losses in line conductors may be offset largely by the use of repeaters applied at suitable points to give transmission gains. The extent to which such losses can be counteracted in non-loaded open wire circuits arranged for two-way operation is illustrated by the present transcontinental circuits between New York and San Francisco in which the total attenuation

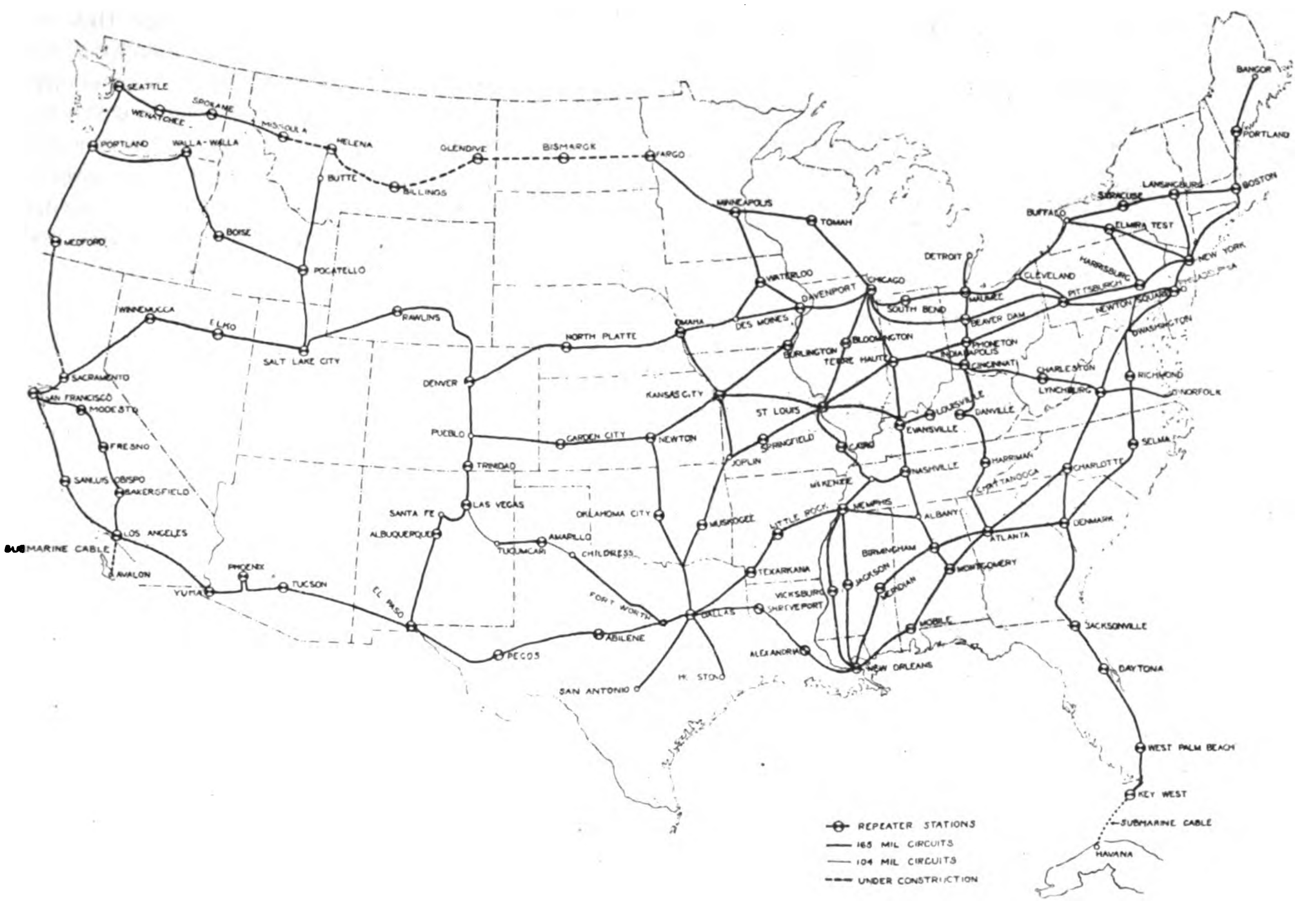

FIG. 1—ROUTES OF TRANSCONTINENTAL-TYPE TELEPHONE CIRCUITS IN THE UNITED STATES

is about 165 transmission units[4] and the total repeater gain about 153 transmission units.

Distortion results when too narrow a band of frequencies is transmitted, or when the volume of transmission of part of the frequencies within the range transmitted is materially different from that of another part of the frequency range. Another form of distortion occurs when currents which are reflected from irregularities in a circuit are again reflected by other irregularities and reach the listener as echo currents

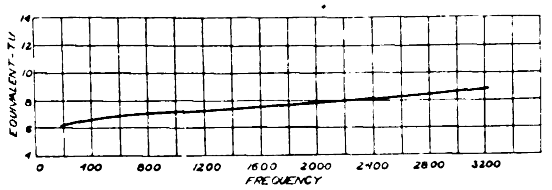

FIG. 2—TRANSMISSION—FREQUENCY CHARACTERISTIC OF 216-MI. REPEATER SECTION OF NON-LOADED 165-MIL PHYSICAL CIRCUIT

appreciably later than the direct transmission, due to the longer path traveled.

Distortion caused by a sloping attenuation-frequency characteristic of a line can be neutralized to a large extent by designing the telephone repeaters and associated equipment to have transmission-frequency characteristics complementary to those of the line. As an illustration of this, Fig. 2 shows the attenuation-frequency characteristic of a typical repeater section of non-loaded 165-mil open wire, 216 mi. in length, while Fig. 3 shows the gain-frequency characteristic of

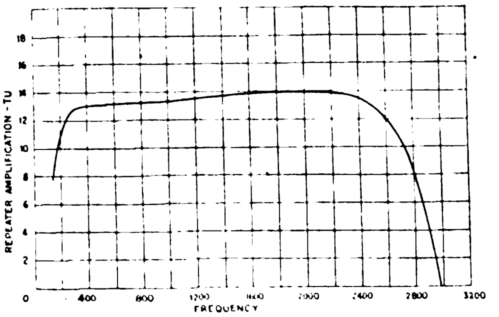

FIG. 3—AMPLIFICATION—FREQUENCY CHARACTERISTIC OF IMPROVED TYPE TWO-WAY TELEPHONE REPEATER

an improved type of telephone repeater which has been adjusted for use with the same section of wire. It will be noted that the attenuation in the line increases with the frequency and that the repeater gain, which corresponds to negative attenuation, also increases at approximately the same rate, so that the result of the combination of the line and the repeater is a transmission-frequency characteristic that is substantially flat. The over-all transmission-frequency characteristic of a long circuit composed of several repeater sections is shown in Fig. 4, which indicates that practically uniform transmission is obtained over the range of frequencies important in speech.

In long repeatered telephone circuits, the time of transmission from one end to the other becomes an important factor in determining the transmission volume efficiency since the seriousness of echo current effects not only is a function of their magnitude compared to the original transmission but also is a function of the amount of delay involved. For this reason the speed of transmission over long telephone circuits must be high as compared with that over shorter circuits, and the line must be reasonably free from irregularities that would give rise to echo currents. Also, throughout the range of frequencies transmitted, the line impedance must be closely matched by the balancing network on each side of each repeater. Loaded circuits are inferior to non-loaded circuits with respect to speed of

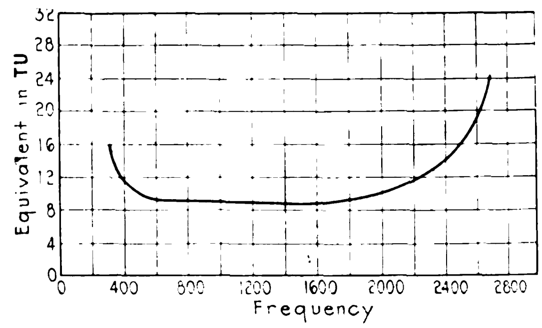

FIG. 4—OVER-ALL TRANSMISSION—FREQUENCY CHARACTERISTIC OF A 1400-MI. NON-LOADED 165-MIL CIRCUIT

transmission and smoothness of impedance-frequency characteristics. From this, it follows that the volume of transmission obtainable with loaded facilities is less than that obtainable with non-loaded facilities of the same length, when tandem repeater operation is involved.

Noise and cross-talk are reduced by transposing the wires at frequent intervals throughout the length of the line so that each wire of a circuit will be as nearly as practicable equally exposed to the disturbing influences which exist, at the same time carefully preserving the balance between the impedances to ground of the wires and associated equipment of each circuit[5]. The intensity of the extraneous influences of course should be controlled and kept within reasonable bounds. In designing the transposition layout, it is necessary to take into consideration the effect of each circuit on the line upon each of the other circuits, including the phantom circuits, as well as the effect of neighboring

4. *The Transmission Unit and Telephone Transmission Reference Systems*, by W. H. Martin, TRANS. A. I. E. E., Vol. XLIII, 1924, p. 797.

5. *Telephone Circuit Unbalances, Determination of Magnitude and Location*, Ferris and McCurdy, TRANS. A. I. E. E., Vol. XLIII, 1924, p. 1331.

power lines. A single series of transpositions which results in substantially equal exposures of each circuit to every other circuit on the line is called a transposition section. In general, one or more sections of this kind are required for each part of the line that is exposed to different outside influences. The phantom transpositions involve interchanging the positions of the two pairs from which the phantom circuit is derived.

Fig. 5 shows the power at different points in a New York-San Francisco connection, when an arbitrarily assumed power of 1000 microwatts is applied to the line at San Francisco. It will be seen that the power is attenuated at the inputs of many of the repeaters to a value which is of about the same order as that which reaches the New York end. Therefore, any noise induced in the circuit at such points may be as strong when it reaches a terminal of the circuit as it is at the points where it originates. In some places, the transmission level is even lower than at New York, as at Beaver Dam; so that noise introduced at such points

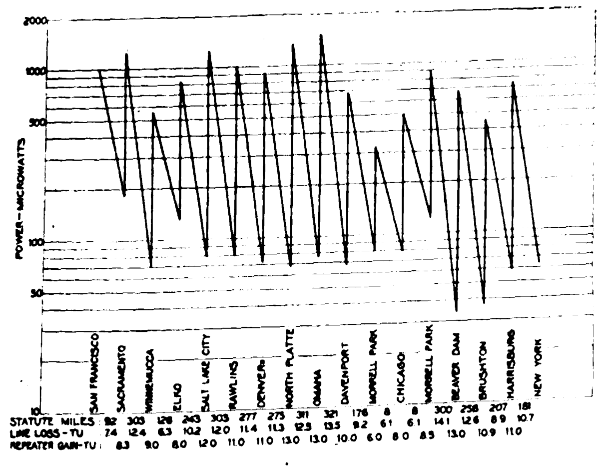

FIG. 5—POWER LEVELS OF SAN FRANCISCO-NEW YORK CONNECTION AT 1000 CYCLES, WHEN POWER OF 1000 MICROWATTS IS APPLIED AT SAN FRANCISCO

may reach New York at greater than its original strength. Thus it is evident that from the noise standpoint, the relative transmission levels at a disturbed point and at the terminals are of particular importance rather than the distances from the disturbed point to the terminals.

Besides providing voice-frequency telephone channels, the open wires composing the network of "backbone" telephone circuits are being used to a large extent for superimposed carrier-current systems[6] as well as for providing ordinary grounded telegraph facilities. An example of this is covered by Fig. 6, which shows, schematically, the various communication channels obtained from four wires of a group of transcontinental facilities between Denver and Sacramento. Altogether, there are twenty two-way communication channels operating on these two pairs of conductors, six telephone circuits and fourteen telegraph circuits. A telephone circuit is obtained from each of the two pairs of wires, and a third from the combination of these "side circuits," to form a phantom circuit. The other three telephone circuits are obtained from a carrier-current telephone system superimposed on one of the pairs of wires.

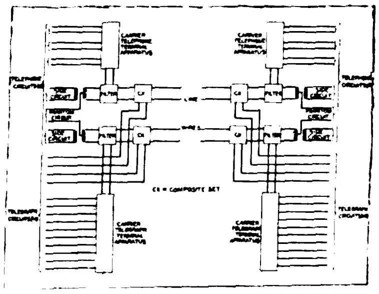

FIG. 6—COMMUNICATION CHANNELS ON FOUR WIRES OF GROUP OF TRANSCONTINENTAL FACILITIES BETWEEN DENVER AND SACRAMENTO

Ten of the telegraph circuits are obtained from a carrier-current telegraph system superimposed on the other pair of wires, and the other four telegraph circuits are direct current channels derived by ordinary compositing arrangements.

In some cases, a similar group of four wires may have a second carrier telephone system superimposed in place of the carrier telegraph system, while in other cases, a second carrier telegraph system is used in place of the carrier telephone system, according to the requirements for these types of facilities.

Fig. 7 shows the bands of frequencies used at present for communication purposes on typical long open wire

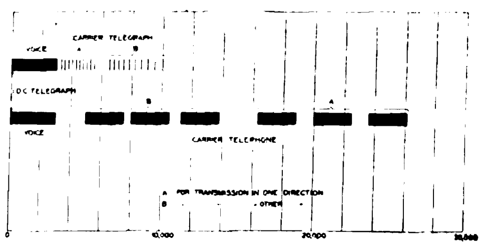

FIG. 7—FREQUENCY ALLOCATIONS ON TYPICAL TRANSCONTINENTAL FACILITIES

circuits. The lowest, from zero to about 80 cycles, is employed for the d-c. telegraph. Each telegraph circuit employs a single wire with ground return, so that two are obtained from each pair of wires.

The voice frequencies occupy the next higher band of frequencies, extending to about 3000 cycles. Some circuits of this type are made efficient at frequencies as low as 135 cycles to permit the employment of a current of this frequency for signaling purposes.

6. *Carrier-Current Telephony and Telegraphy*, by E. H. Colpitts and O. B. Blackwell, TRANS. A. I. E. E., Vol. XL, 1921, p. 205.

Above the voice range, each pair of wires may be arranged for superimposed carrier-current operation, either telegraph or telephone. The former utilizes frequencies as high as 10,000 cycles; the latter, as high as 28,000 cycles.

The general use of large wire and long repeater spacings is advantageous in the case of very long circuits, since this results in a smaller number of repeaters, and, in the case of voice frequency circuits, the lesser number of echo current paths permits somewhat better over-all volume efficiencies to be obtained. Carrier systems involve, at the terminals, large investments in apparatus for converting the voice frequencies or telegraph signals, as the case may be, to carrier frequencies, and vice versa. Thus, in general, the longer the distance to be spanned, the lower is the cost of the carrier circuits per mile. The longer or "back-bone" circuits are usually of 165-mil diameter copper, with repeaters spaced from about 200 to 300 mi. apart, and, consequently, carrier systems have been applied to these much more extensively than to wires of smaller gage. In a few of these circuits, however, 128-mil or even 104-mil wire is used through some sections where repeater spacings and other conditions are favorable.

In carrier-current telephone systems, the frequency employed for carrier purposes is modulated by the voice currents, and one of the resulting bands of frequencies is filtered out from the others and transmitted over the line. At the terminals of the systems, the various bands are separated from each other and from the voice-frequency channels by properly designed filters. In the latest systems, six bands of carrier frequencies are utilized, the lower three for transmission in one direction and the other three for transmission in the opposite direction, these being combined at the terminals to form three two-way circuits. The use of separate channels for the two directions of transmission of each circuit permits the use of one-way amplifiers the gains of which are not limited by balance conditions. At repeater points, the lower bands are kept separate from the upper ones by filters, and each one-way repeater amplifies three carrier channels simultaneously.

In the carrier telegraph system, the fundamental carrier frequencies are under the control of telegraph relays and are applied to the line as spurts of high frequency currents. For a ten-channel system twenty different frequencies are employed, the lower ten for transmission in one direction and the upper ten for transmission in the opposite direction. As in the case of the carrier telephone systems previously mentioned, the group of frequencies transmitted in one direction is kept separate from the opposite bound group at repeater points by means of filters and an entire one-way group of frequencies is amplified by a similar method.

It is necessary, of course, to convert the received carrier telephone or telegraph currents to voice frequencies or d-c. telegraph signals, as the case may be. In the case of the carrier telegraph system the signals are relayed in the form of ordinary direct-current telegraph impulses so that such circuits may be connected to telegraph circuits of other types as desired.

The application of carrier systems employing frequencies as high as 28,000 cycles has brought with it specially difficult problems from the standpoint of cross-talk. With these high frequencies, the transposition spacing requirements become quite stringent and the number of points at which transpositions are necessary is greatly increased. In addition, in toll entrance and intermediate cables, it is necessary usually to arrange the conductors in such a way that those used for carrier systems will not be adjacent to each other.

Frequent reference has been made to telephone repeaters[7] and repeater gains. The amplifying element of a telephone repeater, the vacuum tube, is essentially a one-way device, and for two-way operation it is necessary that the output of the element be prevented

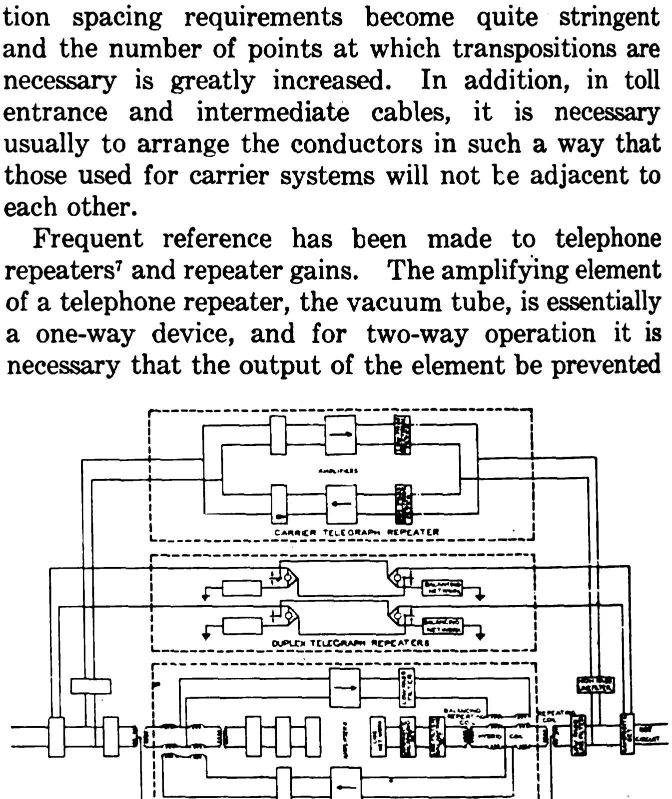

FIG. 8—SIMPLIFIED EQUIPMENT LAYOUT AT INTERMEDIATE REPEATER STATION ON TRANSCONTINENTAL-TYPE CIRCUITS

from getting back to the input side and thus setting up continuous oscillations known as singing or howling. This is accomplished by the use of two amplifying elements, each with its input connected at a neutral point in the output circuit of the other. The neutral point is obtained in a manner very similar to that employed in duplex telegraphy by dividing the output of each vacuum tube between the line and an artificial line having similar characteristics so that the electrical center of the output circuit remains at a constant potential unaffected by the changing currents in the output circuit itself.

Fig. 8 shows the equipment at an intermediate repeater point on one pair of wires of the type used for transcontinental service. The voice-frequency telephone repeater is shown connected to the line in the two directions. Each line, with its associated terminal equipment, is balanced by an artificial line with associated balancing equipment. The hybrid coil located

7. *Telephone Repeaters*, by B. Gherardi and F. B. Jewett, TRANS. A. I. E. E., Vol. XXXVIII, Part II, 1919, p. 1287.

in the electrical center between the line and artificial line is the means by which the transmission in the two directions is separated. Currents amplified by the upper one-way element pass through the so called third winding of the hybrid coil and set up voltages in the line windings. These voltages are of exactly the same magnitude on both sides of the electrical center of the coil and cause equal currents to flow in the line and artificial lines if their impedances balance each other perfectly. In practise, it is impracticable to obtain an exact balance due to the presence of unavoidable irregularities in the line and its associated equipment, the effect of which is to reflect energy which reaches the other amplifier. For successful operation, however, the average of the two transmission losses represented by the ratio between the reflected energy and the applied energy on each side of the repeater, must be substantially greater than the average of the transmission gains of the two amplifying elements.

The line repeating coil is shown in the figure with the mid-point of the line side indicated as the phantom circuit tap. The composite set is essentially a filter which allows the voice currents to pass between the line and the telephone repeater, while direct currents and the low frequency alternating currents involved in d-c. telegraph operation pass between the line and the telegraph repeaters. It will be noted that the telegraph repeaters, also, are arranged for two-way operation involving the employment of balancing networks.

The currents of carrier frequencies are prevented by a filter from reaching the low-frequency equipment but are transmitted easily through a high-frequency path in the filter to the carrier repeater. In the latter, for separating the two directions of transmission, advantage is taken of the fact that the currents in the two directions are of different frequencies so that directional filters can be used to separate them. The repeaters amplify the three one-way channels of a carrier telephone system or the ten one-way channels of a carrier telegraph system simultaneously. In order to avoid interaction or modulation between the various channels, it is essential that the relation between the output current and the input voltage of the vacuum tubes be a straight line function over the energy range employed in the carrier system.

Signal currents, also, must be relayed or amplified on long telephone circuits, just as voice and carrier frequencies are. On some short toll circuits, a signaling current of about 20-cycle frequency is used, the same as that for ringing the bells of subscribers' telephones. On circuits arranged for d-c. telegraph operation, it is impracticable to employ such a low frequency; it is necessary to use a frequency that will be transmitted satisfactorily by the circuit. In actual operation, the signaling channels at the ends of the circuits are arranged usually for 20-cycle operation by means of relays which automatically apply higher frequency signaling currents and receive the incoming signals.

The signaling frequency commonly used on toll circuits of medium length is 135 cycles. With this system, the signals are relayed at least at every other voice-frequency repeater point since the attenuation loss at 135 cycles is greater than that over the main voice-frequency range. In very long circuits, this results in the necessity for operating a train of relays at successive points, which delays the transmission of the signals. To overcome signaling difficulties on such circuits, a system of ringing, employing 1000-cycle currents which are transmitted from end to end of the circuit with the same efficiency as speech currents of that frequency, has been developed and applied. The signaling currents are supplied from a suitable source and are controlled by 20-cycle relays at the terminals. At the receiving end, circuits tuned to the signaling frequency are employed to amplify and convert the signals to currents which operate relays. Interference from speech currents is avoided by interrupting the signaling current at the sending end about twenty times per second, while at the receiving end, the signals pass through a circuit tuned to 20 cycles.

At some points in a long telephone circuit, it is necessary to employ cable, as when passing through a large city. Because of this greater capacity between wires, cable circuits cause much greater attenuation per unit of length than open wire circuits, especially at carrier frequencies. In order to improve the efficiency of the cable circuits they are loaded by means of inductances placed at intervals along the circuit. The inductances and spacing are so chosen as to cause the characteristic impedances of the cable circuits to approximate closely those of the open wire circuits over the range of frequencies transmitted.

Circuits of transcontinental type are used often for special services such as for the transmission of program material to broadcasting stations[8] or to points where such material is desired in connection with a public address system. As this is essentially a one-way service and the programs usually include music, for which the best results are obtained by using a wider range of frequencies than ordinarily is employed for commercial telephone communication, the two-way repeaters in the line are replaced by one-way repeaters and associated equipment for amplifying the currents and equalizing the transmission throughout the wider range of frequencies. Programs are transmitted daily in this manner to a number of broadcasting stations in the eastern half of the country.

Typical of the larger networks that have been set up is that for the inauguration of President Coolidge. Fig. 9 shows the layout arranged for that purpose, which effectively covered the entire country.

8. *High Quality Transmission and Reproduction of Speech and Music*, by W. H. Martin and H. Fletcher, TRANS. A. I. E. E., Vol. XLIII, 1924, p. 384.

On occasions, a speaker in one city addresses a meeting in a distant city, the loud speakers at the receiving end being connected to the transmitting telephone by wire. In some cases, such speeches also are broadcast from one or more radio broadcasting stations.

Another use made of transcontinental type facilities is the transmission of pictures or facsimiles of printed or written matter, fingerprints and similar material. The frequencies employed for this purpose are within the voice range and the currents are transmitted in the same way as voice currents. Special apparatus is required, of course, at the transmitting and receiving ends.

The continuity of the many important services routed over the facilities used in making up these long circuits is dependent upon continuous and efficient maintenance methods and performance. Coordination of the work of the different offices is most essential in order to obtain best results especially on the longer direct circuits and on those built up by connecting together several circuits, as there are many variable factors. To assist in obtaining this coordination, one of the terminal offices of each circuit is designated as the controlling office for that circuit and is responsible for the direction and supervision of tests and adjustments required on the circuit as a whole. In addition to the duties in connection with the maintenance of the complete circuit, each office along the circuit is responsible for the proper physical maintenance of the plant in its territory. To assist in this maintenance work, accurate records of the circuit make-up from end to end, including a complete description of the types of equipment and transmission data, are prepared and furnished to the terminal offices and intermediate repeater stations. These records are made on cards of convenient size as illustrated by Table I, which is reproduced from one of three cards containing the data for a Chicago-San Francisco circuit.

To insure satisfactory over-all transmission and proper functioning of the circuit, various tests and inspections are made at frequent intervals[9]. Some of the more important maintenance tests are as follows: insulation resistance, loop resistance and resistance balance of the line conductors; measurement of the gain-frequency characteristic as well as the gain at 1000 cycles, and tube tests on all repeaters to detect changes in amplification due to possible changes in the characteristics of the vacuum tubes or repeater equipment; balance tests at each repeater station to check the degree of balance between the line circuit and its balancing network; noise and cross-talk measurements; 1000-cycle transmission measurements and transmission-frequency measurements on the over-all circuit to insure that the circuit equivalent is maintained within proper limits; and finally, over all talking and signaling tests.

In making many of the measurements, it is necessary to remove the circuit from service. This would result in considerable lost circuit time if each of the stations made the measurements and tests independently. In order to minimize this lost circuit time, it has been found

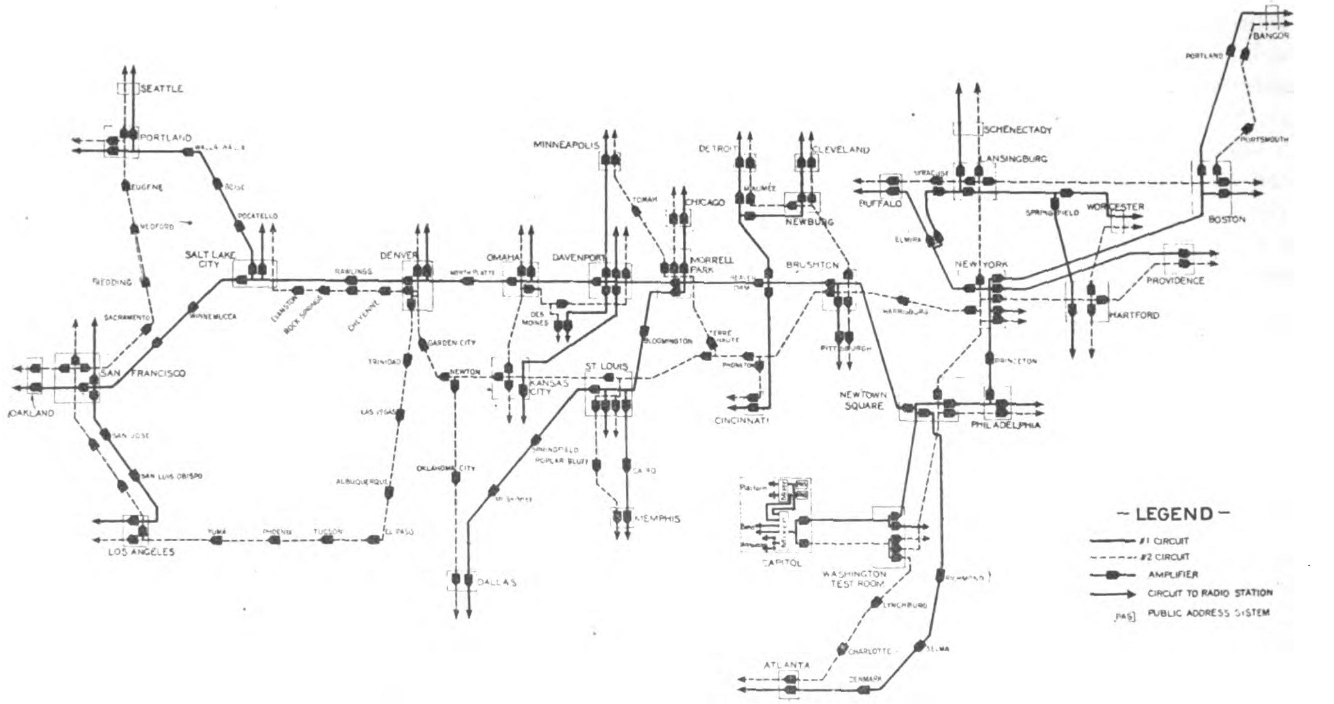

Fig. 9—Network of Circuits for Transmitting Program Material to Broadcasting Stations—Layout Made Available for the Inauguration of President Coolidge

9. *Practises in Telephone Transmission Work*, by W. H. Harden, Trans. A. I. E. E., Vol. XLIII, 1924, p. 1320.

TABLE I.
TOLL-CIRCUIT LAYOUT RECORD

.... E-552

Circuit No. 2 **Chicago** **(E)** **San Francisco** **(W)**

Control Office Chicago	Meas. At Chicago	Class..................	Noise Rat'g......	Equiv. in TU	E to W	W to E	
				Req.	11	11	Circuit order 5785 Item 42
				Meas.	11	11	Date in service 6-1-26
							Card issue No. 1 Date 5-22-26

From 1	To 2	Cable or line 3	Pair or pin numbers 4	Size of wire 5	Loading 6	Length 7	Equiv. 8	Toll line equipment: On side 9	For SX 10	For other use 11	CX 12	Ringer 13	Misc. 14	Loss (Columns) (9 to 14) 15
C Chicago								75 A				3 A		0.8
D	Morl Park	Chg-MP CA 5	151	19	H–44	7.6	3.6	75 A						0.7
E Morl Park	MH 28	West TE CA	1	13	N	2.2	1.1	75 A			TS		KX	1.1
F P 128	P 328	Chg–Omaha	9–10	165	N	3.8	0.1							
G P 328	P 7415	" "	9–10	165	N	166.3	5.5							
H P 7415	P 7445	" "	9–10	165	N	0.7	0.0							
J P 7445	Davenpt	Aer Cable	9	13	N	0.1	0.0							
K Dåvenpt	P 7445	" "	5	13	N	0.1	0.0							
L P 7445	P 7557	Chg–Omaha	35–36	165	N	2.1	0.1							
M P 7557	P 7741	" "	25–26	165	N	4.5	0.1							
N P 12976	P 9047	Stl–Davpt	5–6	165	N	83.4	2.8							
P P 9047	Burlington	Aer Cable	5	10	N	0.5	0.2	75 A			TS		KX	1.1
Q Burlington	P 9047	" "	15	13	N	1.0	0.5	75 A			TS		KX	1.1
R P 9047	P 7930	Stl–Davpt	15–16	165	N	29.5	1.0							
S						Total							Total	

Telephone Repeater Data

Office 16	Type 17	Imp. 18	Toward W: Gain or CC step Req. 19	Toward W: Gain or CC step Meas. 20	Toward W: Net 21	Toward W: Singing point Req. 22	Toward W: Singing point Meas. 23	Toward W: Ringing 24	Toward E: Ringing 25	Toward E: Gain or CC step Req. 26	Toward E: Gain or CC step Meas. 27	Toward E: Net 28	Toward E: Singing point Req. 29	Toward E: Singing point Meas. 30	Misc. 31
T Chicago	C	N	3		13 P	24									
U Morl Pk	2 A C	N	7.1		17 E	24				7.1		13 P	14		
V Burlington	21 P	N	12		17 F	24				12		17 F	24		
W Kans Cy.	21 P	N	12		17 F	24				12		17 F	24		
Z Newtn.	21 P	N	12		17 E	24				12		17 F	24		

Mileage	O. W.	CA. & O. W
This company	2002.3	2021.2
Other company		644.3
Total		2665.5

Net Equivalent	
Four-wire section	
Two-wire section	
Carrier section	

desirable in the case of long telephone circuits to set aside a definite time for making the periodic tests and to coordinate the work of making the tests under the direction of the controling office. This testing routine has been perfected to such an extent that the circuit need not be kept out of service for more than a few minutes even in the case of the longest circuits.

The measurements of line resistance, insulation resistance, and resistance balance are made by means of Wheatstone Bridge arrangements in the testboards located at each repeater station and sometimes at intermediate points in a long repeater section. The amplification, or gain, given by each repeater is measured by means of a visual reading instrument of the vacuum tube type located at each repeater station. Balance between the line and network circuits in each direction at the various repeater stations is roughly checked by means of the repeater itself. This is done by disconnecting the line and network from one side of the repeater and connecting the two amplifying elements of the repeater in tandem, then increasing the amplification until the repeater circuit begins to oscillate. The sum of the calibrated gains of the two sides of the repeater is a rough measure of the degree of balance existing between the line and network circuits connected to the repeater. Measurements of the over-all equivalent of a circuit are made from the terminal offices by means of transmission measuring sets[10] provided with variable frequency oscillators.

The long telephone circuits in the United States form a network by means of which many important points are connected directly to each other, while practically all large centers may be connected by a very few switches which rarely involve more than three such links. Economic use is made of the wires by the large number of telephone and telegraph channels superimposed on the voice-frequency circuits. The plant composing this network extends over the entire country and close coordination is essential to insure the best results both from the technical and the economic standpoints.

Main arteries of communication have been established in this way which bring the widely separated parts of the country into close touch with one another and the network is being augmented and extended to meet the growth in the traffic as it occurs. These arteries are being developed so that continuous service can be given by means of the protection afforded by alternate routes, and they are well maintained to give efficient service under all the varying conditions encountered.

10. *Methods for Maintaining the Transmission Efficiency of Telephone Circuits*, by F. H. Best, TRANS. A. I. E. E., Vol. XLIII, 1924, p. 423.

Abridgment of

Surface Heat Transfer in Electric Machines with Forced Air Flow

BY G. E. LUKE*

Associate, A. I. E. E.

Synopsis.—*Since the insulation of windings in electric machines has comparatively low temperature limits, the problem of cooling these machines with the most economical use of material becomes one of major importance. The design of such machines from a temperature standpoint is usually based on tests of a previously made similar machine or else is of the "cut-and-try" type where such tests are not available.*

The predetermination of the operating temperature depends a great deal upon the rate at which the heat losses can be liberated from the ventilating surface to some cooling fluid such as air, which is considered in this paper. Some data are available regarding this rate of heat dissipation with forced air convection currents; a comparison of the various results published, however, shows them to be inconsistent. The purpose of this paper is to submit additional information that should be of value to the industry and that will also explain some of the inconsistencies in the past tests.

INTRODUCTION

THE main factor that limits the capacity of electric machines is the temperature of the windings. This temperature limit is comparatively low, ranging from approximately 100 deg. cent. to 150 deg. cent., depending upon the class of insulation and the type of machine. Air is used as a cooling medium in the great majority of rotating machines. The heat resulting from the iron and copper losses of the machine is conducted to the ventilating surfaces where it is transferred to the moving air. To conduct this heat through the solid material and to transfer it from a surface to a fluid requires a temperature gradient. Such a flow is shown on Fig. 1 with a radial duct. From the standpoint of heat transfer from a surface, air is one of the poorest of fluids. From 20 to 75 per cent of the temperature rise in rotating machines is due to the gradient necessary to transfer the heat from the surface to the ventilating air. This factor is therefore of considerable importance in the design of an economical machine.

Considerable data in the past have been published concerning heat liberated from surfaces with natural convection currents, but it has been just recently that data applicable to electrical machines with forced air flow have been available. To obtain information regarding the rate at which heat is dissipated with high velocity air flow is difficult since it will depend upon the particular conditions of air flow as well as the mean velocity. Experimental results published by various workers do not agree, therefore, in many cases. The purpose of this paper is to discuss some of the available tests and to submit new tests covering conditions of air flow such as are found in electric machines. The new data presented also will correlate some of the work which offhand seemed to be inconsistent.

COMPARISON OF PUBLISHED DATA

Throughout this paper the coefficient of surface heat transfer will be symbolized (K_v) or W/sq. in./deg. cent., which means watts transferred per square inch of ventilating surface per deg. cent. difference between the surface and mean air temperature flowing in the duct. Thus, in Fig. 1, (K_v) for the particular air flow would depend not upon the minimum air temperature nor upon the mean temperature as given by the curve but upon the integrated mean temperature taking into account the total mass flow. This is the only practical way of defining (K_v) since in any ventilating duct the

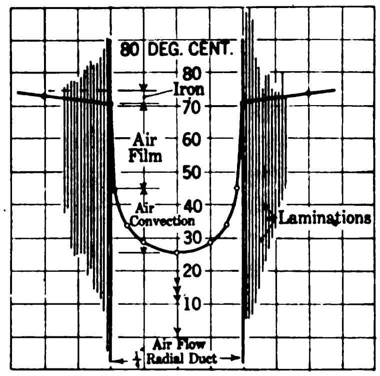

FIG. 1—TEMPERATURE GRADIENT DUE TO HEAT FLOW TO AIR STREAM IN RADIAL DUCT

air temperatures and velocities vary greatly at any particular point.

This coefficient of surface heat transfer is often called "rate of surface heat flow", "dissipation constant" and erroneously, "the emissivity constant". It may also be expressed in other units; the relation of some of these is approximately as follows:

1 B. t. u. per sq. ft. per deg. fahr. per hr. = 0.00366 watts per sq. in. per deg. cent.

1 Calorie per sq. cm. per deg. cent. per sec. = 27.0 watts per sq. in. per deg. cent.

1 Kilo-calorie per sq. m. per deg. cent. per hr. = 0.00075 watts per sq. in. per deg. cent.

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1 watt per sq. cm. per deg. cent. = 6.45 watts per sq. in. per deg. cent.

A few of the experimental results published by Nusselt,[1] Dicksee,[2] Rice,[3] and the writer,[4] giving the rate of surface heat transfer for various air velocities, are plotted on Fig. 2. In all of these tests the air velocity referred to is the mean velocity in ft. per min. obtained by dividing the weight of air, in pounds, passing through the duct by the cross-sectional area of the duct in square feet, and by the weight of air in pounds per cubic

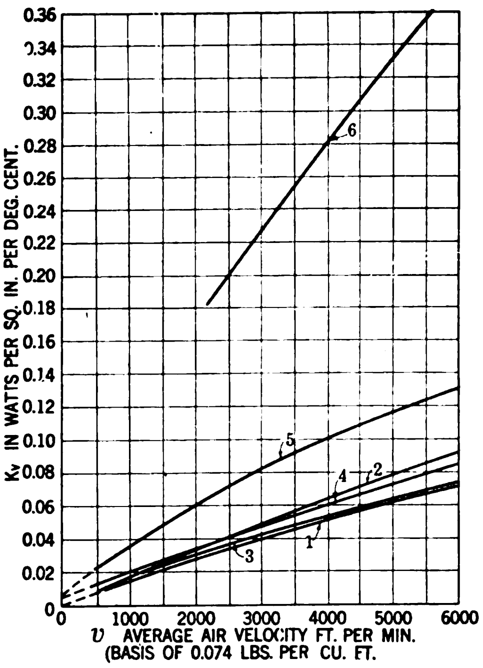

FIG. 2—SURFACE HEAT TRANSFER CONSTANT AGAINST AVERAGE AIR VELOCITY FOR VARIOUS DUCTS OF ATMOSPHERIC PRESSURE

Curve	Author	Type
1	Luke[1]	Smooth circular 1¼ in. Dia. 36 in. long.
2	Luke[1]	Rough circular 1¼ in. Dia. 36 in. long.
3	Nusselt[4]	Smooth circular 0.866 in. dia.
4	Luke[1]	Smooth concentric 25 in. by 26 in. dia. 36 in. long.
5	Dicksee[2]	Smooth concentric 3 in. by 5⅜ in. dia. 7 in. long.
6	Rice[3]	Rough concentric 1.1 in. by 2 in. dia., 5.86 in. long.

feet (0.074). This factor (0.074) is the weight of dry air in pounds per cubic foot at 25 deg. cent. and atmospheric pressure of 29.92 inches of mercury. Thus the weight of air flowing will be proportional to the velocity factor.

Curves 1, 2, and 4, given by the writer,[4] were with air flowing through ducts such as are found in electric machines and are called axial ducts. Curve 1 applies to a smooth brass tube 1¼ in. in diameter and 36 in. long, with air flowing through it. Curve 2 is for a duct similar to Curve 1 except that the surfaces are rough, since the tube was made by stacking washers of 0.017 in. varnished iron with a 1¼ in. inside diameter. Since the punching and stacking varied a few thousandths of an inch, the inside bore was comparatively rough. This increased the coefficient of friction (f) at least 50 per cent and the heat transfer (K_v) from 20 to 30 per cent. Curve 1 provides a reasonably close check on the data given by Nusselt (Curve 3) which were obtained by using a smooth 0.866-in. diameter tube. Jordan[5] also gives the results of surface heat transfer constants (K_v) with air flow through smooth tubes which are slightly below Curve 1.

Curves 4, 5, and 6 were obtained with the air flowing axially between two concentric cylinders. In the tests made by the writer the cylinders were 25 and 26 inches in diameter and 36 inches long. Due to the radiation loss the values are slightly greater than those indicated by Curve 1. This radiation loss is present in Curves 4, 5, and 6, since the heated surface was the outer surface of the inner cylinder. This radiation loss is approximately 0.003 to 0.005 W/sq. in./deg. cent. and will be independent of the air velocity. Curve 5 by Dicksee[2] was obtained with a much smaller heater cylinder upon which were soldered various numbers of radial copper fins with surfaces parallel to the air flow. The values of the heat liberated are about twice those given for Curve 1. Curve 6 by Rice[3] was plotted in terms of mean velocity instead of maximum velocity by using the mean velocity ratio of 0.85. The values of heat transfer are comparatively large, being about five times as great as those of Curve 1 and about 2½ times as great as those of Curve 5.

From past experience in the cooling of electric machines with free convection currents, values of heat transfer from the ventilating surfaces have been obtained that are considerably greater than those given by

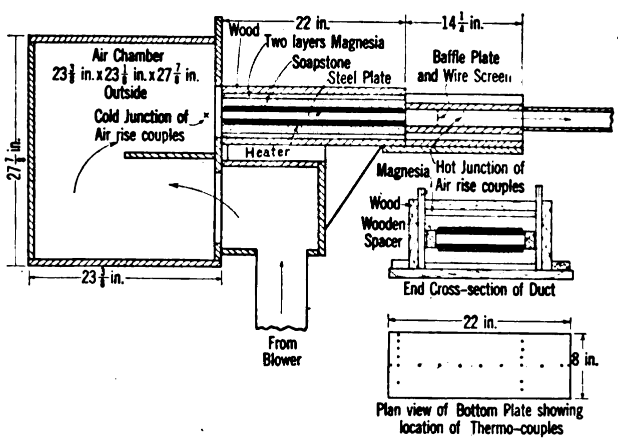

FIG. 3—APPARATUS FOR DETERMINING THE HEAT LOSS FROM FLAT PARALLEL PLATES

Curves 1 to 4. The writer has never obtained such high values, however, as those given by Curve 6 and hence additional tests were planned and executed for the purpose of giving more information concerning the variation of this cooling constant (K_v) as influenced by varied air flow conditions.

EXPERIMENTAL

1. *Air Flow Between Two Parallel Flat Plates.* Electric machines are cooled more by radial ventilating

1, 2, 3, and 4. See Bibliography.

ducts in the iron core than by any other method. These ducts range in width from ¼ in. to 1 in., ⅜ in. being the more common figure. The air flow through them is very turbulent, due not only to the ventilating spacers or fingers and the coils but also to the changing cross-section for air flow. On large bore machines the change in air velocity due to the radial flow may not be great. The first test made was to imitate such conditions where a minimum rate of heat transfer is to be expected.

A sketch of the apparatus is shown on Fig. 3. The air was supplied by a centrifugal fan driven by an adjustable speed, d-c. shunt motor. This fan discharged into an expansion chamber. The air then passed through the ventilating duct formed by two hot plates 8 in. wide by 22 in. long, separated a definite distance by proper spacers. The hot discharge air then passed through an outlet duct where its average temperature was measured.

In all tests on heat transfer with forced air flow the accuracy of the data depends upon the true mean air velocity or volume. This volume may be obtained by using the pilot tube, anemometer, orifice meter, and other similar methods, but in many tests of this nature the writer has obtained the best and most accurate results by using the specific heat method. The volume was obtained after thermal equilibrium had been reached from the watts input to the air and the resulting air temperature rise. The watts absorbed by the air equals the total watts input minus the stray loss as given by the calibration curve corresponding to that particular heater temperature. The temperature rise of the air was obtained by five thermocouples with the hot and cold junction distributed in the outlet and inlet air respectively. The accuracy of this method depended upon obtaining the true temperature rise, which necessitated a thorough mixing of the hot air. This is accomplished best as shown by allowing the air to expand on discharge with a baffle placed in the direct path of the high velocity air, forcing the air to change its path. This scheme functioned successfully as shown by temperature traverses of the air with a single couple. The equation used was

$$V = \frac{1.765\, W_a}{\theta_a}$$

where

V = cubic feet of air per minute (25 deg. cent. temperature)

W_a = watts absorbed by the air

θ_a = resulting air temperature rise deg. cent.

The average air velocity (v) through the duct, then, is

$$v = \frac{V}{A}$$

where

v = average air velocity in feet per minute, and

A = cross-sectional area of duct in sq. ft.

The rate of heat loss (K_v) from the surface for any given velocity was determined from the equation

$$K_v = \frac{W_a}{S\left(\theta_s - \dfrac{\theta_a}{2}\right)}$$

where

K_v = surface heat transfer constant in W/sq. in/deg. cent.,

W_a = watts dissipated to ventilating air,

S = ventilating surface of duct in sq. in.,

θ_s = average surface temperature rise of duct above intake air deg. cent., and

θ_a = temperature rise of the outlet air deg. cent.

A stray heat loss curve for each spacing was obtained

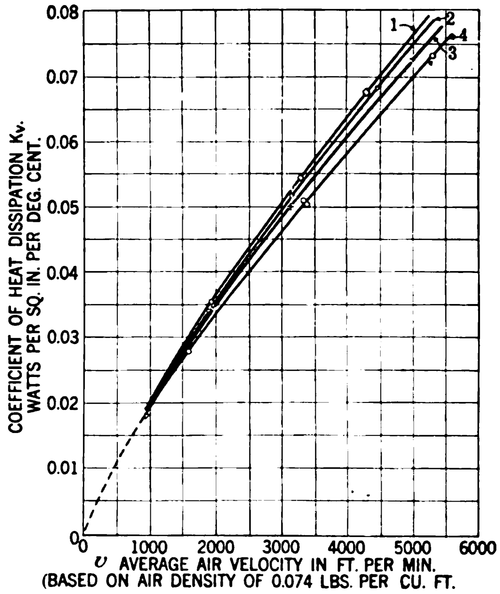

Fig. 5—Curves for Flat Parallel Plate Duct

Size duct 8 by 22 in.
Curve No. 1; (for ¼-in. spacing)
Curve No. 2; (for ½-in. spacing).
Curve No. 3; (for ⅜-in. spacing).
Curve No. 4; (for 1-in. spacing.)

which gave the watts stray loss for any average plate temperature. This was made by completely closing the ends of the duct so as to minimize loss by convection. The heater input, then, when steady conditions had been reached, was the stray loss flowing through the heat insulation. With forced convection the duct was given a definite spacing and air at a constant velocity was forced through. The current through the heaters was adjusted until an average plate temperature of about 80 deg. cent. was reached. When the temperatures became stable all thermocouples and heat inputs were measured. Direct current was used as the heater supply. The voltage dropped across the heater, across a fixed resistance in series with the heater, and the potentials given by the couples were all measured with a Leeds & Northrup type K potentiometer. In this manner tests at various velocities were made for

¼-in., ½-in., ¾-in., and 1-in. spacings, and (K_v) was calculated as previously shown.

The results of these tests are shown on Fig. 5. These curves show a slight decrease in (K_v) with increasing duct spacing. The values of the constant are not materially different from those of Curve 2 in Fig. 2.

In air blast transformers similar ducts between pancake coils are used, the coils being separated by the so called "wavy" fiber spacers. Such spacers will increase the turbulency of the air flow and should increase (K_v). Results obtained with a ⅜ in.-width duct by the use of these spacers are shown on Fig. 6. The air velocity was calculated from the minimum cross-sectional area between spacers (0.375 in. by 1.25 in.), and the surface was taken as the product of the minimum clear distance between spacers times the straight line length of the duct (1.25 in. by 22 in.). This heat loss coefficient is 40 or 50 per cent greater than that found in the duct without wavy spacers. The coefficient of friction (f) was about 100 per cent greater than that for the duct without spacers. Curve 1, Fig. 6, shows that the turbulency of air flow was practically the same as that in Curve 5 of Fig. 2.

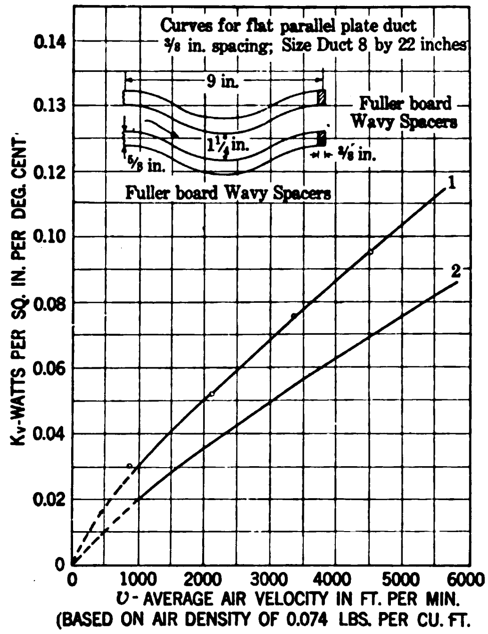

Fig. 6—Curves for Flat Parallel Plate Duct 3/8-In. Spacing:

Size duct 8 by 22 in.
Curve No. 1
3/8-in. duct with 3/8-in. wavy spacers
Curve No. 2
3/8-in. duct without wavy spacers

2. *Air Flow in Radial Duct.* The above described tests were on ducts of constant cross-section. In radial ducts, however, the cross-section is changing from point to point along the air path due to the resulting change in the diameter of the duct. In practise, also, such ducts will contain irregular spacers (ventilating fingers) and will be traversed by the conductors. All of these factors will tend to produce very turbulent air flow which should result in a high rate of heat loss.

A sketch showing the cross-section of the apparatus is given on Fig. 7. The duct proper was formed by separating two parallel hot plate disks. These plates were 24 in. in outside diameter and 10 in. in inside diameter.

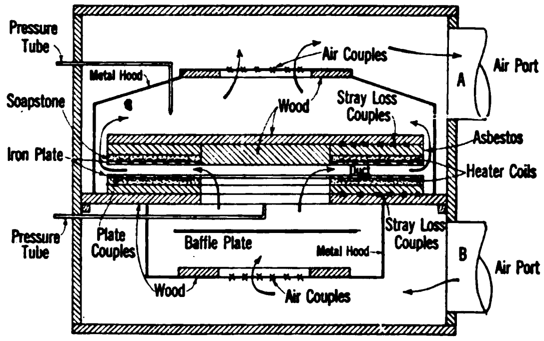

Fig. 7—Arrows Indicate the Direction of Air Flow for Diverging Air

They were made of resistance wire wound uniformly on one side of a ⅛-in. plate; mica was used as insulation with shellac as the binding cement. The heater and plate were likewise cemented to a 1-in. soapstone slab which acted as a heat insulator and also gave rigidity to the heater plate. Two such plates, properly spaced, were enclosed in a wooden box which acted as an air chamber. Ports were provided for attachment to the fan and discharge duct.

The heat loss constant (K_v) was calculated as before,

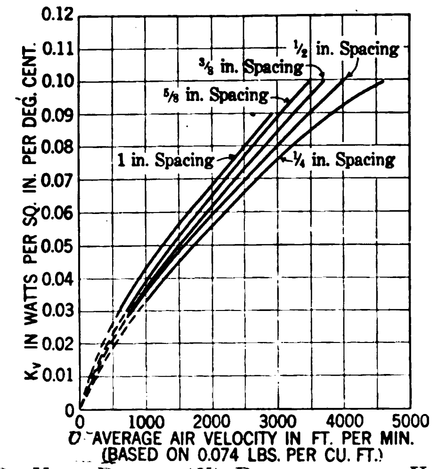

Fig. 8—Unit Power (K) Dissipated vs. Velocity

No fingers or blocks Diverging air
Radial ducts

based upon the average temperature difference $\left(\theta_s - \dfrac{\theta_a}{2}\right)$. The air velocity used in the curves is the average velocity based upon the cross section in the middle of the duct and hence corresponds to the section where the duct diameter is (24 + 10)/2 or 17 in.

When ventilating fingers were used the surface of the fingers was also included.

The results of tests with diverging flow through the unobstructed radial duct are shown on Fig. 8. The heat loss constant at a definite velocity is greater for the 1-in. ducts than for the ¼-in. duct which is the reverse of the case given on Fig. 5. The values are also much higher due to greater turbulency of air flow. These

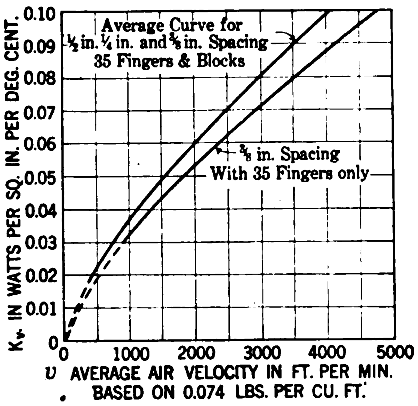

Fig. 9—Unit Power (K) Dissipated vs. Velocity

35 fingers—35 blocks diverging air
Radial duct

values are of the same approximate value as that represented by Curve 5, Fig. 2. The curve of the ⅜ in. or ½ in. duct, Fig. 8, seems to be out of place. The values given, however, were rechecked several times.

When ventilating fingers and conductors are placed in the duct the curves are as shown on Fig. 9. Since the surfaces of the spacers are also included, the results

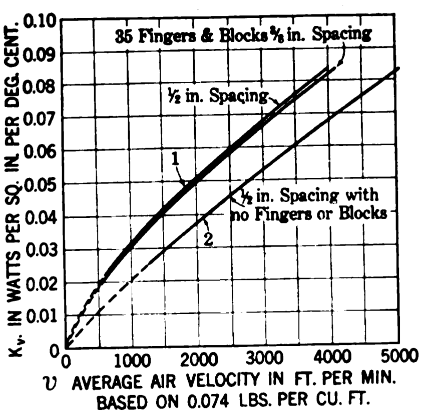

Fig. 10—Unit Power (K) Dissipated vs. Velocity

35 fingers—35 blocks converging air
Radial duct

show that they are almost as effective as the duct surface.

Many machines are now ventilated with air flow radially inward (converging flow) through a portion of the ducts. The results of such a flow are shown on Fig. 10. It should be noted that the values obtained are lower than those obtained with diverging flow; Curve 2, particularly, is materially lower than the similar curve on Fig. 8. This fact is to be expected since it is known that diverging air flow will be more irregular or turbulent than converging flow with the same axial change in cross-section. Thus the turbulence obtained with Curve 2, Fig. 10, is about the same as that found in Fig. 5 with a constant cross section since the rate of heat loss is about the same.

3. *Air Flow between Two Concentric Cylinders.* Mr. C. B. Dicksee,[2] working in this laboratory, investigated the heat loss from an air cooled gasoline engine cylinder with numerous fins attached. Curve 5, Fig. 2, gives the average results of these tests on a cylinder with 5 to 40 axial metal fins attached. These fins extended to the outer cylinder. The heat loss constant (K_v) was independent of the number of fins used. At the time these tests were made the value of (K_v) was considered high and no reason could be suggested why the heat loss should be any greater than, let us say, Curve 2.

The writer at that time had tests made with the smooth cylinder without fins as shown on Fig. 11.

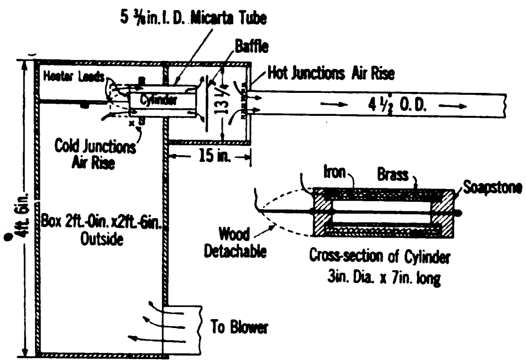

Fig. 11—Diagram of Experimental Apparatus for Determining Heat Loss from a Cylinder with Axial Air Flow

This test equipment was the same as used in the above test. The cylinder was supported as shown, with a square orifice air intake. The average temperature of the inner cylinder was obtained with thermocouples as before; (K_v) was calculated as it had been done previously and the air velocity was calculated from the cross-sectional area of the duct.

Curve 2, Fig. 12, gives the results of these tests. The values of (K_v) are a little greater than those obtained on the finned cylinder, Curve 1. In comparing this Curve 2, Fig. 12, with Curve 4, Fig. 2, a great difference is observed, although the types of air flow system are about the same; the main difference is the length of duct (7 in. and 36 in.).

It has long been known that when air enters a duct of constant cross section from a larger chamber, a convergence or "vena contracta" of the air stream will take place, and later the effective air stream will expand and gradually assume a stable velocity condition. This convergence near the entrance of the duct and the resulting change in velocity beyond the "vena contracta" will result in turbulence and an increase in heat

loss coefficient (K_v). This is evidently the explanation for the high value of (K_v) shown on Curves 1 and 2, Fig. 12. Since the major part of this effect extends over only a few inches, this explains why its influence is small on Curve 4, Fig. 2, with a 36 in. length of duct.

About this time Rice[3] published his Curve 6, Fig. 2. This curve, as previously mentioned, gives values of (K_v) about 2½ times as great as those of Curve 1 or 2, Fig. 12, and as Rice states, about five times those of Nusselt.[1] The explanations suggested were that the conditions of air flow and heater surface were different.

In order to investigate this inconsistency, the writer

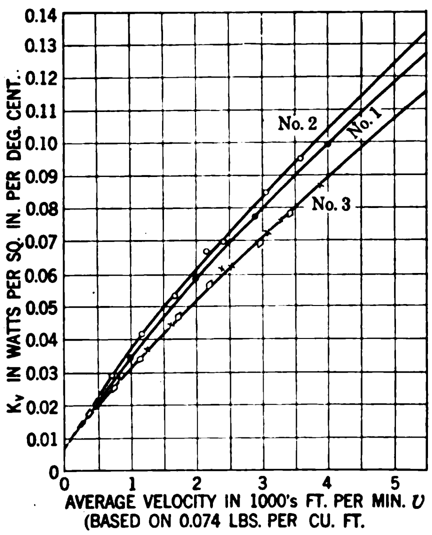

Fig. 12—Heat Loss from a Cylinder with Axial Air Flow

made tests on the smooth cylinder with a converging entrance simulating conditions as described by Rice. This was done by attaching extensions to the cylinders as shown in the dotted lines, Fig. 11. The results of this are given by Curve 3, Fig. 12, and show a decrease in heat transfer instead of an increase. This decrease was expected since a converging entrance will result in less air turbulence than a square entrance.

To check the effect of roughness on the rate of heat transfer, the above 3-in. cylinder was closely wound with 0.0155-in. diameter enamel copper wire (0.0394 cm.). This was insulated from the brass tube and the outer exposed enamel was removed with sand paper. The resistance of this outer wire surface was obtained with a wheatstone bridge from which the temperature was calculated. The results of these tests were practically the same as the results of tests made with the smooth cylinder and line up with Curve 3, Fig. 12, within the error of test.

These test conditions, while not exactly the same as those given by Rice,[3] are nevertheless very similar. The dissimilarities due to size and other conditions should not be expected to give a value of (K_v) of more than 20 to 30 per cent difference. The results as given for 4000-ft. per min. air velocity are, however, 0.09 for Curve 3, Fig. 12, and 0.28 Rice's value, Fig. 2. Such a discrepancy is enormous and the writer's opinion is that Curve 6, Fig. 2, is incorrect since it is out of line with all other tests.

Rate of Heat Loss as Influenced by Duct Length

It was previously suggested that the rate of heat loss due to air flowing through a duct will not be constant for all parts of the duct, even with a constant cross section. It has been observed in machine design that machines with short duct lengths, both radial and axial, can dissipate more heat in proportion to the surface than can large machines with the same type and section of duct but with longer air flow path. A part of this difference was believed to be due to the conditions of air flow. The turbulence caused by the vena contracta at the duct entrance should cause an increase in heat loss comparable to that loss where the stream flow was more uniform. This effect has been masked in many of the past researches due to the difficulty in obtaining the rate of heat transfer over any part of the duct. Thus the work described by Nusselt,[1] Pohl,[6] Rice,[3] Dicksee,[2] and Jordan[5] was all based on an average heat transfer constant taken over the total length of the duct. The writer[4] notices this increased heat loss near the duct entrance but was unable to determine its value accurately because of a variable stray end loss. The Curves 1 and 2, Fig. 2, were, therefore, based upon the average heat loss in the middle ⅓ section of the duct.

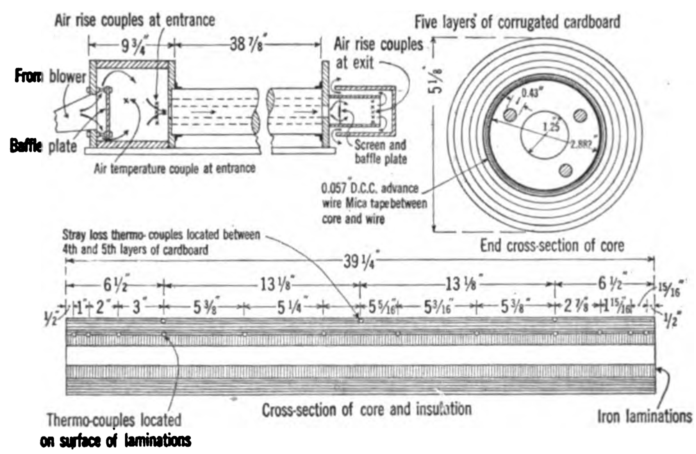

Fig. 14—Apparatus for Determining Rate of Heat Dissipation from Axial Ducts

Curve 4 was based on the average loss over the total duct.

This variation in rate of heat loss with length of duct has been analytically considered by Latzko.[7] He developed a theory of heat transfer as determined by form and dimension with reference to the turbulency of flow. His work was based upon the hydrodynamical principles of fluid flow. No experimental work, however, was available, and none was submitted to substantiate the analysis.

The following work was planned in order to determine this variation in the rate of surface heat transfer with

duct length and also to check Curve 2, Fig. 2, previously submitted.

4. *Air Flow in a Circular Axial Duct.* This air duct used was practically a duplicate of that from which Curve 2, Fig. 2, was obtained. It is called an axial duct since it was made to imitate such ducts found in the punchings of electric machines. The duct was 1¼ in. in diameter and 39¼ in. long. The inside surface was rough since the duct was formed by stacking stampings in the form of washers made from 0.017 in.

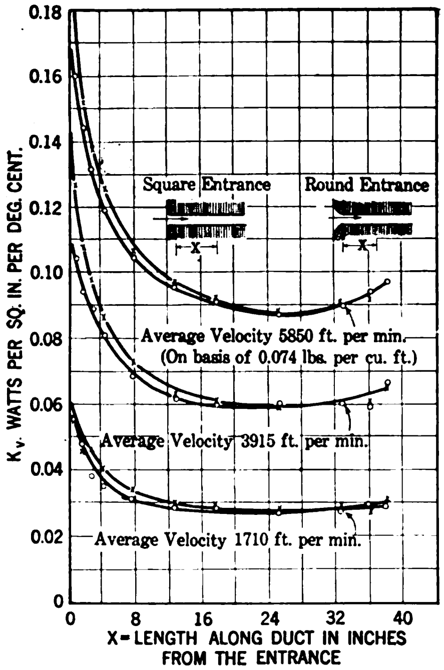

Fig. 17—Rate of Heat Loss from Surface of a Laminated Axial Duct

1¼ in. diameter 39¼ in. long
°These dots are for duct with round entrance
×These dots are for duct with square entrance

sheet steel (1 per cent silicon). These stampings were bolted together by three long bolts running the length of the duct. A sketch of the construction and details is given in Fig. 14.

Tests were made with a sharp or square entrance and with a round entrance as shown on Fig. 17. These values of heat loss (K_v) are the actual values obtained at any particular point along the duct. They verify the previously given theory that the rate of heat loss against duct length will be a variable and should be much higher near the entrance of the duct. For a constant volume, the loss (K_v) is about twice as high for the first inch of the duct as that found near the middle of the duct. It should be noted, also, that there is a slight increase in (K_v) near the outlet of the duct. This shows an increased turbulence and is verified by static air pressure explorations in that region.

The influence of the entrance is shown by an increase in (K_v) with a square entrance over that given with a smooth entrance. Near the middle of the duct the two curves are practically the same.

General Discussion and Conclusions. (a). Expressing the rate of surface heat transfer (K_v) in terms of the average air velocity (v), the following constants for the equation

$$K_v = A\left(\frac{v}{1000}\right)^n$$

are found:

Type of Duct	A	n
Axial smooth surface const. cross section	0.0157*	0.85
Axial Rough surface const. cross section	0.0178*	0.93
Axial Annular smooth surface const. cross section	0.0367	0.75
Rectangular smooth (3/8 in.) const. cross section	.0203	0.82
Rectangular smooth (3/8 in.) (wavy) const. cross section	.0298	0.77
Radial 3/8 in. diverging flow no fingers variable sect.	.0365	0.77
Radial 3/8 in. diverging flow with fingers variable sect.	.0367	0.72
Radial 3/8 in. converging flow with fingers variable sect.	.0310	0.70
Radial 3/8 in. converging flow no fingers variable sect.	.0204	0.88

*This factor will increase as the duct length decreases.

These results show a wide deviation in values of (A) ranging from 0.0157 to 0.0367 and of (n) from 0.70 to 0.93. In general the indications are that when (n) is low the coefficient (A) will be large. The value of (A) of 0.0178 for the axial duct was based on uniform air flow

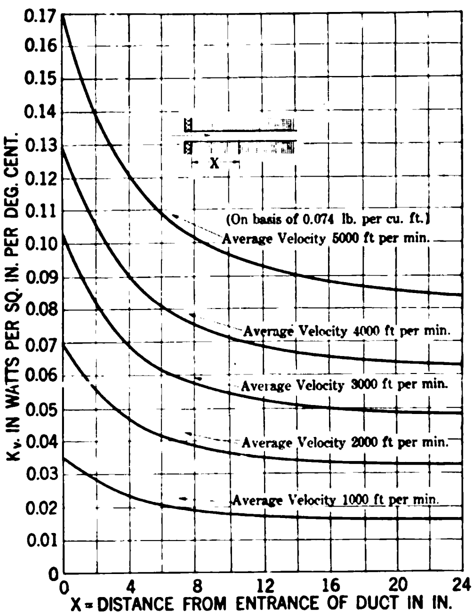

Fig. 18—Rate of Heat Loss from Surface of a Laminated Axial Duct at Various Velocities

These curves are for duct with square entrance as shown 1¼ in. diameter 39¼ in. long

which would exist in very long ducts. As shown in Test 4, Fig. 18, this constant may increase to about double this value for very short ducts. Test 3, Fig. 12, showed that for such short ducts where very turbulent air flow is obtained, the influence of friction upon (K_v) may be negligible. Test 2, Fig. 8, showed that radial ducts with diverging flow and changing cross section also gave irregular flow and hence high values for (K_v). With converging flow, however, the values of (K_v), Fig. 10, were much lower, even approaching

the minimum values found in Curve 1, Fig. 2. The rate of heat transfer (K_v) for Test 1, Fig. 5, with a rectangular duct of constant cross section is also low and indicates a rather uniform air flow.

A general summary of the variation in (K_v) is given on Fig. 23. It shows that the minimum value is given by the smooth 1¼-in. duct, Fig. 2, with regular flow. The maximum value of (K_v) is found in the radial duct, Fig. 8, with a diverging air flow. This curve is closely approached by axial ducts, with a 1- to 2-in. duct length.

(b) Test 4, Fig. 18, giving the variation in (K_v) at any point along the duct explains why many researches along this line have been inconsistent. The majority of these tests have been expressed in terms of a (K_v) averaged over the total duct length and since this length varied greatly (K_v) would also vary as shown by Fig. 18. This variable factor of duct length is in principle a check of Latzko's[7] analysis. His equations,

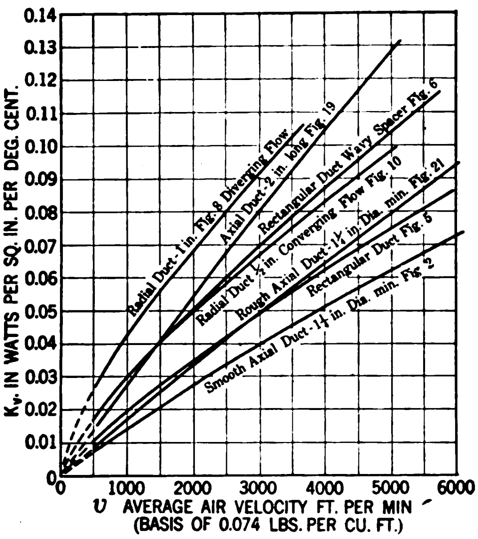

Fig. 23—Summary of Surface Heat Transfer Constant Against Average Air Velocity for Various Ducts

Average air temperature intake 25 deg. cent.
Average surface temperature 75 deg. cent.
Atmospheric pressure

however, do not agree in detail with the curves on Fig. 18. According to his calculations, based purely on hydrodynamical relations, the curves on Fig. 18 should reach their minimum value in a length from the entrance much less than shown.

(c) Over the range of temperatures used, 25 to 150 deg. cent., the rate of heat transfer (K_v) at a constant mass air flow decreases slightly with increasing temperature; its approximate relation is: (K_v) varies as $\sqrt{\frac{1}{T_{avg}}}$ where (T_{avg}) is the average. temperature Kelvin of the wall and air. This is in the direction indicated by Rice,[3] Royds, and Campbell,[11] but is opposite to that given by Nusselt,[1] Pohl,[6] and Jordan.[5]

(d) When air flows through ducts of constant cross-section and has reached a stable flow the heat transfer (K_v) will tend to increase with the coefficient of surface friction. When the air flow is irregular, due to conditions such as entrance or irregular cross-section, (K_v) will be large and may be practically unaffected by surface conditions. With the use of baffles the turbulency of the air can be greatly increased with an increase in rate of heat transfer (K_v). The increase in static air pressure drop, however, will be at a greater rate.

(e) A general analysis of surface heat flow constant for a wide range of fluids and gases has been made by Davis,[12] Rice,[3, 8] Nusselt,[1] Latzsko,[7] McAdams, Frost,[13] and many others. The equations, based upon the physical properties of fluids and upon frictional and hydrodynamical relations, were solved mainly by dimensional analysis. As a general solution, such work is valuable. For specific information regarding the heat transfer covering a definite fluid with definite conditions of flow, temperature, and the like, however, the above general solutions may be seriously in error. The workers listed above have shown that this rate of heat transfer is a function of the physical properties of the fluid such as density, specific heat, viscosity, velocity, thermal conductivity and also a function of the shape and principal dimension of the surface. The tests submitted by the writer have shown that this rate of heat transfer is also a function of the flow lines of the fluid and in this respect becomes a problem of more than a single dimension and at least involves a ratio of principal dimensions. To derive a general solution taking into account the hydrodynamical conditions in addition to the above physical properties seems visionary, at least as regards a practical solution. Thus, for specific information, which is desired by designing engineers of electric machines, experimental results such as submitted on Fig. 23 must be used.

It is also hoped that these specific tests may aid in forming a basis for a better general solution of this surface heat transfer problem covering, let us say, the more restricted field of gas flow which is of great importance in electrical industry.

The writer wishes to express his appreciation of the valuable assistance given in the performance of these tests by Messrs. L. W. Schad, R. R. Sirrs, J. H. Cone, C. G. Veinott, and E. Steinert.

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Some Graphical Solutions of A-C. Circuits
Founded Upon Non-Euclidian Geometry

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Associate, A. I. E. E.

Synopsis.—*1. A graphical method for the solution of alternating-current circuits is developed and discussed.*
2. The application of these transformations is shown graphically by numerous examples.
3. Certain characteristics of circuits are identified which greatly simplify the graphical solutions of circuits.

Introduction

The purpose of this paper is to show how, with the aid of simple functional transformations, it is possible to obtain a mental picture of the limitations, as well as the influence, of each factor in an a-c. circuit upon the resultant voltages and currents. Steinmetz first explained how the influence of the individual factors of a circuit may be computed with the aid of his complex operator. Arnold also indicates how they may be used for constructing loci diagrams. The usual representation of an electric circuit is by the impedance or the admittance diagram; these operate upon the current or voltage in question and also determine the relative phase relations and magnitudes of the voltages and currents in the circuit. The method of analysis now presented has the limitation of the admittance or impedance diagrams for its objective.

Fundamentally, this idea embraces the operation carried out upon a function instead of a particular value. The function has all particular values as special cases. Also, if the functional transformations are simple, the individual operations may be traced after each functional change has been made. In this particular discussion the functions are circles and each particular solution may be followed with great rapidity. The effect of each functional change may be seen and any alteration of each particular factor visualized under various circuit conditions.

The nature of these solutions all have circles for their functions, but the parts of the circle which are physically operative may be greatly attenuated by circuit limitations. Nevertheless, the circle, has a very well defined physical, and also a mathematical, relation to the circuit in question. Although the following transformations transform into similar figures, the circle, as will be seen, is a natural consequence in alternating circuit modifications. This operation upon a circle may take various forms; these are best understood when the equation of a circle is considered.

Operational Changes

The function for simplicity is taken as an impedance and is represented by Z. It may also, however, take the value of a voltage, a current, or an admittance, as conditions require. In Fig. 1, a circle of radius $|r|$ is shown.

The equation of this circle is $Z = |r| \epsilon^{j\theta}$. Every

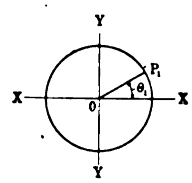

Fig. 1

point on this circle is uniquely defined; for example, $Z_1 = |r| \epsilon^{j\theta_1}$. The center of the circle coincides with the $X X$ and $Y Y$ axis. Certain operational changes may be made upon this function Z which will give rise to another function W; for example, a constant complex value $a = |a| \epsilon^{j\theta_a}$ may be added to every point upon the circle shown in Fig. 2.

$$W = Z + a$$

or

$$W = a + |r| \epsilon^{j\theta}. \tag{1}$$

From Fig. 2, it is seen that the diameter of W is the same but the center has been shifted for O to O'.

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Presented at the Annual Convention of the A. I. E. E., at White Sulphur Springs, W. Va., June 21-25, 1926.

Here it may also be seen that W is a more general expression for a circle.

Again consider the circle $Z = |r| \epsilon^{j\theta}$ but let it be multiplied by $\epsilon^{j\theta_1}$. The new function W now is

$$W = Z\,\epsilon^{j\theta_1} = |r|\,\epsilon^{j\theta} \times \epsilon^{j\theta_1} = |r|\,\epsilon^{j(\theta+\theta_1)}. \tag{2}$$

This is shown in Fig. 3, the circle has the same

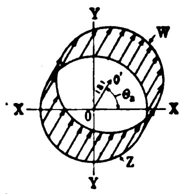

FIG. 2

radius as in Fig. 1, but the points have all been displaced by θ_1 deg.; or the circle has been rotated in a positive sense.

Had Z been multiplied by $|b|\,\epsilon^{j\theta_b}$,
as demonstrated by Fig. 4,
then

$$W = |r| \times |b|\,\epsilon^{j(\theta_b+\theta)}. \tag{3}$$

The original circle Z, having a radius $|r|$, will change

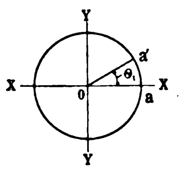

FIG. 3

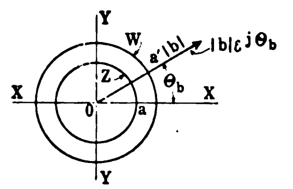

FIG. 4

into circle W, having a radius $|r| \times |b|$, or the product of the radii. The circle W would also be rotated with reference to Z by an angle of θ_b degrees. Point a will go into a', etc.

If a more general equation for a circle had been

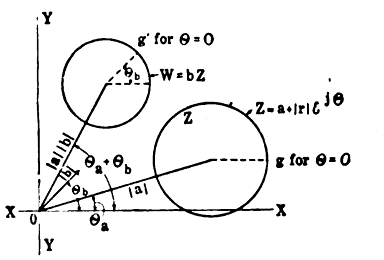

FIG. 5

considered, as $Z = a + |r|\,\epsilon^{j\theta}$, where a is a complex number, as shown in Fig. 5, and had Z been multiplied by $b = |b|\,\epsilon^{j\theta_b}$, the circle Z would have gone into

$$\begin{aligned} W = Z\,|b|\,\epsilon^{j\theta_b} &= [\,|a|\,\epsilon^{j\theta_a} + |r|\,\epsilon^{j\theta}\,]\,[\,|b|\,\epsilon^{j\theta_b}\,] \\ &= |a|\;|b|\,\epsilon^{j(\theta_a+\theta_b)} + |r|\,|b|\,\epsilon^{j(\theta+\theta_b)} \\ &= c + |r'|\,\epsilon^{j(\theta+\theta_b)}. \end{aligned} \tag{4}$$

Notice that the circle Z has been moved through an angle θ_b and has also been revolved about its center by θ_b. Its new radius $r' = |r| \times |b|$ and its new distance from the origin $c = |a| \times |b|$.

To define a circle, three factors are necessary after a transformation, viz., (a) the radius or diameter, (b) the distance and direction from the origin, and (c) the value of θ_b or its zero reference point.

Another equally important transformation is the

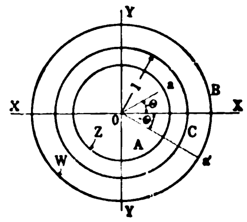

FIG. 6

reciprocal of a circle presented by Fig. 6. $Z = |r|\,\epsilon^{j\theta}$ is a circle about the origin.

Then

$$= \frac{1}{Z} = \frac{1}{|r|\,\epsilon^{j\theta}} = \left|\frac{1}{r}\right| \epsilon^{-j\theta}. \tag{5}$$

From this equation a new circle arises, having a radius $\left|\dfrac{1}{r}\right|$ with angles taken in the negative sense.

Circle Z will go into circle W and vice versa; point a would correspond to a', a circle inside of the unit circle will fall outside, and a circle outside will fall inside, upon inversion. The unit circle will invert into itself but the points on it will not coincide. Should, however, the center of the circle not coincide with the

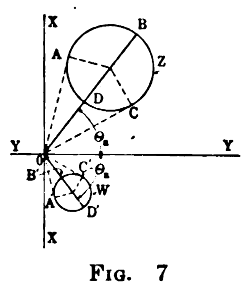

FIG. 7

origin, Fig. 7, then the inversion will also transform the circle into another circle.

Here

$$Z = |a|\,\epsilon^{j\theta_a} + |r|\,\epsilon^{j\theta}$$

$$W = \frac{1}{Z} = \frac{1}{a + |r|\,\epsilon^{j\theta}} = |a'|\,\epsilon^{-j\theta_a} + |r'|\,\epsilon^{j\theta^1} \tag{6}$$

θ and θ' bear no linear functional relationship. This transformation may be proved from similar triangles upon elemental portions of the two circles. The angles, however, do not transform uniformly as a

linear relation since the interval $A\,B\,C$ is compressed in the much smaller arc $A'\,B'\,C'$. Thus, if the circle were considered as a rubber band, this would mean that the band had shrunk and that the tension in the band was no longer uniform; *i. e.*, some points would be stretched and others compressed. The location of this circle is best determined from a line drawn through the center of circle $A\,B\,C\,D$ from the origin. After the transformation, this ray will also embrace the

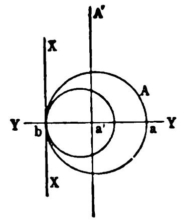

FIG. 8

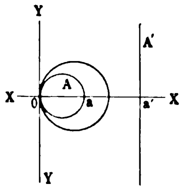

FIG. 9

diameter of the new circle. The angle θ_a will give the direction, since, after the transformation, the angle changes into $-\theta_a$. The radius of

$$W \text{ is } \frac{1}{2}\left[\frac{1}{|a|-|r|} - \frac{1}{|a|+|r|}\right] = \frac{r}{a^2-r^2}$$

$$= |r'| \qquad (7)$$

The distance of the center from the origin of W is

$$a' = \frac{1}{2}\left[\frac{1}{|a|-|r|} + \frac{1}{|a|+|r|}\right] = \frac{a}{a^2-r^2} \qquad (8)$$

It should be remembered that for every point on the circle Z there always will be a corresponding point

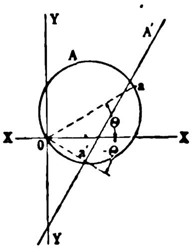

FIG. 10

upon the circle W, and that the points are continuous on the circle.

If the circle touches the origin, Fig. 8, and lies on the $X\,X$ axis, the reciprocal will be the straight line A'. Since point a will go into a' and b will go to infinity, the radius will be one-half of infinity; hence A' will be a circle of infinite radius, or a straight line.

Circles inside of the unit circle, Fig. 9, will go into straight lines outside of the unit circle, since the reciprocal of a is greater than unity. Also a circle outside of the unit circle will go into a straight line within the unit circle. All of these circles (Fig. 8 and Fig. 9) touch at the origin O, or have one point in common; hence after the transformation they again will have one point in common or the parallel straight lines will touch at one point, at infinity.

Other circles A, Fig. 10, located at an angle θ with respect to the origin, will transform as a reciprocal, into the straight line A'. The distance $o\,a' = \dfrac{1}{o\,a}$ is determined by the diameter $o\,a$. An interesting case of these transformations is shown in Fig. 11.

As before, circle A will go by inversion into the straight line A' and circle B into the line B'. Also the point of intersection between the two circles a will, after the transformations, have the point a' in common, or the intersection of the lines A' and B'. Since the circles intersect again at the origin the two straight lines will intersect again at infinity, from which it

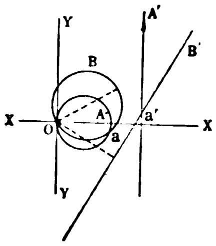

FIG. 11

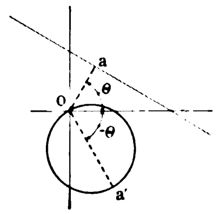

FIG. 12

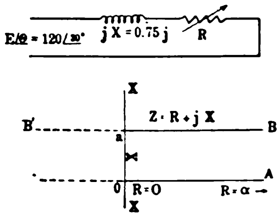

FIG. 13

follows that two straight lines intersect at two points and that the direction of infinity from the origin is not definite.

The converse of this is also true; a straight line by inversion will go into a circle represented in Fig. 12.

The reciprocal of the perpendicular distance $o\,a$ will determine the diameter $o\,a'$. The direction of the diameter is determined by the angle θ; therefore, the length $o\,a$ and its direction are immediately determined the circle locus.

APPLICATIONS

Consider the very familiar circuit of Fig. 13 which has a reactance X in series with a variable resistance R. The equation of the current in the circuit

$$I = \frac{E}{R + j\,X} = E\,.\,\frac{1}{R + j\,X} = E\,.\,\frac{1}{Z} \qquad (9)$$

where R ranges from O to infinity.

The locus of R is shown by the line $O\,A$, beginning at the origin and extending in a positive direction to the right; $Z = R + j\,X$ is shown by the line $a\,B$. This line $a\,B$ may be continued to the left; this would be a negative resistance and therefore not a physical part of the problem. The equation of I shows that Z occurs as a transformation in that it must be inverted

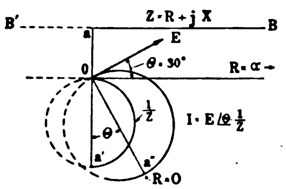

FIG. 14

(see equation **6**). It is very obvious that the inversion of the straight line $a\,B$ is a circle, Fig. 14, with a diameter $o\,a' = \dfrac{1}{o\,a}$.

The region shown by the full line corresponds to the portion of the straight line $a\,B$ and the dotted portion, to $a\,B'$ which latter portion has only an interest in carrying through the transformations.

This value of $1/Z$ must be multiplied by $E/\underline{\theta}$ which will give the locus of I. Thus the diameter of $1/Z$ is

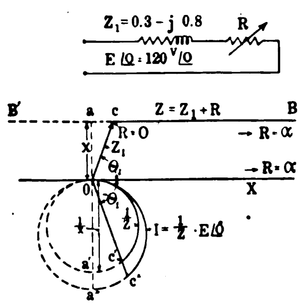

FIG. 15

changed and the circle is turned by θ degrees, as shown. This gives the resultant value of current and shows that a circuit in general which has a straight line as a function or a circle as a variable will lead to other circles, after transformations have been made.

The circuit as explained may be modified so that it is composed of an impedance in series with a resistance (Fig. 15), as, for example, a non-inductive load on a feeder circuit.

In this case, as before, draw $O\,X$, the locus of R, and to this locus add at every point Z_1; this is the impedance $Z_1 + R$.

Now $I = \dfrac{1}{Z_1 + R}\,E/\underline{0}$ from which it is seen that $Z_1 + R$ must be inverted. Extend the line $c\,B$ to B' and at the point a let it cut the $Y\,Y$ axis. The reciprocal of this inversion is the circle whose diameter is $O\,a^1$. The line only has physical significance from C on toward B. This corresponds to $R = 0$ at C, and $R = \infty$ at B. The point C upon inversion will determine the active part of the circle. Notice that C' on the circle has the same angle as Z_1 here in the negative sense and the range is from C^1 to O. This circle must be multiplied by $E/\underline{0}$ to obtain the current whose diameter is $O\,A''$ and whose limitations are again between the points C'' and O.

The voltage on the load is deduced from the relation E_L = load voltage $= E - I\,Z$. Instead of a particular current the loci circle I is multiplied by $-\,Z_1$ and then added to $E/\underline{0}$, as shown in Fig. 16.

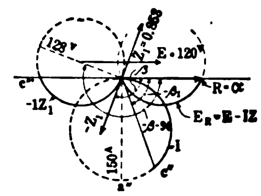

FIG. 16

From the foregoing it is seen that this method of analysis is applicable to all types of circuits which may be reduced to a simple equivalent circuit.

A further illustration is shown in Fig. 16A of a circuit similar to that of Fig. 15 in which the inductive reactance is equal to twice the resistance of the circuit. It is desired to reduce the short circuit current by one-half with added reactance from a choke coil and to compare the maximum current possibilities at various power factors.

The impedance vector Z_1 corresponds to the circuit before the reactance $a\,b$ has been added and Z_2 represents a distance numerically twice as long as Z_1. Draw a circle about Z_1 as a diameter and also one about Z_2 as a diameter. These circles are the loci of all minimum impedances possible with any desired power factor of load Z_L. Consider the general case, here represented as 50 per cent p. f. leading; the lines $o\,k$ and $o\,m$ are perpendicular to $a\,k$ and $b\,m$ respectively and represent the shortest resultant impedance of line and load.

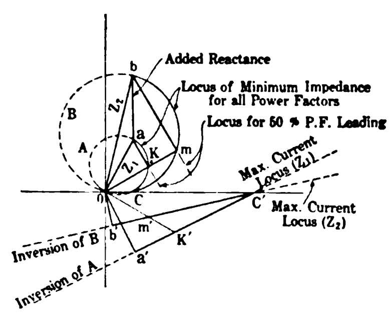

FIG. 16A

Before the reactance is added the current in the circuit is proportional to $\frac{1}{Z_1 + Z_L}$ and afterwards to $\frac{1}{Z_2 + Z_L}$ where, for example, Z_L is taken as a 50 per cent power factor locus.

It is evident that there is a short-circuit current for $Z_L = o$, but from the diagram it is seen that this may not be the maximum current possible in the circuit. For a definite range of power factors touching the circles between $a\ k\ c$ and $b\ m\ c$ maximum currents greater than the short circuit current are possible. The inversion of the circles A and B indicates the locus of these maximum currents which are the straight lines $a'\ c'$ and $b'\ c'$. These two lines intersect at c', corresponding to the intersection at c of the two circles which is the resonant point in both instances. For this point the

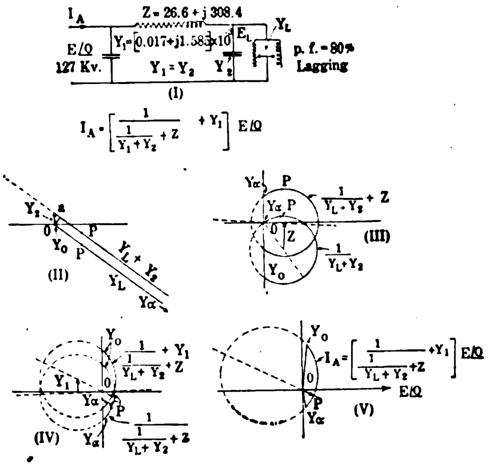

FIG. 17

ratio of the short-circuit currents corresponding to line impedance Z_1 and Z_2 is $\frac{o\ c'}{o\ c'} = 1$; for $Z_L = 0$ the ratio is $\frac{o\ b'}{o\ a'} = 0.5$; at 50 per cent power factor leading it is $\frac{o\ m'}{o\ k'} = 0.633$. Here again the dotted portions of the loci represent the mathematical possibilities and the full lines the physical limitations. The points c and c' are the same for any reactances which may have been added to Z_1; hence they may be called invariant points in the comparison.

Another example is the location of the generator current locus for a high-tension transmission line, in this case the 500-mile line published in the JOURNAL of the A. I. E. E. for September, 1924. Fig. 17 (I) shows the line reduced by the simple reduction formulas of Dr. Kennelly. It is loaded at a constant power factor of 80 per cent lagging current at the load. The equation of the current at the generator is

$$I = \left[\frac{1}{\frac{1}{Y_L + Y_2} + Z} + Y_1 \right] E\underline{/0}\,. \qquad (10)$$

The successive operations which are necessary are indicated in this equation. The variable Y_L is the load admittance; the other factors are constants which are indicated as per Fig. 17, (I). The graphical operations are accomplished in the order in which equation (1) is derived and are indicated as follows:

Y_L and $Y_L + Y_2$ [Fig. 17, (II)]

$\frac{1}{Y_L + Y_2}$ and $\frac{1}{Y_L + Y_2} + Z$ [Fig. 17, (III)]

$\frac{1}{\frac{1}{Y_L + Y_2} + Z}$ and $\frac{1}{\frac{1}{Y_L + Y_2} + Z} + Y_1$ [Fig. 17, (IV)]

$$I = E\underline{/0} \left[\frac{1}{\frac{1}{Y_L + Y_2} + Z} + Y_1 \right] \text{[Fig. 17, (V)]}$$

It will be seen from Fig. 17, (V) that the current is a minimum at P. In order to determine the exact value of load Y_L for this minimum current, this value of P may be traced through each transformation and is indicated by P on every locus.

From purely physical considerations of this circuit it is evident that the voltage at open circuit is the same, irrespective of the value of admittance Y_L as gradually decreased to zero. Also, the voltage at a short circuit is zero irrespective of how Y_L was increased to infinity. Hence there are two invariant points in this system common to any kind of loading, that for open circuit $Y_L = Y_0$, and that for short circuit $Y_L = Y_\infty$. All of the current loci will intersect at these two invariant points.

DISCRIMINANT LOCI

Certain loci may have something common with other loci which allow the rapid evaluation of a large number of loci by the use of this locus. A locus which can be used in this manner may be called a discriminant locus. For example, suppose it were desired to compute all the generator current loci for all power factors of loading Fig. (18) and of circuit Fig. 17 (I).

Here are shown various power factors of loading Y_a = 50 per cent leading, Y_b = 86 per cent leading, Y_c = 86 per cent lagging, and Y_d = 50 per cent lagging as illustrated. It would be, with the above simple method of current evaluation, rather tedious to carry through each evaluation as per Fig. 17. From Fig. 18 (II) it is seen that $Y_L + Y_2$ produces, for every power factor, a circle locus 123056; this circle has one point in common for every power factor in addition to the invariant points Y_0 and Y_∞; it is a discriminant locus. Now by treating this circle as a special type of

load and carrying it through as per Fig. (17) a locus of I is found, Fig. 18, III. All power factors, Y_a, Y_b, Y_c, and Y_d, have the points 5, 6, 2 and 3 respectively, on this circle. Since the current loci must also pass through Y_0 and Y_∞ in addition to a point on this locus, it is possible to draw a new circle through these three points, for example, point 2, Fig. 18 (IV), to determine the current locus at 86 per cent power factor. The small shaded area shows the change from 80 per cent power factor of Fig. 17 to 86 per cent power factor, or the range of generator current due to change of power factor at the load. The phase angle of the current I at the generator and the voltage $E\underline{/0}$ can be obtained directly from the diagram. Because all current loci have their centers in line $M N$, this line is also a discriminant locus. It can be seen from Fig. 18, (V), that a change of load power factor from 50 per cent to 80 per cent, leading, corresponding to loci Y_a and Y_b, produces a much greater change of current at the generator than a similar change from 50 per cent to 86 per cent lagging, or circles Y_c and Y_d.

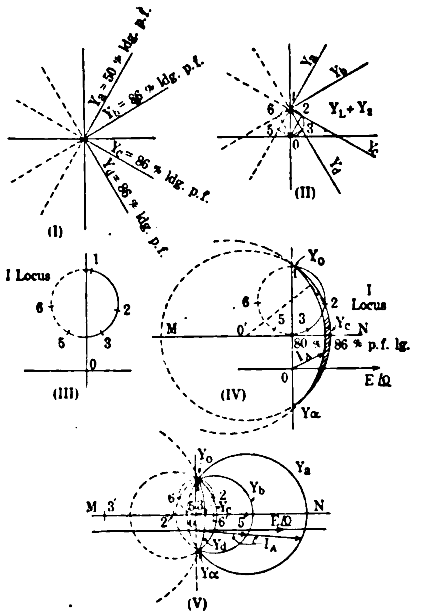

FIG. 18

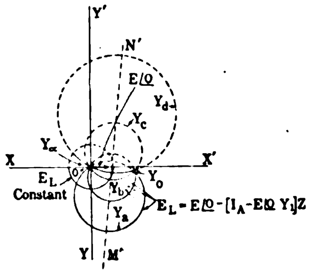

FIG. 19

In order to determine the voltage E_L at the load, the relation

$$E_L = E\underline{/0} - [\,I_A - E\underline{/0}\ Y_1\,]\,Z \qquad (10)$$

is used, and the transformations are followed as indicated in the equation, (see Fig. 19). All of the generator current loci of Fig. 18 (V) were operated upon as indicated in equation (**10**). The discriminant line $M N$ of Fig. 18 (V) transforms into the line $M' N'$ and allows a very rapid determination of the voltage at the load E_L. This diagram shows what values of Y_L must be chosen if the system is to have a constant voltage at the load end in conjunction with a constant voltage at the receiving end of a transmission line.

The well-known asynchronous machine can be graphically visualized with these transformations. The standard circuit of the induction machine is shown in Fig. 20 (I).

Remembering that the slip

$$s = \frac{\omega_1 - \omega_2}{\omega_1} \qquad (11)$$

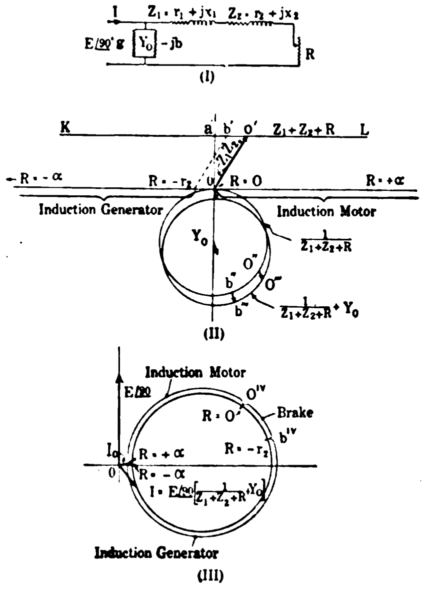

FIG. 20

in which ω_1 is the synchronous speed and ω_2 the speed of the rotor, in the equivalent circuit

$$s = \frac{r_2}{R + r_2} \qquad (12)$$

or

$$R = \left(\frac{r_2}{s}\right) - r_2 \qquad (13)$$

where r_2 is the rotor circuit resistance and R is the resistance equivalent to the mechanical load on the rotor.

The range of speed for the induction motor is

$$0 < \omega_2 < \omega_1$$

for which R varies from 0 to ∞ resistance.

The range of speed for the induction generator is

$$+ \infty > + \omega_2 > \omega_1$$

for which R varies from $- r_2$ to $- \infty$.

The range of the frequency converter or brake is

$$- \infty < \omega_2 < 0$$

for which R varies from $- r_2$ to 0.

Here the critical locus is R, which has all valuesfrom $+ \infty$ to $- \infty$ with singular points at O and $- r_2$ as shown in Fig. 20 (II). The effect of adding the primary and secondary impedance is shown in the line $K\,L$. Upon inversion the circle through the origin is realized and the points $R = + \infty$ and $R = - \infty$ are the same point at O.

The current delivered to or from this circuit is shown in Fig. 20, (III)

$$I = \left[\frac{1}{Z_1 + Z_2 + R} + Y_0 \right] E\underline{/90} .$$

The voltage is chosen at 90 deg. to make the diagram similar to the conventional representation of the Heyland diagram.

Further application of these methods to transformers, generators, filter circuits, vacuum tubes, etc., is obvious, once the view point is ascertained.

CONCLUSIONS

This analysis indicates how, with the aid of a few elementary transformation theorems, the operation of electric circuits, machinery, and vibrations of all kinds may be visualized and their limitations and possibilities discerned without the aid of extensive mathematical formulas.

It indicates a method for the computation of charts showing changes upon individual units comprising the system. It will show, for example, how a system may be operated with greatest efficiency or flexibility and what units added to this system will give best results.

The writer wishes to acknowledge the many kind suggestions of Dr. Whitehead and the careful comparisons of the proof by M. W. Pullen.

Standards for Measuring the Power Factor of Dielectrics at High Voltage and Low Frequency[1]

BY HARVEY L. CURTIS[2]

Fellow, A. I. E. E.

Synopsis.—*This paper points out the need which exists in the electrical industry, particularly in connection with the testing of high-voltage cables for convenient standards for use in the measurement of dielectric loss. At present most laboratories make use of air condensers. In the paper these are classified and certain sources of error which must be guarded against are mentioned. Condensers with solid dielectrics would be much more convenient, more portable, and cheaper, but so far none have been produced which have satisfactory constancy for use as standards at high voltage.*

In any kind of measurement the need of standards is not apparent until the importance of this kind of measurement becomes evident. For example, standards of resistance were not needed so long as men were interested only in electrostatics. It was only when current electricity became of importance that resistance standards were developed. Likewise, the recent realization by industry of the importance of measuring the power factor of dielectrics has raised the question as to whether or not suitable standards can be prepared and maintained.

At the present time practically all laboratories which make measurements of the power factor at high voltages use an air or gas condenser as a standard. It is assumed that there is a negligible loss in such a condenser. Descriptions of a number of these condensers have appeared in print.[3] Also a number of concerns, in response to a circular letter, have furnished the author with descriptions of the condensers which they are using.[4] Space does not permit a detailed description of all of these condensers. However, it is possible to classify them under certain general headings and thus indicate the important features of the condensers which are now being used.

In all of these condensers, great care has been exercised to so design the condensers that no corona will

1. Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

2. Senior Physicist, Bureau of Standards.

Presented at the Regional Meeting of District No. 1, of the A. I. E. E., Niagara Falls, N. Y., May 26-28, 1926.

3. Shanklin, *G. E. Review*, Vol. 19, 1916, p. 844. Whitehead & Isshiki, TRANS. A. I. E. E., Vol. 30, 1920, p. 1076. Atkinson, *Electric Jour.*, Vol. 22, 1925, p. 62. Rayner, *Jour. Sc. Instruments*, Vol. 3, 1925, p. 33. Dawes & Hoover, JOUR. A. I. E. E., April, 1926, p. 337.

4. The following firms have furnished unpublished descriptions:

American Steel & Wire Company.
Electrical Testing Laboratories.
Habirshaw Cable & Wire Corporation.
Safety Cable Company.
Simplex Wire & Cable Company.
Westinghouse Electric & Manufacturing Company.

occur at the highest voltages at which they are to be used. This requires that the spacing between the plates shall be adequate and that the edges of the plates shall be finished by a curved surface having at all points a large radius of curvature. If a large room is available, these conditions are not difficult to meet.

The condensers may be classified either in regard to the kind of dielectric or in regards to the shape of the electrodes. When classified in regard to the kind of dielectric, the condensers naturally fall into two classes, (1) condensers using air at normal pressure as a dielectric and (2) condensers using a compressed gas as a dielectric. As the dielectric strength of a gas increases approximately in the same ratio as the pressure of the gas, the plates of a compressed gas condenser can be placed relatively close together, decreasing greatly the size required for a given capacitance. With a pressure of only 10 atmospheres, the plate separation for any given voltage need be no greater than with an oil condenser for that voltage. Moreover, there are no data to show that there is any dielectric loss in a compressed gas. The advantages and disadvantages of a compressed gas condenser in comparison with one using air at atmospheric pressure is shown in the following statement furnished by Mr. R. W. Atkinson:

Advantages	Disadvantages
Compactness	Lack of adjustability
Portability	Necessity of maintaining pressure
Cheapness	Inaccessibility of electrodes
Constancy	Difficulty of designing a gas-tight, high-tension bushing
Complete shielding	

Air condensers for high voltage may also be put in two classes as regards the shape of electrodes, *i. e.*, those using flat plates and those using coaxial cylinders. Those using flat plates may again be divided into those having a single high-voltage plate and those having several high-voltage plates. When there is a single high-voltage plate, most laboratories use two low-voltage plates, one on either side of the high-voltage plate. This doubles the capacitance with an increase in the cost of only 50 per cent. Many laboratories use a guard plate to shield each of the low-voltage plates of the condenser.

In the condensers made of coaxial cylinders, two types are used; those having the high voltage on the inner cylinder and those having the high voltage on the outer cylinder. In either case guard rings are generally used at the ends of the low-voltage cylinder. If the low-voltage cylinder is outside, it is customary to surround the low-voltage plate by a metallic screen which is connected to the guard rings at the end, thus completely shielding the low-voltage plate. If the low-voltage plate is on the inside cylinder, the guards at the end of the cylinder form a complete shield for this plate.

Certain difficulties arise in the use of air condensers as standards for power-factor measurements. There is often some uncertainty concerning the loss in the leads which go to the air condenser as well as those which go to the specimen. In case a substitution method is used, care must be exercised to see that the loss in the leads is the same when the specimen is being measured as when the air condenser is substituted.

If the condenser does not have any guard plates, then it is important that all the lines of electrostatic force passing from one plate to the other shall go through air. Such condensers should be kept well away from the walls of the room, and the solid insulating material used to support the low-voltage plate must be so arranged that the loss in it is negligible.

In condensers using a guard, there is frequently a large capacitance between the guard and the shielded plate. If the guard plate is at every instant kept at the same potential as the shielded plate, then this large capacitance has no deleterious effect. However, in

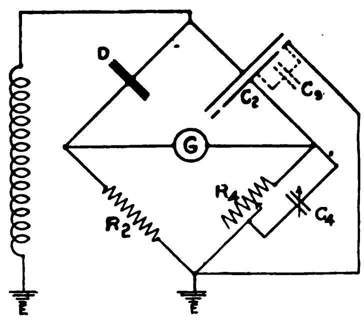

Fig. 1

very few of the published methods is any provision made for keeping the voltage of the guard plate the same as that of the shielded plate.

The effect of a slight difference of potential between the guard plate and low-voltage plate can easily be illustrated by reference to the Schering bridge.[5] This bridge, arranged for use with a guarded condenser, is shown in Fig. 1. The capacitance C_s between the shielded plate and the guard plate is in parallel with the measuring capacitance C_4. The power factor of the specimen D is given by the equation

$$\text{Power Factor} = 2\,\pi\,f\,R_4\,(C_4 + C_s)$$

Hence, if the value of C_s is omitted in computing the power factor, an error is introduced, the magnitude of which will depend on the relative values of C_4 and C_s. For a given sample, the error will increase as R_4 is increased. A rough estimate of the value of the capacitance C_s that may be expected in types of condensers now in use indicates that if R_4 is as much as 1000 ohms, the error would be of the order of 0.01 per cent in the power factor, whereas if R_4 is 10000 ohms the error would be of the order of 0.1 per cent.

All other methods of measuring power factor with a

5. See description by Everett S. Lee, Jour. A. I. E. E., Feb. 1925, p. 160.

guarded condenser are subject to errors of the same magnitude as those indicated for the Schering bridge. The current that flows through the capacitance from the shielded electrode to earth decreases the current through the measuring instrument. Unless special provision is made to insure that the guard electrode is at the same potential as the shielded electrode, the errors that may result in the power factor of the specimen under test may be quite as large with a guarded condenser as with an unguarded condenser.

The problem of making power-factor measurements would be considerably simplified if suitable condensers with solid dielectric were available. These condensers could be certified for power factor in a standardizing laboratory. In order to be suitable, such condensers must be small enough to be portable and should have a low power factor which is stable with time and which is nearly independent of voltage, frequency, and temperature. No condenser which fulfills these requirements at high voltages has been produced. A mica condenser serves admirably at low voltage, but as yet it has not been adapted to high voltage.

Paper condensers for use on voltages up to 3000 volts are now a commercial article. Some unpublished experiments performed at the Bureau of Standards indicate that their power factor may change with time. Hence such condensers cannot at present be considered suitable for standards.

Glass condensers have been used in some cases. While very stable, the loss with most kinds of glass is high and there is a large change with temperature. Such condensers are not suitable as standards. There are unpublished data indicating that glass having a much lower loss than ordinary glasses will soon be available. This offers interesting possibilities for use in standard condensers.

Clear-fused quartz, often called silica glass, has been suggested as a suitable dielectric for high-voltage condensers. It answers the requirements of stability and of low dielectric loss. However, the effect on the power factor of changes in voltage, frequency, and temperature has not yet been determined. Until a condenser of this type has been given a complete test, there will be no certainty that fused-quartz condensers will make satisfactory standards for power-factor measurements.

The situation today in regard to power-factor standards at high voltage in many ways resembles the voltage situation forty years ago. Then if one wished to measure a voltage he must himself set up a Daniell cell which he could use as a standard. Now, practically every voltage measurement depends directly or indirectly on values maintained at a standardizing laboratory. The change from the first condition to the second has taken place gradually as new methods of maintaining standards have been developed, and as standardizing laboratories have been able to convince industry that the standards which they furnish are reliable.

Now it is practically necessary for every laboratory that wishes to measure power factor at high voltage either to build an air condenser which is supposed to have zero power factor or to resort to difficult absolute measurements. However, if there is sufficient demand, standards will be developed and standardizing laboratories will put themselves in a position to certify to the value of the power factor under working conditions.

ESTABLISHMENT OF RADIO STANDARDS OF FREQUENCY BY THE USE OF A HARMONIC AMPLIFIER

Scientific Paper No. 530 of the Bureau of Standards, by C. B. Jolliffe and Grace Hazen, bears the above title, and describes a method for measuring the ratio of a radio to an audio-frequency by the use of a harmonic amplifier. The harmonic amplifier makes it possible to use harmonics of a very high order from a known low-frequency source, such as a standard tuning fork. The method consists essentially of the production of harmonics of the fundamental frequency of an alternating current by means of the nonlinear characteristics of electron tubes, the selection of any desired harmonic by means of tuned circuits, and its amplification to sufficient power to operate a standard frequency meter (wave meter). Any harmonic of the source may be selected, and thus from a known audio-frequency source a frequency meter may be standardized throughout its entire range.

The harmonic amplifier consists of two units, one having a range from 8 to 450 kc, the other from 400 to 4000 kc. The first unit supplies a harmonic which is used as the fundamental for the second unit. The harmonic amplifier is given a preliminary calibration, so that the harmonic multiples can be readily determined.

A fixed frequency generator, such as a piezo oscillator, may be standardized with the aid of an auxiliary device to determine the frequency of the beat note occurring between a harmonic of the amplifier and the fixed frequency. The device used for this purpose is a sonometer. It consists of a steel piano wire mounted horizontally across two movable knife-edges with a known tension applied. The beat-note frequency is applied to the wire through a telephone receiver. The wire vibrates when its frequency is equal to the applied frequency. The frequency of vibration may be computed from the length, tension, and mass per unit length of the wire. Two audio-frequencies may be compared very accurately by the use of the harmonic amplifier and sonometer.

Copies of the complete paper may be obtained from the Superintendent of Documents, Government Printing office, Washington, D. C.

Mercury Arc Rectifiers

BY D. C. PRINCE[1]
Fellow, A. I. E. E.

***Synopsis.**—Mercury rectifiers have been known for about twenty-four years, but until the last few years their principles of operation have not been understood with any certainty, and all are not yet conclusively proved. In the first part of this paper, the probable mechanism of the electron source or cathode spot is outlined, the source of the various losses is indicated, and the probable mechanism of arc back, that is, failure to rectify, is described.*

The second part of the paper is devoted to the principles of simple rectifier circuits, while the third shows a variety of rectifiers of different kinds and sizes.

THE mercury arc rectifier has been known for about twenty-four years, but, in spite of the length of time which has elapsed, there are a great many things about it which are not understood with any degree of certainty. A good deal has, however, been found out, especially in the last few years, and since interest in rectifiers is growing, it may be worth while to go over some of the principal features so as to get a general idea of the rectifier and its problems.

Fig. 1 represents a standard, 50-ampere, 100-volt mercury arc rectifier. This form is shown for purposes of explanation on account of its simplicity. It consists of an evacuated glass bulb containing, in this case, two main anodes composed of graphite located in the anode arms projecting at either side of the bulb; two

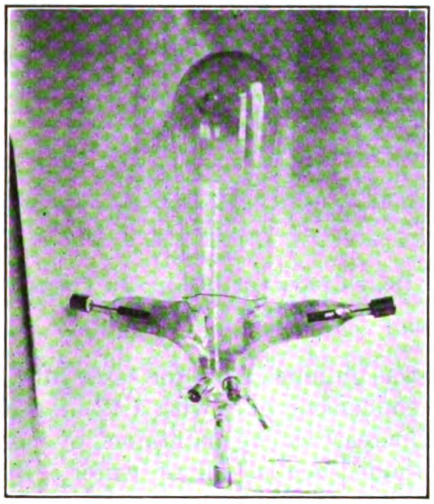

FIG. 1—50-AMPERE LOW-VOLTAGE RECTIFIER

auxiliary anodes also made of graphite lower down and on the front of the bulb; a starting anode made of mercury at the lower right; and a mercury cathode pool at the bottom.

The principle of operation in its barest essentials is similar to that of the vacuum tubes used in radio reception, with which most people are now familiar. In a vacuum tube a filament is heated until the electrons in it have so much energy that they are able to break through the metallic boundary into the surrounding space. If the anode (plate) is positive, these electrons are attracted toward it and current flows. If the anode is negative with respect to the filament, the electrons will be drawn back upon the filament and no current can flow. Rectifier or check-valve action is thus established, since current can be carried in one direction only. In the high-vacuum rectifier the electrons filling the space between anode and filament produce a charge known as the "space charge" which tends to drive the electrons back. This causes a loss which becomes very high if it is attempted to draw considerable current.

In the mercury rectifier in place of the filament we have a small, bright, dancing spot called the "cathode spot" which is the source of the electrons. Electrons are drawn from this spot to the anodes when they are positive just as in the high vacuum tube, but when the anodes are negative they do not constitute a source of electrons, so that no current can flow and rectification is obtained. There is some difference of opinion as to what occurs in this spot. The electrons proceeding from it strike neutral molecules of mercury vapor and ionize them; that is, one electron is removed from the molecule and the remainder of the molecule then has a positive charge. These positively charged molecules, called positive ions, are attracted toward the cathode, and, since they are quite heavy, their striking represents considerable energy and the spot where they strike is heated. There is thus some action analogous to the heating of a filament. In addition to this heating, the positive ions, being heavy, move slowly, and a large accumulation of them near the mercury surface produces a high potential gradient which tends to draw electrons from the mercury surface at a temperature lower than that at which they would be able to leave it if there were no such strongly attractive force. The electrons drawn out ionize new molecules which heat the surface of the mercury and draw electrons from it, so that the process once started is self-continuing provided the potential necessary to make the current flow is present. To start the spot in the first place, an arc is drawn by tilting the tube so that the mercury in the cathode makes contact with the mercury in the starting anode. The potential is impressed on the starting anode through a small resistance. When the tube is returned to the vertical position, this circuit is broken and the resulting arc initiates the cathode spot.

Measurements have been made of the current density in the cathode spot, and it is believed to be of the order

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1. Research Laboratory, General Electric Co., Schenectady, N. Y.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

of 26,000 amperes per sq. in. The heat due to bombardment of the positive ions evaporates a great deal of mercury. From this and other causes a pressure is built up at the cathode spot of the order of two atmospheres, although the vessel as a whole has been evacuated as perfectly as possible. The large glass bulb operates as a condenser to condense this jet of evaporated mercury. The high-pressure vapor is thus projected into a condenser where the pressure is of the order of 50 microns, that is, 5/100 of a millimeter.

The temperature of the cathode spot has not been definitely established. Some authorities give it as 2000 deg. cent., which would be the temperature required to produce the electron stream by heat alone. The actual temperature is probably much lower, although the amount has not been established. The potential drop required to maintain the cathode spot is approximately 10 volts. Approximately half of this 10 volts is consumed in latent heat of ionization of the mercury (work function 4.4 v.) and in the energy of the individual electrons as they escape from the pool. The remaining five volts appear as heat at the surface of the mercury pool, about half being used in evaporating mercury while the other half is conducted away through the liquid mercury in the pool. When the electrons combine with molecules, either on the walls of the vessel or at the anodes, the five volts represented by their energy are returned also as heat. Such electrons as combine with positive ions to form neutral molecules in the space give up some of their energy in the form of the greenish light so characteristic of the mercury arc rectifier.

About four or five amperes are required to maintain a stable cathode spot. For higher values of current the area of this spot increases, and above 40 amperes more than one spot may exist simultaneously. The spot, or spots, always move very rapidly from place to place due to the strong blast of mercury vapor and impinging positive ions. In order to make a rectifier operate down to zero load current, the auxiliary anodes are provided which draw a current of approximately five amperes so that the cathode spot is maintained in readiness even though the load is disconnected. These auxiliary anodes were not provided in some of the earlier rectifiers, but their provision facilitates many things and may be considered standard in future rectifiers both large and small.

The 10-volt cathode drop does not make up the entire loss. In the high-vacuum tube a drop is produced due to the presence of the electrons in the space. In the mercury arc this drop is eliminated by the presence of the positive ions. Whenever a drop tends to exist at any point, the electrons are accelerated until they are able to ionize neutral molecules. The resulting positive ions are of the opposite sign to the electrons so that the net space charge is reduced to approximately zero but does not disappear completely for some drop is necessary to replace ions lost by recombination and collection by the walls.

Fig. 2 shows the form of arc drop curve for a small rectifier. The two lower curves apply to a tube of the same general form as that shown. That is, it has short, straight arms. The lowest curve gives the arc drop characteristic of the bulb cooled only by natural air circulation. To determine whether the anode area is important, the current has been collected by one anode, or by two, and it is observed that the total drop is almost exactly the same in both cases. The characteristic drop reduces to a minimum at 10 amperes and then rises. Below 10 amperes, therefore, it has the nature of a negative resistance. In order to operate a mercury rectifier, it is, therefore, necessary to include an impedance sufficient to make the average impedance positive; otherwise the tendency would be for the current to rise indefinitely or fall until the arc was extinguished. The rise in the drop beyond 10 amperes is due to excessive vapor pressure produced by heat. The next higher curve which has its minimum at about

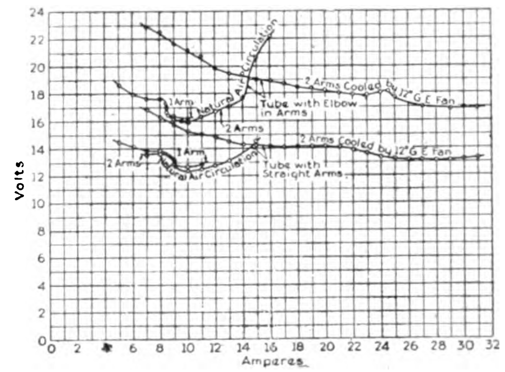

Fig. 2—Arc Drop Curves of 10-Ampere Tubes Taken with Direct Current

28 amperes was obtained from the same tube merely by cooling the condensing bulb with a 12-in. desk fan. A still greater increase can be maintained by more positive cooling methods such as oil or water. Beyond the minimum points, although the arc drop rises with increase in current, the response to instantaneous variations in current is still that of a negative resistance, so that even though rectifiers are operated beyond the point of minimum drop, two anodes still cannot be paralleled without some impedance to force a division of current.

The two higher curves on this figure are corresponding curves for a tube of the same size but having an elbow in the anode arm. Such a tube will be shown in a later figure. It appears that increasing the length of the path adds a nearly constant voltage drop. Since the drop in the rectifier is a function of current only, the capacity and efficiency are greater the higher the voltage used.

There is naturally a limit to the voltage that can be applied, and Fig. 3 shows the nature of this limit.

This figure shows what is known as the "arc back characteristic" of a 20-ampere glass rectifier with natural air circulation. It appears that for any current, there is a maximum voltage which the tube will rectify. Above this voltage one of the anodes becomes a cathode, so that the unidirectional conductivity of the device is lost.

Like the point of minimum arc drop, the current

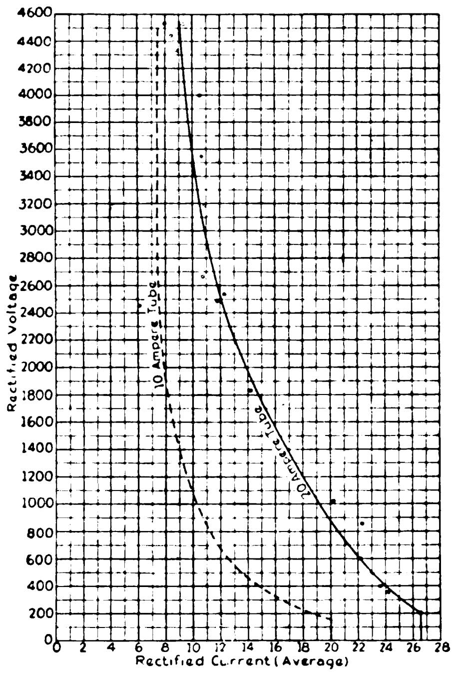

Fig. 3—Arc Back Curve for 20-Ampere Tubes with Bent Arms.

at which such a failure or arc back occurs can be increased by cooling. The probable mechanism is substantially as follows. When the anode is negative, some of the positive ions will be attracted toward it and will strike it with considerable velocity. Under normal conditions very few of these collisions will produce electrons from the anode. Some few will be drawn out, however, and these will proceed toward

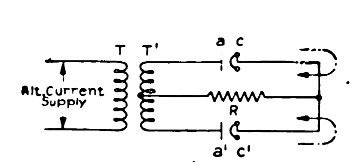

Fig. 4—Ideal Single-Phase, Full-Wave Rectifier Circuit

the cathode, ionizing further molecules as they go. The additional positive ions produced in the neighborhood of the anode will return toward it, and they also will produce a certain small number of electrons. The higher the negative voltage on the anode, the more of these electrons will be produced. The higher the vapor pressure, the more collisions each electron will make and the more positive ions they will produce. Thus a point is reached where, by increasing vapor pressure with temperature or by increasing voltage, so many electrons will be drawn from the anode that it will become a cathode and rectification ceases.

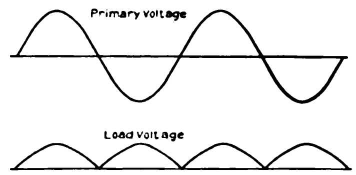

Fig. 5—Wave Shapes Obtained with Circuit of Fig. 4

This covers in a general way the principal phenomena of the rectifier. Under normal conditions it gives an almost perfect unidirectional action with a relatively small drop, so that in circuit determinations we may neglect all but the unidirectional effects.

Fig. 4 shows the most elementary rectifier circuit. Power is supplied from any alternating current source to transformer primary T. The secondary T' is connected at its terminals to anodes a and a'. In this case high-vacuum rectifiers are indicated. The cathodes c and c' are connected together and to the midpoint of transformer secondary T' through the load R.

Fig. 5 shows the primary voltage and voltage and current across load resistance R. During the half-cycle that anode a is positive, electrons flow from c to a; that is, current in the usual sense flows from a to c and returns through R in the direction shown by the arrow.

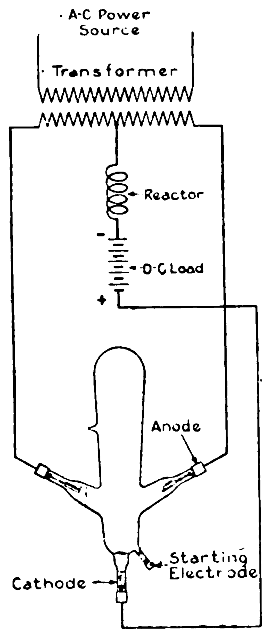

Fig. 6—Mercury Arc Rectifier Circuit with Smoothing Inductance in Output Circuit

During the other half-cycle, a' is positive and current flows from a' to c' and returns through R in the direction shown by the arrow, that is, during both of these half-cycles, current has flowed in the same direction

through R and rectification has been obtained. Since there is no other form of impedance present, the current through R and the voltage drop across R are both sinusoidal in form, but, due to the rectifier action, both half-waves are in the same direction. There would be no object in supplying rectified current to a resistance,

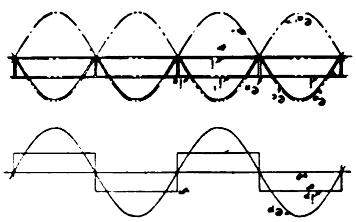

FIG. 7—PRIMARY AND SECONDARY VOLTAGES AND CURRENTS OF THE RECTIFIER SHOWN IN FIG. 6

so these figures are primarily interesting to show the rectifier action in its simplest terms.

To remove the current pulsations, an inductance may be connected in series with the load. Fig. 6 shows a circuit similar to that of Fig. 4, but including such an inductance and also including a battery as load in place of the resistance. A mercury rectifier is shown instead of the high-vacuum, hot-cathode rectifier. The inductance prevents the current from falling to zero, so that the cathode spot is maintained. A mercury rectifier could not be used in the circuit shown in Fig. 4 because it allows the cathode current to fall to zero.

If this smoothing reactor has a large value of inductance so that the rectified current is held constant, the various waves have the form shown in Fig. 7. The sinusoidal primary voltage is impressed through the transformer on the two anodes a and a'. The cathode will assume a potential just enough less than the most positive anode to cause current to flow. The cathode potential is shown as trace e_c. This cathode potential is impressed upon the load circuit consisting of the storage battery and the reactor. Since the reactor maintains the current constant, there can be no variation in voltage across the battery. The entire voltage variation appears, therefore, across the reactor. The steady rectified current is shown at i_R. This current flows from whichever anode is positive for the moment. i and i' are, therefore, the respective anode currents. Neglecting transformer exciting currents, the transformer primary current must be of the same shape as the secondary. i_p is, therefore, the form of primary current obtained.

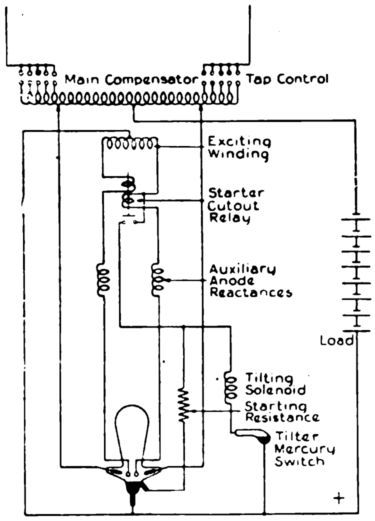

FIG. 8—WIRING DIAGRAM OF BATTERY-CHARGING RECTIFIER

For storage battery charging, it is not necessary to employ a steady direct current. If the mercury rectifier is equipped with auxiliary holding anodes supplied from a separate source, a battery charging equipment can be arranged as shown in Fig. 8. With this arrangement a small current of approximately five amperes is maintained by an auxiliary transformer winding. The battery to be charged is then connected between the midpoint of the main compensator winding and the rectifier cathode. Current will flow to charge the battery only while the anode voltages are higher than the battery counter-electromotive force. Between times, the cathode spot is maintained by the auxiliary winding through auxiliary anode reactors which serve both to maintain the current at a steady value and to limit that value. This diagram also shows the arrangements for automatic starting. A relay which is normally closed is connected with its holding coils in the two auxiliary anode leads. When voltage is thrown on the rectifier, current flows through the contacts of this relay to a tilting solenoid and mercury switch which set up a rocking motion in the tube. A circuit is also made to the starting anode through a resistance. As soon as the cathode spot has been formed, the relay opens the circuit to the starting mechanism, and the rectifier is then ready for business. It is kept in an active condition by the auxiliary anodes whether the load is connected or not, a very desirable state where an unknown battery which may be badly sulphated or even open circuited is to be charged.

FIG. 9—MERCURY ARC RECTIFIER SET FOR CHARGING BATTERIES OF INDUSTRIAL TRUCKS

Fig. 9 is a photograph of one of these rectifiers.

Fig. 10 is a diagram of a three-phase rectifier. The transformer windings T_1, T_2, and T_3 are connected in delta and supplied from a three-phase, alternating-

current source. The transformer secondary windings t_1, t_2, and t_3 are connected so as to form a Y. The outer ends of the Y are connected to anodes a_1, a_2, and a_3. The cathodes are connected through an inductance L, and the load R to the Y point of the transformer. Hot cathode rectifiers are indicated although no change would be involved in inserting a mercury rectifier.

Fig. 11 shows the wave forms obtained by this

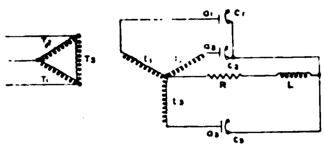

FIG. 10—CIRCUIT DIAGRAM OF THREE-PHASE RECTIFIER

arrangement. The three-phase or anode voltages are shown as e_1, e_2, and e_3. The cathode follows these in succession, always assuming a potential sufficiently below the more positive anode to cause the current to flow. The total current is maintained constant by the inductance L so that the drop across the load is the average cathode potential and is shown at E. Since the total current is constant as shown at I and current flows always to the more positive anode, the three anode currents are as shown in i_1'', i_2'', and i_3'', each one having full value of the rectified current for $\frac{1}{3}$ of a cycle. Since the transformer will not transform direct current, the transformer primary will carry only the alternating

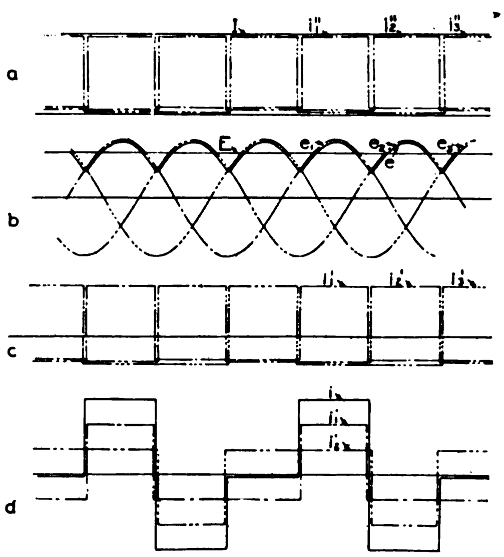

FIG. 11—PRIMARY AND SECONDARY VOLTAGES AND CURRENTS OF THE RECTIFIER SHOWN IN FIG. 10

component of these waves. These components are indicated as i_1', i_2', and i_3'. Combining these currents in pairs at the corners of the delta gives the three line currents i_1, i_2, and i_3. It is observed that both line and delta currents are not symmetrical. This indicates that with this connection there are even harmonics of current present. Even harmonics have an opposite phase rotation from the normal and so are still more objectionable than odd harmonics. Two three-phase rectifiers may be connected as shown in Fig. 12, however, to form a six-phase rectifier. With this arrangement, instead of providing two inductances L, a single compensator or

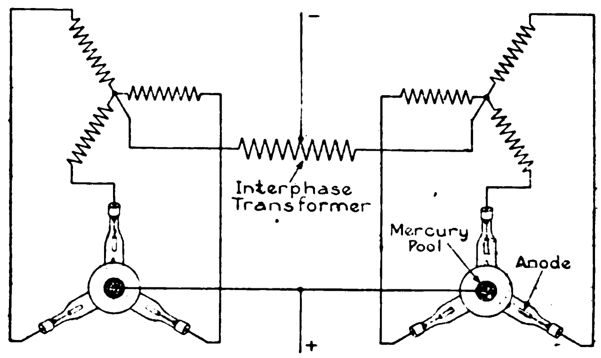

FIG. 12—DOUBLE THREE-PHASE RECTIFIER

"interphase transformer" can be used provided the two three-phase rectifiers are connected 180 deg. out of phase as shown. The resulting six-phase rectifier is the one which is usually used for power installations.

The foregoing wave diagrams are made on the assumption that there is no inductance in the alternating circuits. On this same assumption a mercury rectifier has a perfectly definite voltage ratio. If we have a rectifier of p phases, the cathode will follow the anode of one phase for the fraction of a cycle $\frac{2\pi}{p}$. Since the pulsations are absorbed by the inductance L, the direct voltage available is the average of a sine wave for this interval. By referring to Fig. 13, the average voltage may be obtained by integrating a cosine wave from $\frac{-\pi}{p}$ to $\frac{+\pi}{p}$. This gives a value for the direct-current voltage $G = \sqrt{2}\, E \frac{p}{\pi} \sin \frac{\pi}{p}$. This general expression gives the light load voltage for a rectifier of any number of phases. The rectifier in

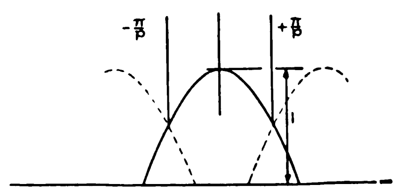

FIG. 13

Fig. 12 was made up of two three-phase units and therefore has an output voltage corresponding to three phases.

The perfectly square current waves shown in the current diagrams could only exist in an inductance less

circuit, since otherwise it would require infinite voltage to produce an instantaneous change of current. Actually, therefore, the current does not change instantaneously. Instead, when the point of the cycle is reached at which two anodes have the same potential, the current begins to shift from one to the other. Since this shift is brought about by a sinusoidal voltage difference between the two anodes, the changing component of

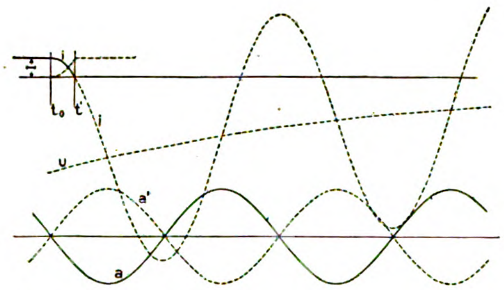

FIG. 14—GRAPHICAL REPRESENTATION OF CONDITION ARISING FROM THE SUPPOSITION THAT THE TRANSFORMER SHOWN IN FIG. 6 HAS LEAKAGE REACTANCE

current will be sinusoidal, and, if the primary impedance is nearly all inductive, as it usually is, the current will start to change just as though an alternating voltage were suddenly impressed on a circuit carrying a direct current. The condition is shown in Fig. 14. A steady current is maintained at a value I by the inductance L up to the time t_0, at which time there is no difference of potential between the anodes a and a'. At this point the current will begin to change as though it were going to follow the dotted curve i. This curve is exactly the curve that would be obtained in impressing a voltage on a circuit of inductance and small resistance; that is, it has an axis u which has the decrement factor $\epsilon^{\frac{-rt}{L}}$. The alternating component has a constant

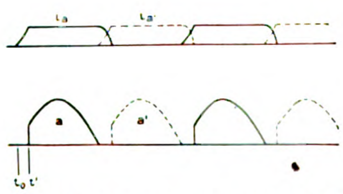

FIG. 15—OUTPUT CURRENT AND VOLTAGE WAVES, SHOWING EFFECT OF 26-DEG. PERIOD OF SHORT CIRCUIT DURING WHICH CURRENTS ARE TRANSFERRED AND NO VOLTAGE IS PRODUCED BY THE RECTIFIER

amplitude. Of course, this current cannot continue to flow, as by the time t', the current to the anode a has been reduced to zero, and it is prevented from reversing by the unidirectional conductivity of the rectifier tube. We are therefore interested in only a part of this transient curve which takes place between times t_0 and t'.

During the interval t_0 and t' during which current flows from two anodes, those two anodes must be at the same potential. The transformer secondary is thus in effect short circuited for this interval, and there is no output voltage. This relation is shown in Fig. 15. i_a and i_a' represent the anode currents. a and a' represent the corresponding anode voltages. The cathode now follows these lines, and it, therefore, has an

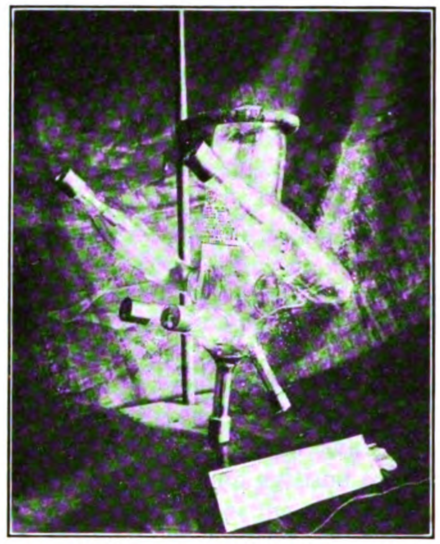

FIG. 16—10-AMPERE, 300-VOLT GLASS RECTIFIER

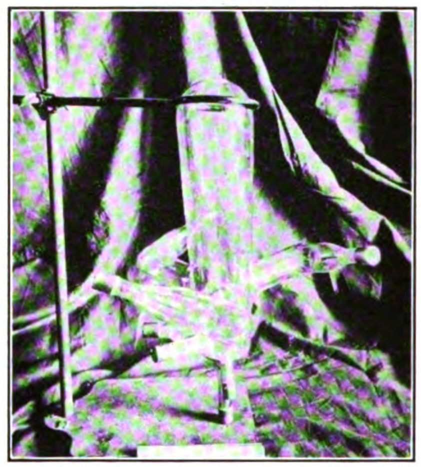

FIG. 17—THREE-PHASE, 20-AMPERE GLASS RECTIFIER

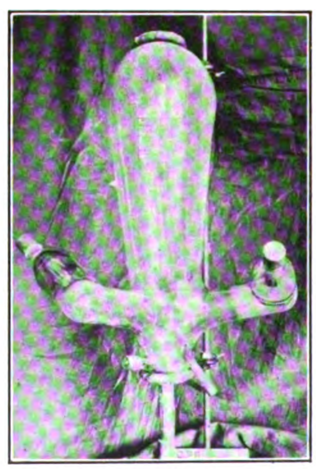

FIG. 18—50/100-AMPERE, THREE-PHASE RECTIFIER

average value somewhat less than in the case where no inductance is present.

This is the mechanism which acts for rectifier voltage regulation. Elaborate equations have been worked out to give the amount of this regulation, but they will not be dealt with at this time.

Leaving now the rectifier circuits, we shall review

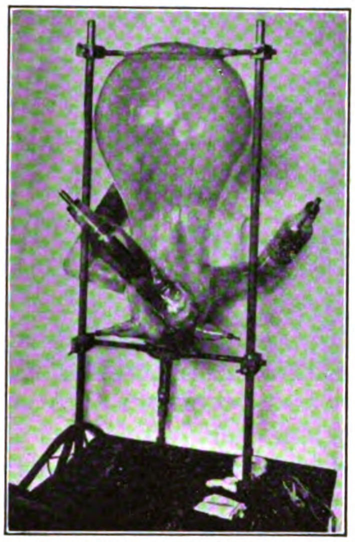

Fig. 19—250-Ampere Glass Rectifier

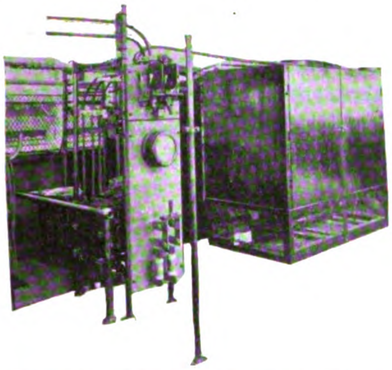

Fig. 20—100-Kw. Rectifier using Two 250-Ampere Tubes

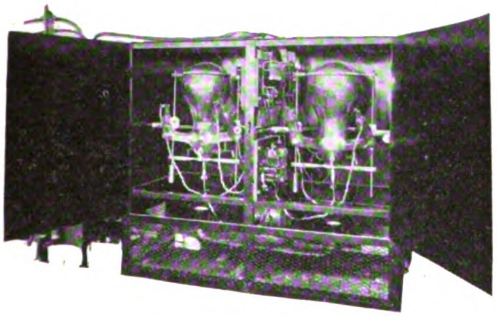

Fig. 21—Interior of a 100-Kw. Rectifier

some of the forms of rectifiers which have been made.

Fig. 16 shows the smallest mercury rectifier now made by the General Electric Company. This rectifier has a rating of 10 amperes and 300 volts. It has an overall height of approximately 8 in.

Fig. 17 shows a three-phase, 20-ampere glass rectifier.

Fig. 18 shows a 50/100-ampere, three-phase rectifier. This rectifier is approximately 30 in. high and is the largest glass rectifier made by the company before 1925. The two ratings given are one for natural air

Fig. 22—Early Iron Rectifier

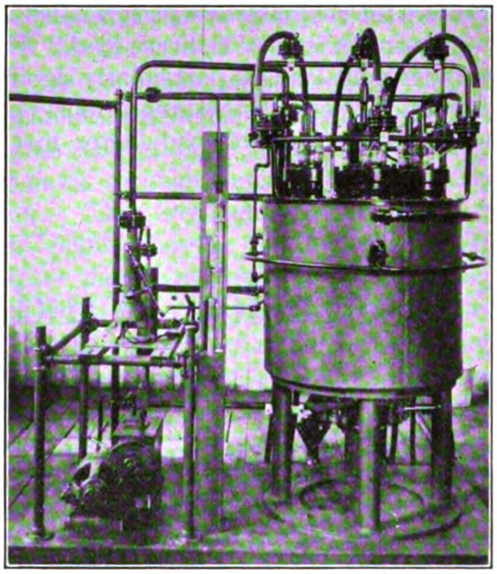

Fig. 23—Modern Iron Rectifier

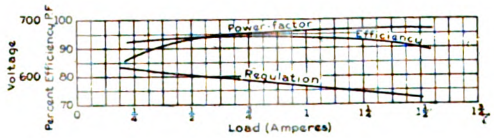

Fig. 24—Characteristic Curves of an Iron Rectifier

cooling and the other for fan cooling. The current ratings apply to approximately 220 volts and must be reduced somewhat if higher voltages are used. It is quite feasible to use voltages as high as 3000 for these tubes.

Fig. 19 shows the new 250-ampere glass rectifier

developed during the last year. The normal rating is 250 amperes, 250 volts fan cooling. One of this type was operated in oil at 200 amperes, 3000 volts and withstood repeated short circuits opened by a high-speed breaker.

Fig. 20 shows a 100-kw. rectifier now supplying a shop circuit in the Schenectady works. This rectifier employs two of the 250-ampere glass tubes. The interior of it is shown in Fig. 21. From the earliest days, attempts were made to make rectifiers of iron in large sizes. Fig. 22 shows one of these early rectifiers which was modeled quite closely in form after the glass rectifier. As iron is not subject to the same limitations as to form, later rectifiers have been made similar to Fig. 23, which is a photograph of the rectifier shown at the Atlantic City convention during the fall of 1925.

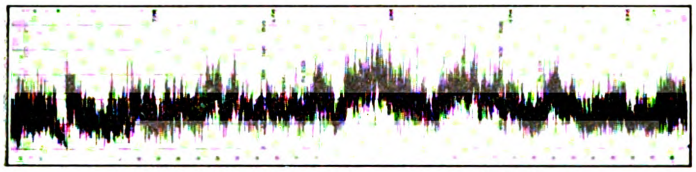

Fig. 25—Typical Street Railway Load

Fig. 24 shows the characterisitc performance of such a rectifier operating a street railway load. The high efficiency under light loads is particularly significant as the load factor of street railways is notoriously poor.

Fig. 25 shows the kind of load factor met in this service.

One objection to the iron type of rectifier as usually constructed is that some leakage always occurs with bolted joints, although the amount may be very small. For this reason, it is necessary to have a vacuum pump attached to the rectifier, although it need not be operated at all times. Attempts have been made to avoid the need for a vacuum pump by the use of seals fused directly to the metal parts. The rectifier shown in Fig. 23 has no clamped joints between metal and insulation, and, by the use of well fitted metal to metal joints, the danger of leakage is greatly reduced. It is possible to go still further and make rectifiers in which the sealing is complete. Fig. 26 is a small one of this kind which showed no indications of impaired vacuum three months after being evacuated and sealed.

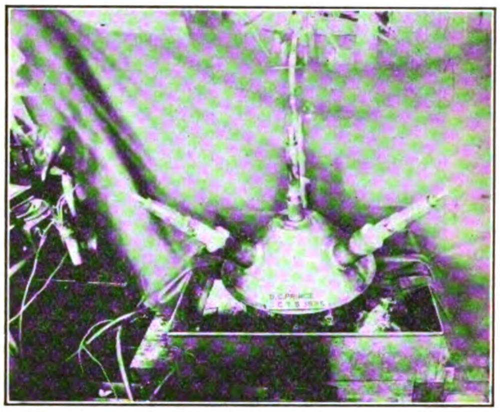

Fig. 26—Small Iron Rectifier with All Joints Welded

Multiplex Windings for D-C. Machines

BY CARL C. NELSON[1]

Enrolled Student

Synopsis.—*With the increase in capacity of d-c. machines, the question of their successful operation has become more and more important. It is thought that multiplex windings offer creditable advantages if they are designed so that cross connections can be suitably applied and the circuits thereby kept balanced, a feature which was not given thorough consideration when multiplex windings were first tried.*

This paper describes machines in which the proper design may be secured when standard construction is used. Both the lap and wave types of windings are considered. The principles are applied to duplex windings in this paper, but if so desired they may be applied also to triplex and other multiplex windings.

A brief description of "frog leg windings," a recently developed type of multiplex winding, is also given.

THE use of multiplex windings in large d-c. machines offers marked improvements provided the windings can have armature cross connections properly applied to them, so that the armature circuits can be kept balanced; that is, the currents in the circuits may be kept equal. This result has been successfully accomplished with multiplex windings on practical machines with the ordinary type of cross connections in a few cases (see references 6 and 7), and it seems probable that the same good results can be obtained in other cases.

Multiplex windings have, in general, more parallel paths and, consequently, less current per coil than the corresponding simplex windings which are usually used. Accordingly the current to be commutated is much smaller and therefore the amount of sparking is reduced. The fact that an increase in the number of parallel paths in an armature winding improves commutation, (other things being equal,) is exemplified by the

1. Massachusetts Institute of Technology.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

well-known case of an armature which is of such rating that either a wave or lap winding could be used. The latter is distinguished by more paths in parallel, more and narrower commutator bars and better commutation, as is well-known from practical experience. If, then, multiplex windings, having even more paths in parallel than the ordinary lap windings, can be safely used and kept properly balanced, another step in the improvement of commutation may be expected. The advantages to be obtained justify further study and trial of multiplex windings.

The windings used in practise at the present time are usually simplex wave, simplex lap, and, occasionally, an eight-pole, duplex wave winding. This is a very limited assortment.

A number of machines tried in the past with multiplex windings were not designed properly and armature cross connections could not be applied suitably. The desirable condition would be the interconnection of equipotential points in one individual part of a multiplex winding to equipotential points in another individual part of the multiplex winding, and so on. In this way all the individual parts would be joined together. In addition, the winding should be so arranged that the resulting potential distribution on the commutator would be uniform and the volts per bar would be of a low value. Arnold has advocated the use of cross connections and has shown triplex wave windings[2] with the cross connections joining equipotential points of the three individual parts of the winding, which is the desirable condition. In describing Fig. 12 (reference 7), it is stated that triplex lap windings have been made with efficient cross connections on one end of the armature and have operated successfully. Arnold, however, has not shown duplex lap and triplex lap windings with simple cross connections joining the individual parts of the winding together. In his early work he has shown duplex lap windings[3] so arranged that equipotential points in the same part of the duplex windings were joined, thereby giving a potential distribution on the commutator such that bars in pairs were at the same potential. This has the same effect as using half the number of bars and therefore is not desirable. In his later work, Arnold has shown duplex lap windings with equalizing rings[4] both on the front and back of the windings and with connections from the front to back joining these rings, thus interconnecting the individual parts of the duplex winding. This method introduces the complication of cross connections at both front and rear ends of the armature, and of connectors along the shaft. It would be more desirable to use the arrangement proposed in this paper, in which all the cross connections are at the rear end of the armature.

It is very desirable that multiplex windings be used where they are successful, since by means of them d-c. machines can be designed to have as many and as narrow commutator bars as possible. This results in a commutator bar in large machines from 3/16 to 3/8 in. in width, which is considerably narrower than many in use. The benefit of the smallest current per circuit as well as a corresponding improvement in commutation will thus be obtained.

A preliminary investigation as to the number of slots and bars and their relations in certain machines using multiplex windings has been made by the author in the Electrical Engineering Department of the Massachusetts Institute of Technology. It is his wish to duly acknowledge a number of valuable suggestions made by Professor H. B. Dwight of this department.

The windings used in the figures for purposes of illustration have been shown as applied to cores with extremely few slots and should therefore not be considered as actually, usable windings. This has been done so as to present clearly the principles which are to be applied to practical windings. The naming of the types of windings herein is similar to that used in the *Standard Handbook for Electrical Engineers.*

Multiplex windings were proposed in the early writings on d-c. machines, but little or nothing was said about cross connections. Where there are four or more parallel paths through the armature, these are usually necessary. The cross connections must be made between points having mathematically the same voltage, the flux being the same in all poles. This is provided for in the windings suggested in this paper.

The type of winding proposed is an ordinary multiplex winding so arranged that a system of cross connections, all at one end of the armature, can be conveniently applied to equipotential points, thereby joining to one another the individual parts of the winding[5] and producing a uniform distribution of potential on the commutator. These connections are shown on the diagrams of this article.

The shape of the coils of a duplex lap winding is the same as that of the coils for a simplex lap winding and no departure is made from the usual construction. All the coils for any one machine are of the same size and shape. The ends of the coils in a duplex lap winding are connected to bars 1, 3, 5, ... and so on to all the odd numbered bars. Another part of the winding placed in the slots connects to bars 2, 4, 6, ... and so on to all the even numbered bars. There are two cases to be considered. In Case I, when the total number of commutator bars is even, the two parts of the winding are separate and independent except as they

2. See p. 87, *Die Gliechstrommaschine Arnold—la Cour*, Third Edition, 1919, Julius Springer, Berlin.

3. See p. 177, *Die Gleichstrommaschine, Arnold*, Second Edition, 1906, Julius Springer, Berlin.

4. See p. 82, Same reference as 1, and Fig. 14, p.604, *Standard Handbook for Electrical Engineers*, Edition of 1922.

5. See p. 244, *The Dynamo*, C. C. Hawkins, Volume I, Sixth Edition, 1922, Sir Isaac Pitman & Sons, Ltd., London.

are joined by equipotential or cross connections. A two-part winding of this type is known as doubly re-entrant and will be referred to herein as such. It is represented by the four-pole diagram, Fig. 1, and by the symbol OO .

In Case II when the number of commutator bars is odd and the coil ends are connected to every other bar, the first part of the winding goes around the armature and leads into the second part of the winding, which, after going around the armature, connects to the first

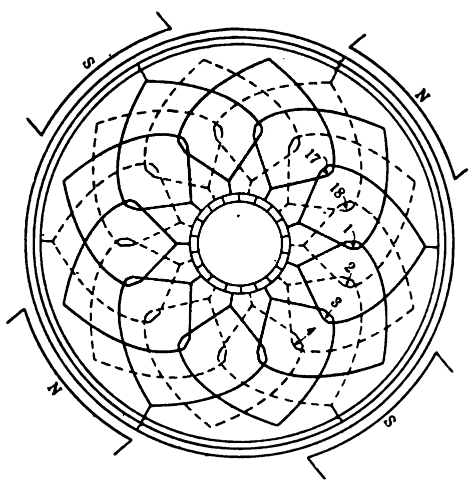

Fig. 1 (Case I)—Duplex Lap Winding, Double Re-entrant
Four poles, 18 slots, 18 bars, 8 paths. Cross connections as shown

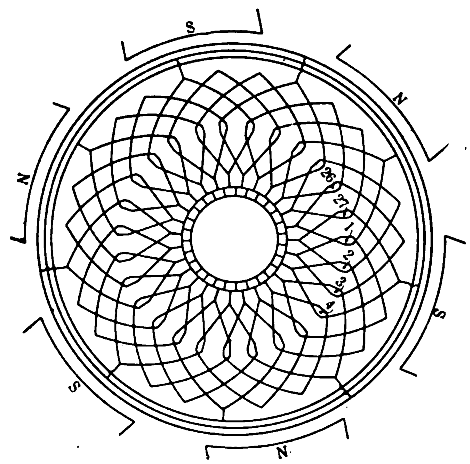

Fig. 2 (Case II)—Duplex Lap Winding, Singly Re-entrant
Six poles, 27 slots, 27 bars, 12 paths. Cross connections as shown

part, resulting in a continuous winding. This winding is referred to as singly re-entrant and is represented by the six-pole diagram, Fig. 2, and by the symbol .

The diagrams show the cross connections joining the two parts of the duplex lap winding, which is a desirable feature. The commutator potential is shown to progress fairly uniformly around the commutator, which is also desirable. To arrange the cross connections properly and to secure these results certain numbers of slots and bars must be used. The method of cross connecting,as shown, can be used with duplex lap windings on the following machines when the choice of slots and bars is made as indicated in Table A.

TABLE A
DUPLEX LAP WINDINGS

Number of Poles	Slots per Pair of Poles	Total No. Slots	Bars per Slot	Total No. Bars	Re-entrancy	
a. 4	Odd no.	Even no.	Odd no.	Even no.	Double	OO
b. 6	Odd no.	Odd no.	Odd no.	Odd no.	Single	
c. 8	Odd no.	Even no.	Odd no.	Even no.	Double	OO
d. 10	Odd no.	Odd no.	Odd no.	Odd no.	Single	
e. 12	Odd no.	Even no.	Odd no.	Even no.	Double	OO

There may be a cyclical change in the number of slots per path but this is quite possibly not harmful, for it occurs with two-circuit windings which operate successfully. The great improvement in commutating

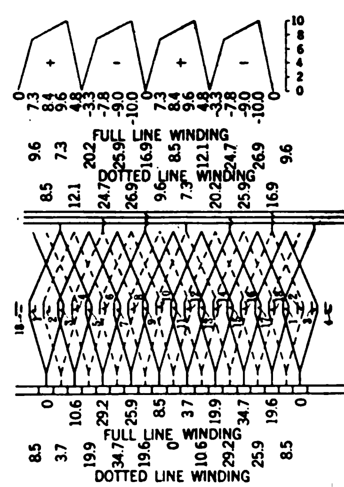

Fig. 3 (Case I)—Voltage Distribution Diagram for Duplex Lap Winding, Doubly Reentrant
Four poles, 18 slots, 18 bars, 8 paths, (same winding as Fig. 1)

characteristics obtained by having only half as much current per path to be reversed at one time would seem to be the important consideration in connection with this type of winding.

In determining the voltage distribution (see Fig. 3) the developed winding is laid out and a field form as might naturally be expected is plotted above the winding. As the voltage in a conductor is proportional to the flux it cuts, an excellent idea of the voltage distribution may be secured by summing up the voltages induced throughout the winding. In doing this, it is assumed that any conductor in a slot generates a voltage proportional to the flux directly above the center line of that slot.

Another type of winding is the duplex wave winding having four parallel paths through the armature. This type would give an intermediate step between the simplex wave and the simplex lap winding and although

the benefits to be derived from the use of this type are not expected to be as great as those obtained with the duplex lap winding, certain cases may justify the use of this type. An eight-pole, duplex wave winding is used rather extensively at the present time and has proven satisfactory. Such a winding with cross connections joining equipotential points of the individual parts of the duplex winding is advocated and shown by Arnold.[6]

Cross connections joining the two parts of a duplex wave winding are possible in certain cases. These connections should join points having mathematically the same voltage when all poles have an equal amount of flux. They can be used on the following machines when the choice of slots and bars is made as indicated in Table B.

TABLE B
DUPLEX WAVE WINDINGS

Number of Poles	Total No. Slots	Bars per Slot	Total No. Bars	Re-entrancy
f. 8	Even no.	Odd no.	Even no.	Single or double according to whether commutator pitch is odd or even.
g. 12	Even no.	Odd no.	Even no.	
h. 16	Even no.	Odd no.	Even no.	

Of course these windings must be such that the commutator pitch, Y, is a whole number where

$$Y = \frac{\text{number of bars} \pm 2}{\text{pairs of poles}}$$

The cross connections in the windings of the above table will span half the number of poles, or in other words, they are diametral. When the number of pairs of poles is odd, such as in the six- or ten-pole machine, cross connections to equipotential points diametrically opposite are not possible. This can be explained as follows: Suppose that the choice of slots is made so that a point of one part of a duplex winding has a certain position relative to a pole with one polarity; then a corresponding point in the other part of the duplex winding has a position under the influence of a pole of opposite polarity, a condition which does not lend to cross connections. It may be possible that six- and ten-pole, single re-entrant windings of the duplex wave type would be successful even though they do not have cross connections.

Triplex windings could be designed on the same basis as the duplex windings herein described, but only duplex windings have been treated in this paper, since they involve the least departure from simplex windings, and so should be the first to be tried out.

Since the preparation of this article was commenced, a very interesting paper[7] on *Frog Leg Windings* by W. H. Powell and G. M. Albrecht has appeared. This illustrates the general principles of using a multiplex wave winding in the same slots with a lap winding either simplex or multiplex to a less degree than the wave winding, so that both windings produce the same voltage at the brushes and are connected to the same set of commutator bars. The wave winding connects the circuits of the lap winding and the lap-wound coils connect the circuits of the wave winding thereby producing a thoroughly cross-connected winding. The name *frog leg* is used because of the peculiar shape of the coils which consist of a lap-wound coil and a wave-wound coil taped together. The advantages obtained by the authors are first, better cross connections, and second, the use of multiplex windings.

In Part III of the above described paper, a triplex winding with external cross connections as previously mentioned, and not of the frog leg type, is mentioned as having been made and operated successfully. If triplex windings, not of the frog leg type as referred to above, have been successful, then a duplex winding should also operate well when the choice of slots has been made properly and the cross connections applied efficiently as outlined herein.

It is possible that duplex lap windings with ordinary cross connections as shown will give some of the advantages of the frog leg winding without the complication of having two complete windings in the slots.

6. See p. 86, *Die Gleichstrommaschine Arnold—la Cour*, Third Edition, 1919, Julius Springer, Berlin.

7. P. 345, *Iron and Steel Engineer*, September 1925.

ELECTRIC WELDS FOR BUILDING CONSTRUCTION

A pressure machine capable of applying a load of 10,000,000 lb. was used at the Bureau of Standards in Washington to determine whether steel girders welded by electricity can stand stresses necessary in skyscraper construction. The welds made good. In order to make the test some steel plates were fabricated by electric welding into a plate girder 15 ft. long having a web plate ½ in. thick and 24 in. deep. The flanges were 12 in. wide, one was 1¾ in. thick and the other 1⅞ in. thick. A 9½-in. cover plate was used on the top and bottom flanges. Pressure was applied in the middle of a 13½-ft. span. The web buckled and the girder had deflected several inches before the electric welds connecting the web to the top flange failed at the ends. The welds withstood a load of well over 410 tons which was considered to be the full strength of the web.

NEW COPPER BEDS DISCOVERED IN CANADA

According to report received from the American Consul at St. John, Canada, comparatively high grade copper ore has been located from recent prospecting near Elgin, Albert County, New Brunswick, the preliminary examination covering an area of approximately two square miles. According to official assays the ore value runs as high as $15 per ton.

Shafts have been sunk over the prospected area and copper ore discovered in every instance, in most cases from within 16 inches of the surface and as far down as diggings were made.

Present Practises in Protection

Annual Report of Committee on Protective Devices*

E. C. STONE, Chairman

To the Board of Directors:

FOREWORD

Because of the many developments during the past few years within the scope of the Committee on Protective Devices, it was held desirable to present, this year, a survey of the present state of the art in the field of protective devices for power systems, and the following annual report has been prepared with this purpose in view. The Committee has also, during the past year, given careful attention to the possibilities of further standardization in the field of protective devices, and has certain definite recommendations to make.

As heretofore, the work has been carried on by subcommittees, each under the direction of its own chairman. The subjects covered and the chairmen in charge are as follows:

Automatic Substations. W. H. Millan, Union Elec. Lt. & Pwr. Co., St. Louis, Missouri.

Current Limiting Reactors. E. A. Hester, Duquesne Light Company, Pittsburgh, Pa.

Lightning Arresters. H. Halperin, Commonwealth Edison Co., Chicago, Illinois.

Oil Circuit Breakers. J. M. Oliver, Alabama Power Company, Birmingham, Alabama.

Protective Relays. J. A. Johnson, Niagara Falls Power Co., Niagara Falls, New York.

The Subcommittee on Grounding of Systems, which reported last year, was not continued this year, as it was felt that it had completed its work, for the time at least.

Following are some of the more important subjects dealt with in the report:

Full automatic stations of the following types are in successful operation:

Hydroelectric generating stations

Railway substations for city and heavy traction, as well as interurban service

Edison d-c. substations

Mining and steel mill substations

Alternating-current substations (reclosing breakers)

Synchronous condenser stations.

Mercury arc rectifiers for arc lighting and power service are now being provided with automatic switching equipment.

Thorough periodic inspection and maintenance are essential to the successful operation of automatic stations.

There is a marked trend toward the use of reactors with insulated conductors, in order to obtain protection from external interference.

Lightning protection on low-voltage circuits (230-115) in general appears to be unnecessary. For distribution circuits up to 6.6 kv., having numerous transformers connected, satisfactory protection is being obtained from available types of arresters in many cases.

On circuits rated at 73 kv. and below, the general tendency is to install arresters, usually of the high discharge rate type. The installation of arresters on circuits from 73 kv. to 154 kv. is debatable, but there is a growing tendency to provide some means to reduce over-voltages due to lightning. On circuits at 154 kv. and higher, the tendency is to omit lightning arresters.

The Dufour oscillograph and klydonograph for measuring transient phenomena are expected greatly to increase our knowledge of lightning arrester performance and requirements for lightning protection.

Relative interrupting capacity ratings for oil circuit breakers under various operating duties have been agreed upon by the N. E. L. A. and Electric Power Club, and are presented herein.

Progress in the problem of short circuit interruption is recorded in further short circuit tests on operating systems, additional testing facilities in manufacturer's plants, and improvement in details of design. The problem still remains one of outstanding importance, however, and seems far from satisfactory solution.

In relay practise, definite trends are reported as follows:

a. Integration of entire system into one unit, so interconnected and relayed that its integrity shall not be broken by a fault.

b. Fault isolation by use of balanced relay systems or systems responsive to location or specific nature of the fault.

c. Use of "back-up" protection, in the form of a second system of relays to function in case of failure of the first system.

d. Use of devices for detection of approaching faults before they actually occur.

The committee has given active attention to the obtaining of papers for Institute meetings. Reference is made herein to a number of important subjects which should be covered by papers next year.

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*Committee on Protective Devices:

E. C. Stone, Chairman
F. L. Hunt, Vice-Chairman

W. S. Edsall,	George S. Humphrey,	W. H. Millan,
H. Halperin,	J. Allen Johnson,	J. M. Oliver,
F. C. Hanker,	M. G. Lloyd,	N. L. Pollard,
S. E. M. Henderson,	H. C. Louis,	E. J. Rutan,
R. A. Hentz,	A. A. Meyer,	E. R. Stauffacher,
E. A. Hester,		H. R. Summerhayes.

Presented at the Annual Convention of the A. I. E. E., at White Sulphur Springs, W. Va., June 21-25, 1926.

Automatic Stations

Survey. A brief survey of the present status of the automatic station art seems desirable at this time. For convenience, this survey will be considered under several pertinent topical headings.

Automatic hydroelectric generating stations have been the subject of extensive development during the past three years. Stations containing two 9000-kv-a. units are now in successful operation, while many ranging from 100- to 5000-kv-a. are regularly being installed and operated. Automatic synchronizing has been perfected and is now used where large units are connected to small systems. Governor design has been improved to meet the rigid requirements of automatic station operation. In fact, practically all small hydroelectric developments and many moderate sized ones are now designed for automatic operation and uniformly successful results are reported.

Railway substations now being purchased are invariably automatic with rare exceptions due to local conditions. They are not only considered standard for interurban service but also standard for heavy city service and electrified portions of steam railroads. All kinds of service find them economical and reliable and their use is now being rapidly extended not only by the installation of new stations but also by the conversion of existing stations from manual to automatic operation.

Automatic substations for Edison, three-wire networks have now been in successful operation on small and moderate size systems for over four years. Their first application to two of the largest systems has just been completed. Their success for this class of service seems assured although more operating experience is desirable before extensive installations are made on important projects.

Mining substations now being purchased are all either completely or partially automatic as individual local conditions warrant. The various designs offered have been subjected to operating service for over five years. As a result the automatic substation is today considered standard by the electrical profession for the motor generators and synchronous converters used in the coal and metal mining industries for electricity supply.

Steel mills have been the latest industry to adopt automatic stations. One small installation of partially automatic-controlled synchronous motor-generators has been in successful operation over five years. Another extensive installation of completely automatically-controlled synchronous motor-generators has been in service almost two years. About eight additional extensive installations are now in progress so that it would seem as though steel mill electrical engineers have started toward adopting automatic stations as standard for their service.

Automatic feeders for alternating-current supply constitute by far the largest field for completely automatic operation. In practical application, the art is still in an initial state of development. The equipments so far offered have simulated manual practise with the only improvement of more prompt operation. Successful a-c. motor-operated mechanisms are now being applied to the largest oil circuit breakers thus eliminating solenoids and batteries for reclosing service. Automatic reclosing relay and oil circuit breaker combinations are now in operation which permit clearing transient feeder faults without appreciable service interruption. These so far, however, have been applied only to moderate sized, relatively low pressure service, although in one particular case 44,000-volt feeders are being automatically reclosed on a relatively large capacity power system.

Synchronous condensers for power factor correction were first made automatic about ten years ago. Only a few installations have been made but each has been uniformly successful and the use of this type of automatic switching equipment is spreading with a relative degree of rapidity.

Mercury arc rectifiers for arc lighting and power service are now being provided with automatic switching equipment. The smaller sizes with glass tube rectifiers have been in service a sufficient length of time to demonstrate their success. Those for larger units using metal tanks are just being placed in service so that next year's report may contain further data concerning their performance.

Railway signal and automatic train control substations are the latest addition to the rapidly growing list of automatic applications. Some of these have been in successful operation for over three years. Many are now being installed to furnish power for the operation of track signals and train control circuits.

Symbols. Symbols for automatic station wiring diagrams have been attracting increased attention during the past year. Data which will give the existing practise are being collected by the subcommittee. It is then planned to correlate the various symbols, adjust differences where they exist, and finally prepare a simple, agreeable set which may be submitted to the Standards Committee for approval and promulgation.

Nomenclature. Nomenclature for various types of a-c. reclosing feeders was suggested in the 1925 report. These suggestions have been before the electrical engineering public for about a year and no unfavorable comments have been heard or received by the committee. Instead, it has been found that many of the designers and purchasers of automatic d-c. feeders have adopted the proposed nomenclature. It has, therefore, been presented to the Standards Committee for approval and inclusion in the A. I. E. E. Standards.

Protection. Recommended protection for railway and Edison automatic stations with synchronous converters and synchronous motor generators, as well as for automatic switching equipment in a-c. feeder service, was given in the 1925 report. These recommen-

dations have been adopted as standard by the principal manufacturers and users of these classes of automatic stations. This year there have been developed recommendations for the protection of mining and steel mill automatic stations using synchronous converters and motor generators as well as synchronous condensers in voltage regulating substations and hydroelectric generating stations using synchronous generators.

Steel mill substations are quite generally provided with synchronous motor generators. Some are partial automatic as when an attendant is constantly on duty in the vicinity. Others are completely automatic as when the stations are non-attended and locked. The partial automatic stations are similar in design to the completely automatic ones except that certain protective and re-starting features are omitted. The items to be omitted vary from installation to installation so that it is difficult at this time to make any complete recommendation for the partial automatic. For this year's report, therefore, consideration will be given only to the completely automatic synchronous motor-generators in steel mill service. It is recommended that these be provided with protective features as follows:

A-c. undervoltage
Severe a-c. overload
Single-phase starting
Excess temperature due to sustained moderate overload
Imperfect start
Loss of field of a-c. machine
Loss of field of d-c. machine
Reversed phase rotation
D-c. reverse power
Excess bearing temperature
Machine overspeeding

Mine substations are usually equipped with synchronous motor-generators although some stations have synchronous converters and a few have induction motor generators, with mercury rectifiers beginning to be used. The recommended protection for synchronous motor-generators in mine substations is the same as that for synchronous motor-generators in steel mill service. Few induction motor-generators are now being applied and only two or three mercury rectifiers have been installed in mine service so that recommendations for these are omitted for the time being. For synchronous converters in mine service it is recommended that protection be given as follows:

A-c. undervoltage
Severe a-c. overload
Single-phase starting
Excess temperature due to sustained moderate overload
Imperfect start
Loss of field
D-c. overload
Incorrect polarity
D-c. reverse power
Excess bearing temperature
Overspeeding

The protection for automatic hydroelectric stations with synchronous generators and for synchronous condenser stations is quite similar. For synchronous generators in automatic stations, the recommended protection is as follows:

A-c. undervoltage
Severe a-c. overload
Excess temperature due to sustained moderate overload
Single-phase operation
Imperfect start
Loss of a-c. machine field
Exciter overvoltage
Excess bearing temperature
Machine overspeeding

Synchronous condensers usually have, in addition, a-c. undervoltage and single-phase starting protection. They are usually provided with automatic voltage regulators so that the exciter overvoltage protection included for synchronous generators is in that case omitted.

Storage Batteries. The majority of automatic stations are not provided with storage batteries. If they are automatic hydroelectric stations, a small turbine or waterwheel directly connected to a generator seems to be the preferred source of control power. If they are substations, then the source of power suitably transformed is used to supply the operating current.

Some designs of automatic stations, particularly those used for certain classes of Edison service and for all classes of remote supervision, require relatively small operating batteries. Practically all types of standard batteries have been used with an equal measure of success although some are better adapted than others for this service. In general, the batteries are trickle charged through rectifiers or motor generators. In a few unusual designs, a motor-generator is provided to carry the operating load with a battery floated on it for stand-by purposes.

Oil Circuit Breakers. Oil circuit breakers are used in automatic stations between incoming lines and the station equipment and between the station equipment and outgoing lines and feeders. The two applications require quite different treatment in the selection of the oil circuit breaker equipment if a maximum of reliability is obtained.

When used between the incoming line and the station equipment, the oil circuit breaker is closed each time the machine in the station is started and opened each time it is stopped. Usually such an oil circuit breaker is operated most frequently to make or break currents less than its normal continuous current carrying capacity. However, it may be required to operate from two to one hundred times each day depending upon the service conditions.

Oil circuit breakers used between the station equip-

ment and outgoing feeders are normally closed. They are opened usually only in case of trouble or to permit of circuit maintenance. These oil circuit breakers will consequently operate infrequently. Usually, however, when they do operate, they will be called upon to interrupt currents approximating their circuit interrupting capacity.

In the first case, a so called "one-shot" breaker suffices if its mechanical parts permit the required frequent operation. In the second case, the circuit interrupting capacity on successive interruptions is the more important function with the mechanical life of secondary consideration.

To meet the frequent operating requirements of the breaker located between the incoming line and the station equipment, there have been developed new designs of universal motor operating mechanisms. Some of these have been in service in excess of five years. They eliminate the difficulties experienced with the older type of operating mechanisms and give a very much improved automatic station equipment.

For improving the requirement of successive circuit interruption to clear feeder faults, various schemes have been approved and are being tried. Double tanks, slow release of gases, ventilating ducts, and explosion chambers are all in use with no marked preference conceded at this time.

Reclosing Cycle. The reclosing cycle used for oil circuit breakers which protect feeder service in automatic stations varies from application to application. In one extreme case, each time a feeder breaker opens, it is held open until closed from a central operating point; *i. e.*, it is closed under the supervision of an operator so that in case the trouble persists the operator can immediately report the difficulty to a central load dispatcher. At the other extreme is the application where an oil circuit breaker may reclose on a fault five or six times in rapid succession.

So far as is known by the committee, there are only two installations where the operation of the breakers is supervised after each automatic opening and only one installation where the breakers reclose five or six times in rapid succession on a circuit fault.[4] By far the majority of automatic reclosing feeders in alternating-current service are reclosed two, three, or four times on a fault before being locked out.

The reclosing cycle having three reclosures before lock out is almost universally standard. The time intervals, between reclosures, however, vary between relatively wide limits. One group of operators, which is rapidly growing, prefers to have the breakers reclose immediately after the first or initial circuit interruption. They want this time made as short as practicably consistent with positive relay and oil circuit breaker operation. The majority of operating companies, however, appear to be satisfied with a time interval ranging from five to twenty seconds between the time the breaker opens initially and the time of the first reclosure. Practically all classes of operators are content with automatic reclosing the second time from fifteen to thirty or forty seconds after the second circuit breaker opening. Those who use third and fourth reclosures appear to be satisfied with a time interval between the second and third and the third and fourth reclosures of about one minute each. There are some unusual conditions, however, where the time intervals between the first and second reclosure and the second and third reclosure are even longer, being as much as three minutes and five minutes respectively, but these are again unusual.

As a result, it is seen that there is a wide range of operating adjustments in the automatic reclosing of alternating current feeder circuits indicating that the art has not yet become stabilized.

Relays. Relays of many varieties form the primary basis on which successful operation of automatic stations depends. The devices have been the subject of much study, development and observation in automatic station practise. Relays are used not only for performing protective functions, but are also used for controlling operating sequence and as preventatives against avoidable damage to service and apparatus.

The early designs of automatic stations included relays which had been developed for use in manual stations. Gradually, however, most of these have been replaced by relays or their equivalents specially designed to meet the arduous service and strict regulation required for automatic station operation. However, not all of the relays or other similar devices employed in automatic stations today can be considered perfect. Service records indicate though, that as a result of relay development, automatic stations are today equally, if not more, reliable than the equivalent manual stations.

Inspection. Periodical inspection of automatic stations is essential to their successful operation. The frequency and extent of such inspection depends upon service requirements. Experience indicates that automatic stations provided with rotating machines and supplying important service should be inspected daily. Such inspection rarely requires over an hour in the station after the inspector has become proficient. For less important service, automatic stations with rotating machines may be inspected weekly while transformer stations with reclosing feeders only are inspected at even greater intervals. This class of inspection serves to detect any tendency for the devices in the station to change their adjustment or operating characteristics and prevents unnecessary service interruptions.

Inspection as thus outlined must not be confused with periodical maintenance. Quite different personnels are required for the two sets of functions although where the automatic stations are small the same staff may perform both duties.

Most of the systems having several or more automatic stations make it a rule for each inspector to file a

written report after each inspection of an automatic station. This report summarizes the work done in the station together with the observations which have been made. The reports differ from organization to organization depending upon local conditions. In general, however, these reports contain the time and date of the inspection, together with a list of devices inspected and comments on any device which requires attention. In some cases, the reports list the readings of the counting devices in the station and indicate the number of operations of the principal functions. Of course, reports are properly signed and dated and otherwise identified.

Maintenance. Periodical maintenance is equally as important as periodical inspection. The frequency of maintenance will depend upon the number of operations the automatic station is called upon to make. If only six or eight operations a day constitutes the cycle, thorough examination of the equipment with such cleaning of contacts and replacing of worn parts as is necessary ought to be made bi-monthly. If several hundred operations per day is the schedule, then weekly examination with such maintenance as is needed is generally recommended.

Maintenance reports are usually prepared on the moderate size and large systems which use automatic stations. Their form follows, in general, the inspection reports mentioned above, except that they may elaborate on the details of devices which require more than usual maintenance as well as list the renewal parts which are installed.

A clear distinction should be made between inspection and maintenance. One reviews, casually, the condition of each device or piece of apparatus in the automatic station. The other should be a minute inspection accompanied by such cleaning and adjusting and replacing of worn parts as the service may require. Every effort should be made not to confuse these two, and in many systems the distinction has been drawn so clearly that inspection is charged to the operating account while maintenance is charged to the usual maintenance account.

Records. Records of automatic station performance are quite necessary for their efficient adjustment and operation. These records may be divided into two classes as follows:

1. Records of device and functional performance.
2. Records of station performance.

Device and functional performance records are usually made chronological and recorded in a log book kept in the station. Here are listed the date and time of the visits of inspectors, maintainers, and others, with their observations and the adjustments and changes they may make from time to time in the station equipment. Brief summaries of the station log may be prepared and forwarded to a central supervisor from time to time and from these may be prepared condensed operating reports.

Station performance records are usually obtained automatically by curve drawing or recording instruments and meters. Sometimes the instruments and meters form a permanent part of the automatic station equipment. Ofttimes portable curve drawing instruments or meters are used at regular intervals to check service requirements and station operation. This portion of the automatic station art is just being developed and not many definite data are available as a result of service experience.

Fire Extinguishment. Automatic fire extinguishment in automatic stations has been considered by the committee for the past two years. Practically nothing has been done in automatic stations along this line. The art of automatic or even partial automatic fire extinguishment in manual stations is even now just in the experimental stage. The committee is watching all installations quite carefully and expects to report further progress next year.

Remote Supervision. Remote supervision of automatic stations is becoming more and more important. A number of systems are in the open market and some of the operating companies have manufactured their own systems. A general review of the situation was presented by Mr. Chester Lichtenberg under the auspices of the Protective Devices Committee at the Midwinter Convention in New York, February 1926, and reference is made to his paper for an up-to-date survey of the situation.

Telemetering. Telemetering is just now being developed particularly for automatic station service. There are about one-half dozen installations in partial or complete service, but this, too, is a new development in the art which will probably serve as the subject of further comments next year.

Ventilation. Ventilation of automatic stations forms a very important part of the design of these stations. In general, automatic stations are smaller than the equivalent manual stations. Therefore, a less volume of air is available for carrying off the heat generated in the station. This means that there must be larger openings provided for the air to enter and leave the station if the apparatus is to be maintained at a reasonable temperature. Very thorough studies of this subject are now being made by several members of the Institute and at least one member has promised to prepare a paper on this important topic for presentation to the Institute in the near future.

Other Topics. Other topics not yet studied by the automatic station subcommittee are as follows:

Nomenclature for types of automatic reclosing a-c. feeders.

Terminology for operations in automatic stations.

Protection against failure of cooling mediums.

Automatic warning of approach of apparatus failure.

Dielectric failure of oil where used as an insulating or cooling medium.

Loss of oil in transformers.

Current Limiting Reactors

A review of the status of current limiting reactors in the light and power industry during the past year reveals nothing revolutionary either in application or in manufacture and design. Preceding reports have indicated a general stabilization of both application and design practises and these tendencies have become even stronger. The practise of sectionalizing generating stations with reactors is on the increase and their use at other points on the system to localize faults and reduce short-circuit currents is becoming quite general.

The practise of insulating the coil conductors is increasing in popularity, and tests have been made which show the efficacy of this method of preventing trouble from external sources.

There is some activity in the development of oil immersed, steel enclosed reactors, and it is expected that the next year will show considerable progress. There has been one installation of this type of reactor operating successfully at 66,000 volts for some time.

The mechanical and electrical reliability of reactors seems to be quite definitely established in the minds of operating engineers. Cases of failure due to inherent weakness continue to occur but with such infrequency that they may be attributed to accidents of manufacture. It is felt that with reasonable care in installation and inspection for freedom from foreign objects the reactor may be counted among the most reliable of electrical equipment. Of the serious failures which have occurred recently the greater number may be attributed to the presence of something foreign to the reactor.

Out of a total of almost 5000 reactors installed during the past five years only thirty-seven failures have been reported and only a few of these could not be attributed to something other than defective design or manufacture. These results were reported by 43 operating companies. Of these 43, 11 reported that no reactors had been installed during the last five years.

In presenting last year's report the subcommittee made several recommendations of subjects requiring investigation.

The matter of thermal capacity and conductor cross-section continues to furnish material for discussion. Most operating companies appear to be specifying a thermal capacity of about five seconds and require a cross-section having the same carrying capacity as the cables to which the reactor is connected. This is a somewhat more liberal allowance than was usual some years ago where two seconds were allowed and a smaller cross-section used. It hardly seems logical to make the reactor the weakest link in the system and the longer time is the result of the more general use of the so called "back-up" protection.

The two-second idea seems to have grown out of the fact that this was the maximum allowable time for relay settings. Should the circuit breaker fail, then the reactor was as good a place as any for the short circuit to burn clear. Now, there is usually at least one back-up circuit breaker and in the case of extreme contingency the time may run well above two seconds.

Attention has been given to the matter of providing reactors with taps and it is the general opinion of the subcommittee that this is undesirable except in cases of extreme necessity. It is recognized that occasions will arise when there is no alternative, as for instance, in the balancing of feeders, but it is suggested that each case be made the subject of special treatment. The manufacturers are willing to supply such reactors on special order but are unwilling to attempt to make them a standard product on account of manufacturing difficulties. Finally there is the objection to having many dissimilar reactors on the system with resulting chances of confusion.

Under the subject of shielded reactors two general classifications may be made, first, those having each individual conductor insulated, and second, those which are oil immersed and totally enclosed.

The insulated conductor reactor has proven quite popular and effective and it is predicted that they will largely replace the bare type on new installations, especially in generating stations. The number of failures due to the presence of foreign material is very likely to show a marked reduction.

There is not a great amount of data available on oil-immersed, totally enclosed reactors although there are some in operation. In order that the status of this type of apparatus may be put before the industry it is hoped to present a paper during the coming year, covering operating experience and possibilities.

It has been suggested that your subcommittee consider the use of current-limiting reactors with static condensers to aid in smoothing out surges, to limit the fuse current, and to increase the capacity of the condenser. Your subcommittee feels that, since a reactor considered in this light becomes a part of a specific device, it should be studied by the committee under whose jurisdiction static condensers are placed. The function of this subcommittee is to study the reactor as an individual piece of apparatus and its effect on the system as a whole.

There has been much discussion in the past few years as to whether the use of reactors actually increases the duty on oil circuit breakers. In the light of recent developments and tendencies in practise it would appear that the duty is actually decreased rather than otherwise. The fact that the installation of reactors in a great number of cases makes it possible for the oil circuit breaker to interrupt the short circuit current is clear indication that the gain in smaller current over-balances the disadvantage of a possible higher recovery voltage.

There are still two schools on the question of the efficacy of resistance-shunted reactors. The one side contends that the resistance is quite effective in ab-

sorbing the surge voltage while the other maintains that it has no appreciable effect. There are some of both types in service and a few tests have been made, but thus far the results have not been very conclusive. It is hoped that with the assistance of the Dufour oscillograph and the klydonograph, described in another section of this report, some definite settlement of the question may be obtained. A paper covering operating experiences with the two types is also recommended.

Some trouble has been experienced because of circulating currents in two-winding reactors due to unbalance in windings. Consideration of this brought out the fact that it is purely a manufacturing problem and therefore the concern of the particular manufacturer and the user experiencing the difficulty.

The effect of reactors on nearby magnetic materials has been mentioned as a subject for investigation. Your subcommittee is of the opinion that this is a fairly definite thing and that it has been well taken care of by the manufacturers in the printed specifications covering each type of reactor. Special cases must be subject to special attention by the manufacturer.

The arrangement of single-phase reactors on three-phase circuits and the position of the reactor with relation to the oil circuit breaker is sometimes brought up for discussion. This, however, is so often subject to local conditions that no set rules can be laid down with reference to physical arrangement. Obviously, the reactor must be between the source of power and the circuit breaker whose duty is to be limited but this again is subject to a great many variable factors and no standard can be applied.

The problem of standardization in reactors is a rather difficult one as is obvious from the foregoing considerations. Something may possibly be done on thermal capacity and conductor cross-section and your subcommittee is now considering this with the manufacturers.

The wide variety of reactance values and current ratings now in use is rather astonishing and it is suggested that the succeeding subcommittee look into the possibility of reducing these to some standard basis. It would seem feasible to standardize certain sizes with respect to current, voltage, and reactance values, as has been done with other types of equipment.

In reviewing papers which have been presented during the past few years a few points were found to be rather incompletely covered. This suggests the desirability of a few additional papers and the following are recommended:

1. Status and Operating Experience on Oil Immersed Reactors.

2. Effect of Shunting Resistance in Reducing Surge Voltages.

3. Further Operating Experience with Insulated Conductor Reactors.

Lightning Arresters

General. In general, during the past year there have been no radical changes in the fundamental principles of lightning arrester design, and the efforts of manufacturers and operating companies have been directed mainly to increase in reliability of the arrester and economy in its use. One modification is the development by a manufacturer of a liquid type of arrester with an electrolyte, which is claimed to have a freezing temperature of about minus 48 deg. cent.; this development has been also accompanied by some changes in the construction of the arrester. Other recent developments have been more in the nature of increased ruggedness, additional refinements, and increased attention to special features imposed by operating conditions. The general tendency is to install arresters outdoors wherever possible.

For high-voltage networks, it has been found that the transient overvoltages which appear on the high-tension side of a transformer may also be induced on the low-tension side (and lines connected thereto) by means of electrostatic induction. This effect varies with the physical dimensions of the transformers, and there have been cases for transformers of large dimensions, that the induced voltage on the low tension side has been high as compared with normal overvoltages on that side; therefore, it appears that some consideration must be given to reducing such voltages.

Development and Practise. The A. I. E. E. Standards state that "a lightning arrester is a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration." In operation the device must shunt or divert the transient current in a sufficient amount so that the resulting rise in the voltage will not be above what the apparatus will withstand. Since maximum shunting occurs when the impedance of the circuit is zero, it is evident that the most effective protection during the transient over-voltage will be secured when the impedance of the arrester and its connections to the ground is minimum.

The earliest efforts in overvoltage protection consisted in providing air-gaps connected between line and ground and so arranged that when the transient voltage appeared, the gap would break down and practically connect the circuit directly to earth. Usually the arc through the arrester would not break until the generator voltage and resulting system voltage became quite low. Neglecting the effect of the voltage fluctuation, this might have been satisfactory on some of the small systems, especially some years ago when generators of high impedance were used; but with the larger systems which have generators with lower impedance, the arc would be maintained and furthermore there was the possibility of accompanying high voltages due to what was in effect an arcing ground. The operating difficulties were so great that later some impedance, usually resistance, was introduced in the connection to ground

in order to facilitate the breaking of the arc; but this reduced the efficiency of the arrester as a protective device.

The operation of systems with inadequate protection was found to be impractical on account of many interruptions of the service, and, as the art developed and the customer grew to place more and more dependence upon continuity of electric power supply, greater and greater efforts were exerted by the operating companies to eliminate interruptions and large voltage fluctuations. The persistance of this demand led to the development of arresters with characteristics which provided a comparatively free path for flow of surge current at voltages above the operating voltage, but which did not permit current in detrimental amounts to flow, except during overvoltage. This important characteristic has been described as an "electric valve action" and arresters of these characteristics are known as "valve type" arresters.

The earliest of these was the electrolytic arrester, which, after some modification made through service experience, had very good protection characteristics. It had certain mechanical disadvantages, such as the use of oil and the use of an electrolyte which froze, and made the arrester practically inoperative at very low temperatures. There was some expense to operating these arresters on account of the periodic maintenance and daily charging during the warm weather, and, if the arrester was remotely located, then the expense became considerable.

There is now almost a universal agreement that for a high degree of protection a lightning arrester should have a high discharge rate, a short dielectric spark lag, and the ability to interrupt the dynamic current. This is borne out by theoretical considerations which have been presented on several occasions and tests and operating data reported by manufacturing and operating companies.

According to Peek,[1] "an induced stroke of lightning may produce a voltage on an overhead line equal to about 100 kv. per foot of elevation of the wires above ground. In the average case, this factor has been found to be 30 kv. per foot." On the low voltage lines, the line insulation is a smaller portion of the probable usual voltage induced by lightning than it is for the high voltage lines, for instance, on a 220-kv. line without a ground wire, the ratio of the usual highest lightning voltage to the insulator spark over voltage is about 1.1 while the corresponding ratio for a similarly designed 70-kv. line would be over two and for still lower voltages, this ratio would become larger. Direct strokes of still greater severity may be expected occasionally.

The present practise is approximately as follows:

1. Low-Voltage Circuits. Due to the fact that on such systems lightning arresters are spaced rather closely, a high individual discharge rate is not as essential for low-voltage circuits as for high-voltage lines. A variety of arresters are being used with comparative success, and among other factors the simplicity of design is of considerable importance.

Experience on one system has shown that where the wires of low-voltage secondaries are placed directly under the wires of higher-voltage primaries, say rated at four kv. and the length of the secondaries are not, more than about 600 feet, it has been found unnecessary to place arresters on secondaries when the primary wires are well protected from lightning by means of arresters connected to them. In the experience on another system it has been found that secondaries under 1000 feet in length, whether under protected primaries or not, do not require arresters. Theoretically, there is some question as to the degree of protection offered to secondaries by protected overstrung primaries, but there is no doubt that the general practise of grounding one secondary wire affords effective protection to the secondary circuit. Where the length of the secondaries is longer and there are no wires above them to protect them, it has appeared necessary to put arresters on the secondaries in order to obtain protection from lightning.

2. High-Voltage Circuits (0.6 to 154 Kv.). On high-voltage circuits, the lightning arresters are usually spaced a great distance apart so that the individual arrester, to be of any value, should have a large discharge rate which limits to a few types the number of arresters suitable for this purpose. The general tendency is to install arresters on circuits rated at 73 kv. and less. The installation of arresters on circuits from 73 kv. to 154 kv. seems to be debatable, but there is a growing tendency among engineers to provide some means to diminish the over-voltages due to lightning. This is done by either the rearrangement of the phase wires into a horizontal configuration in order to diminish the value of the induced voltage from lightning, or by the use of the ground wires to further reduce the induced voltage, or both, and also by the use of lightning arresters in order to protect the apparatus and circuits.

3. Extra High-Voltage Lines. There is a tendency to omit lightning arresters from lines operating at 154 kv. and higher, the main argument being that the line insulation is able to withstand the induced over-voltages and the direct strokes of lightning cannot be handled effectively by existing arresters.

As no arrester will insure an absolute protection against a direct stroke of lightning, a certain amount of damage to existing equipment is to be expected, its amount being dependent upon the degree of protection provided by a given installation of arresters. The installation of arresters by operating companies has been shown by Roper, Atherton, and others to be warranted only on a basis of the improvement and reliability of service to the customer, as the cost of installing and operating an arrester is many times the revenue that would be lost by the operating companies during the time of interruptions.

1. Address by F. W. Peek, Jr., at meeting of N. E. L. A., Overhead Systems Committee, February 11, 1926, Kansas City, Missouri.

The degree of protection to be selected for each case depends primarily on the economic considerations, and the problem can be treated in a manner similar to that described in an article by A. L. Atherton.[2] As an example, the Commonwealth Edison Company has found for business and residential sections with a high density of load, that on its 4000-volt distribution system, there is slight advantage in having more than 135 arresters per square mile. The less expensive line types of arresters are used on the lower voltages, except on important installations where the larger station type is installed. Above 50 kv., only the station type arresters are used.

New Devices

The outstanding recent event in the field of lightning arresters has been the application in this country of two excellent tools for investigations, that is, the Dufour cathode ray oscillograph and the klydonograph.

The Dufour oscillograph, which is essentially a laboratory instrument, was constructed in Europe several years ago, but it was not used in this country until recently. It will make records of voltage or current transients of a very much shorter duration than is possible by the ordinary vibrating type of oscillograph. (For further details see Appendix 1.) In the work of the subcommittee in the past few years, the measurement of the voltage-time curve (see JOURNAL of A. I. E. E., June 1924, p. 575) was recommended as a basis of comparing various lightning arresters. Until recent time, there have been no facilities available to determine this curve experimentally, but now this can be done with the Dufour oscillograph. This apparatus also affords a means of determining the relative time lag of insulations which is also important in the study of lightning protection.

The klydonograph makes it possible to obtain records of transient voltages as they appear on the systems. It makes a record which gives a direct indication of the polarity and the approximate magnitude of the overvoltage and an approximate indication of the wave front of the surge. (Further details are given in Appendix II.)

Both of these devices will give more definite information as to the nature of the surges due to lightning and other sources, and also determine the effect of lightning arresters on reducing the surges.

Further Work

Some further work to be done is as follows:

1. Standardization of technique for using lightning generators for testing lightning arresters.
2. Determination of voltage-time characteristics of lightning arresters, including rate of discharge and the dielectric spark lag.
3. Statistical data of operating experience on high voltage lines, especially those ranging above about 73-kv., should be gathered and correlated for systems which have one or more of the following conditions that affect the amount of the over voltages due to lightning and the methods of coping with these voltages:

   a. Wires of a given line in a horizontal arrangement.

   b. Wires in other configurations.

   c. Lines with and without arresters.

   d. Line protected by ground wires (See Peek's[3] article.)

   e. Lines constructed so that corona acts as lightning arrester.[4]

Dufour Cathode-Ray Oscillograph

For the first time in the history of the art of lightning arrester protection it is possible to secure oscillograms showing the voltage, current, and time relations of an electrical transient which may occupy a time of 1/100,000,000 of a second or less. This achievement has been made possible through the application of the Dufour cathode-ray oscillograph[5] to the measurement of transient phenomena encountered in the art of lightning protection.

This oscillograph makes use of a beam of electrons moving at high velocities which produce a photographic impression by impinging directly on the photographic film located inside of the vacuum chamber. Since such a beam of electrons can be deflected by both electrical and magnetic fields, it is possible to take volt-ampere curves of any device operating on a transient by super-imposing on the electron stream two fields at right angles, one proportional to the current and the other proportional to the voltage. Such curves may be taken in a millionth of a second and give information on the operating characteristics of apparatus subjected to transients which has not been obtainable in the past.

If the volt-time or current-time curves are desired, it is necessary to supply time axis usually perpendicular to the direction of deflection of the transient. For very slow speeds this may be conveneintly done by the use of a moving film. For high speeds the moving film is impracticable because of the tremendous peripheral velocities involved; therefore, means are provided to move the electron stream at a uniform rate across the stationery photographic film. This is done by the use of a magnetic field whose change of intensity is suitably controlled. The upper limit of velocity, which is about ¾ miles per second, is reached because of the increasing difficulty in timing the unknown transient so as to get the record on the films while the spot moving at the ¾ miles per second rate is tra-

2. *Lightning Arrester Application from the Economics Standpoint*, A. L. Atherton, TRANS. A. I. E. E., 1924, page 581.

3. *Lightning and Other Transients on Transmission Lines*, F. W. Peek, Jr., JOURNAL A. I. E. E., August 1924, page 697.

4. *The Corona as Lightning Arrester*, J. B. Whitehead. JOURNAL A. I. E. E., October 1924, page 914.

5. *Studies of Time Lag of Needle Gaps*, K. B. McEachron and E. J. Wade, JOURNAL A. I. E. E., January 1926, page 46.

versing a film four in. by five in. in size. The timing accuracy obtained in usual operation is 50 microseconds.

For phenomena which takes place in 50 microseconds or less, the time scale must be greatly magnified, which is accomplished by the substitution of a high-frequency

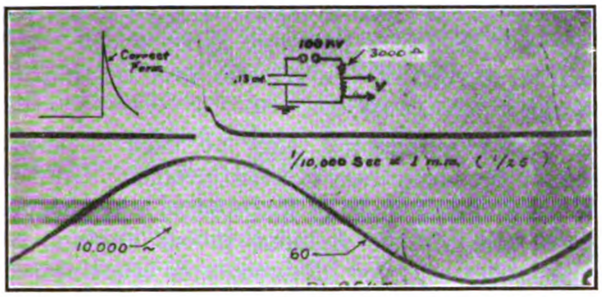

Fig. 1

field at right angles to the direction of deflection of the unknown transient. Thus the time taken to cross the film is determined by the frequency of the source and films have been taken using a frequency of 1,000,000 cycles, the time to cross the film being 1/2,000,000 of a second.

Frequently it is desirable to draw out the high frequency wave so as to render the results more intelligible, thus giving a zero line which may be many feet in length on the four in. by five in. film. This is accomplished by applying a uniform time motion perpendicular to the motion of the high frequency timing wave. The transient being studied also pro-

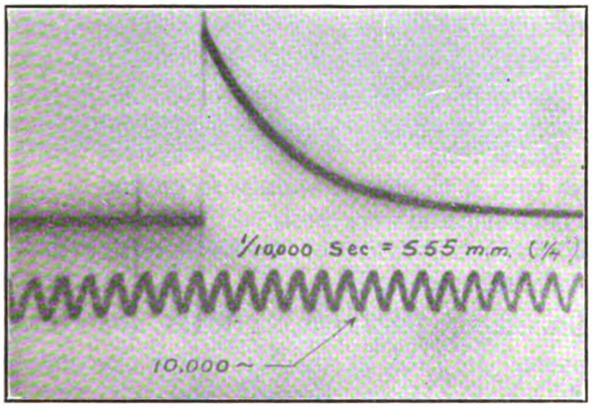

Fig. 2

duces its motion in the same direction as that of the uniform time motion but is usually very fast in comparison.

To show the use of this oscillograph of measuring transient phenomena, a series of films have been prepared of which four of the most typical films are shown here. A surge generator, similar to that used by Peek[6], was used to send current impulse of known characteristics through non-inductive resistance across a part of which were connected the leads of the oscillograph. With such an arrangement, the voltage impulse across the oscillograph leads will be exactly similar in shape to the current surge in the main circuit. The first two films were taken on the same wave front. The first film (Fig. 1) shows the limit of speed of the ordinary Duddell or Blondel oscillograph. The second film (Fig. 2) shows the cathode-ray oscillogram of the same transient and the same 10,000 cycle wave, the time being such that 1/10,000 of a second equals 5.5 mm. It should be noticed that no distortion ap-

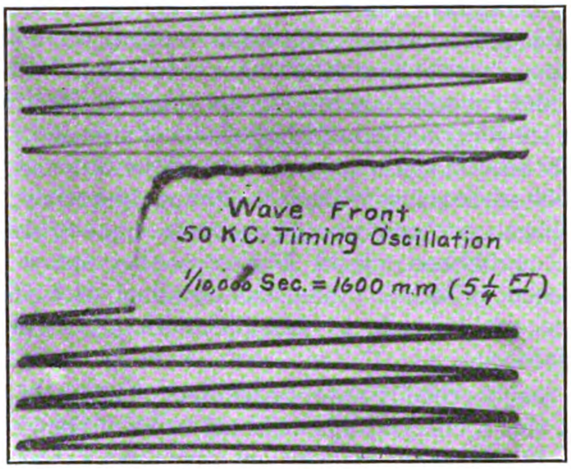

Fig. 3

pears in the transient voltage wave such as found in the first film due to inertia effect of the ordinary oscillograph.

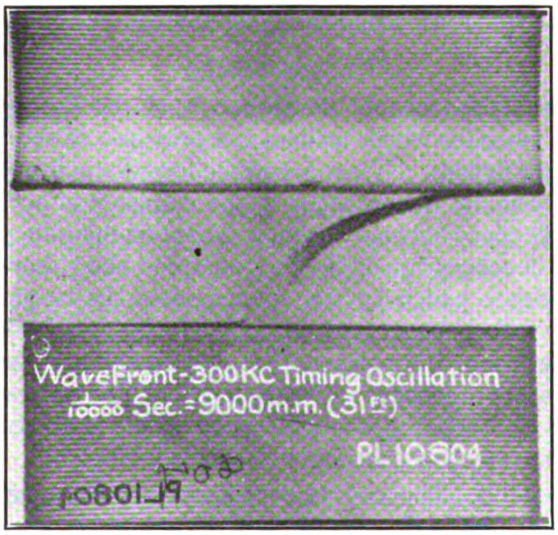

Fig. 4

The second group of films shows the use of the high-frequency timing wave and the uniform sweeping motion combined; they were taken on the same transient. The first of the group (Fig. 3) used the 50,000 cycle timing wave, which represents a multiplying

6. *The Effect of Transient Voltages on Dielectrics*, F. W. Peek, Jr., Trans. A. I. E. E., Vol. XXXIV, 1925, page 1857.

factor of 1600 compared with that of Fig. 2. When taking the oscillograms shown in Fig. 4, the timing frequency was increased to 300,000 cycles and now it is possible to get an accurate picture of the wave front itself. The transients shown on Figs. 3 and 4 can be replotted on rectangular co-ordinates to eliminate the distortion effect of the timing oscillation on the shape of the wave front; however, such error is usually so small that it is not necessary. It will be noticed that there are high-frequency oscillations on the wave front of the main impulse which are due to reflections in the connecting leads between the oscillograph and the impulse circuit. However, in order to measure these high-frequency oscillations on the wave front, a timing frequency of 1,000,000 cycles would be necessary and for such conditions, the time required to traverse the film once is but 1/2,000,000 of a second. The oscillations on the wave front are of the order of 100,000,000 cycles and with such timing frequency, it is possible to get some idea of the wave shape of some of these oscillations. With Dufour oscillograph a magnification of 30,000 times that obtained with the ordinary oscillograph is possible without disturbing inertia effects.

As may be readily appreciated, from a study of these films, this oscillograph is destined to be of tremendous value in the study of transient phenomena since it is now possible to depict accurately the operating characteristics of any device under the action of an impulse. Studies which are being made will lead to a determination of the characteristics of all kinds of protection equipment, will give information concerning the breakdown of insulation with very short times of application, and will determine the nature of the overvoltages which appear on transmission and distribution systems.

Klydonograph

The klydonograph[7] developed by J. F. Peters is a surge recorder which utilizes the principle of the Lichtenburg figures. When a voltage impulse is impressed on a terminal in contact with the emulsion of a photographic plate between it and a grounded metallic plate, upon development of the photographic plate there will be a figure which by its size indicates the magnitude of the voltage impressed and by its appearance indicates the nature of the voltage, that is, polarity and the approximate steepness of wave front. This instrument lends itself readily to application where a continuous graphic record of transient voltages is desired.

Uses. 1. The use to which the klydonograph is best adapted is the recording of surges on transmission lines. Since the range of voltages which may be applied directly to the klydonograph is from 2 kv. to 20 kv. in order to apply it to high voltage lines, a potentiometer, or multiplier, is necessary. This may be conveniently accomplished by taking the klydonograph potential from the middle plate of two suitably adjusted air condensers connected between the high tension conductor and ground.

2. A klydonograph connected as above to give the nature of the surge, and another connected to measure the voltage across a non-inductive resistance inserted in the ground lead of a lightning arrester will give the discharge current of the arrester and the nature of the surge which caused it.

3. The klydonograph may be used to measure indirectly the abruptness of a disturbance. To do this on a transmission line the instrument is connected to measure the voltage induced in an antenna loop. In the laboratory, the klydonograph is connected to measure the potentials across a non-inductive resistance and a concentrated inductance. From these the frequency of the disturbance may be calculated.

4. By the speed of propagation of the figures on the plate it is possible to measure time intervals of the order 10^{-8} of second. Thus it can be used to estimate the time lags of spark gaps, insulators, etc.

5. Finally, the klydonograph lends convenience to all measurements where heretofore spark gaps have been used. This is for the reason that the klydonograph will indicate the correct voltage with one trial, while a spark gap indicates only minimum values.

Results. 1. Extended field tests have added to information on the magnitudes of surges due to lightning switching, arcing ground, etc. On three 120- and 140-kv. systems, three direct strokes of more than 1,000 kv. crest value were recorded in one season. Induced lightning up to 650 kv. was recorded on a 140-kv. system and exceeding 400 kv. on a 66-kv. line. In general they were single impulses, and the few oscillatory records were highly damped. The latter were probably line oscillations. On a 120-kv. system switching surges with a maximum voltage to ground of 390 kv. were recorded, and were rarely oscillatory.

Fig. 5 shows a section of film taken during an actual test on a transmission line.

Oil Circuit Breakers, Switches, and Fuses

Papers. In 1918, at the Midwinter Convention of the A. I. E. E., Messrs. Hewlett, Mahoney, and Burnham presented a paper on *The Rating and Selection of Oil Circuit Breakers.* Since then much additional experience has been gained in the design and operation of oil circuit breakers. Factory and field tests have been conducted, methods of determining short-circuit current have received further attention, and new decrement curves have been prepared. Preparation of another paper bringing this information up-to-date is very desirable. The three larger manufacturers of oil circuit breakers have under consideration the preparation of such a paper and it is hoped that this paper will be available within the next year.

Standardization. Revised sections of the A. I. E. E.

7. *Klydonograph and Its Application to Surge Investigations,* J. H. Cox and J. W. Legg, Journal A. I. E. E., October 1925, page 1094.

Standards dealing with Oil Circuit Breakers (number 19) and Disconnecting and Horn Gap Switches (number 22) were adopted in June 1925 and are now available. The revised Standards cover these subjects more completely than ever.

As a result of its work during the present committee year, the Protective Devices Committee recommends the following additions to the above mentioned section of the Standards for Oil Circuit Breakers:

a. Rule No. 19-102. Add to present rule—"By rated voltage is meant the voltage from line to line as distinguished from line to neutral."

b. Rule No. 19-104. Add to present rule—"By normal voltage is meant line to line voltage as distinguished from to neutral."

c. In referring to interrupting capacity ratings, the term "arc amperes" is often used, and should be defined as—"The r. m. s. value of the current taken during the first half cycle of arc between contacts during the opening stroke."

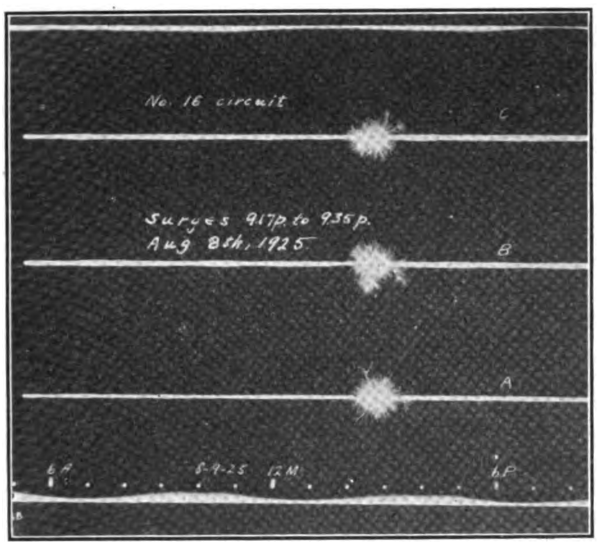

FIG. 5

Definitions of Normal (or Working) Voltage, Normal (or Working) Current, and Interrupting (or Recovery) Voltage should be adopted by the A. I. E. E. A tentative definition of Recovery Voltage, not approved by the Protective Devices Committee, is given here as a matter of interest:

Recovery Voltage is defined as the maximum peak value, measured from normal zero, of the voltage divided by $\sqrt{2}$ which may occur on the live side of the breaker after the interruption of the arc and before normal voltage conditions are restored.

Attention is called to the following typographical errors in the revised Standards, Sections 19 and 22:

19-63—use "Isolating" instead of "Isolated."

22-55—use "Disconnecting" instead of "Disconnection."

22-59—second line—incorrect reference to "oil circuit breaker."

22-155—second line—incorrect reference to "oil circuit breaker."

Future revisions of the A. I. E. E. Standards should take into account the factors which determine the interrupting duty which may be imposed upon oil circuit breakers. No reference to these factors, or so called "Prescribed Conditions," is made in the revised Standards; however, the available fund of information upon this subject is limited and much further study will be necessary before definite recommendations can be agreed upon. Factory and field tests should materially assist in clearing up this matter. Particular attention is called to a paper by Mr. E. C. Stone on *The Oil Circuit Breaker Situation from an Operator's View Point*, presented at the Annual Convention of the A. I. E. E. at Saratoga Springs in June 1925 (see A. I. E. E. JOURNAL, July 1925, page 756). In this paper some of the factors affecting current to be interrupted and recovery voltage are set forth and discussed.

Standardization of interrupting ratings has progressed to the point where definite recommendations have been made for uniform standard interrupting capacity ratings. The recommended steps of rating, based on the standard operating duty (2-OCO), for power house indoor oil circuit breakers at 15,000 volts and below are given in the following tabulation:

Arc Amperes	Rated Volts	Arc Kv-a.
2,500	4,500	20,000
2,000	7,500	25,000
1,500	15,000	40,000
2,500	15,000	65,000
3,500	15,000	90,000
5,000	15,000	125,000
7,000	15,000	175,000
10,000	15,000	250,000
14,000	15,000	350,000
20,000	15,000	500,000
30,000	15,000	750,000
40,000	15,000	1,000,000
60,000	15,000	1,500,000
100,000	15,000	2,500,000

Definite progress is being made toward recommendations of standard steps of interrupting rating on oil circuit breakers rated from 15,000 to 220,000 volts. Standardization of this kind, it is believed, will materially reduce the present extensive lines of breakers and great variety of interrupting capacity and voltage ratings which manufacturers are forced to carry, ultimately leading to reduction in oil circuit breaker costs.

Progress is being made toward recommendations of definition of high-voltage fuse ratings. Steps have also been taken for preparation of a uniform test procedure for testing the interrupting rating of high-voltage fuses, similar to the procedure recently prepared for testing oil circuit breakers.

Research is under way for the determination of relative accuracy of current transformers and shunts to be used in connection with oscillographic records of short

circuit tests; results and recommendations will probably be available within another year.

Interrupting Capacity Ratings. The following relative interrupting capacity ratings for oil circuit breakers have been approved by the N. E. L. A. and the Electric Power Club:

a.	One-unit operating duty...... 100 per cent to 125 per cent. Rating varies between limits given with design of breaker.	
b.	Two-unit operating duty, two-minute interval (Standard operating duty)	100 per cent
c.	Four-unit operating duty, two-minute intervals	70 per cent
d.	Four-unit operating duty, one-half minute intervals	60 per cent
e.	Four-unit operating duty, no time intervals	25 per cent
f.	300-unit operating duty, 15-minute intervals	30 per cent
g.	Four-unit operating duty, successive intervals of 0, 30, 75 seconds	30 per cent
h.	Four-unit operating duty, successive intervals of 15, 30, 75 seconds	40 per cent
i.	Three-unit operating duty, one-minute intervals	70 per cent

1. With reference to operating duties (d), (e), (g) and (h), while there are no known limitations which prevent the general application of these operating cycles to all oil circuit breakers, still in view of lack of operating experience and possible hazard, it is recommended that these operating cycles be confined to breakers having interrupting rating on operating cycle (b) of not over 250,000 kv-a. and having voltage ratings of 37,000 and lower.

2. Zero means no time delay between full open position and start of closing.

3. The present factor which the operators are using for operating duty (e) is 30 per cent, but it is the opinion of the Power Club that 25 per cent is more suitable.

In the above tabulation a unit operating cycle is understood to consist of a closing of the circuit breaker followed immediately by its opening without purposely delayed action.

Oil Circuit Breaker Tests. High capacity testing facilities are now available at the plants of two large manufacturing companies. Plans are also under way for several operating companies to undertake a series of cooperative oil circuit breaker tests, interchanging results among the companies participating, all tests to be made according to recommendations of the uniform test procedure. It is believed that much valuable data as to oil circuit breaker performance, and conditions affecting interrupting duty, will be secured from such tests.

General. Improvements in the details of design have been made by the various manufacturers who are continuing the development of their oil circuit breakers on the basis of different design features as follows:

High-speed contacts,

Explosion chambers,

Multiple contacts in series,

Resistance introduced into breaker circuit to reduce energy released by arc in the breaker,

Various methods of relieving gas pressure.

Armored, or metal clad, switch gear which has been used extensively in Great Britain and Continental Europe has been introduced in this country. The unit of metal clad switch gear is the three-phase circuit breaker with mountings and all auxiliaries. Each unit contains, within itself, the main oil breaker, bus bars, disconnecting devices, instrument transformers, cable potheads, and necessary minor features. All of the live conductors involved in this assembly are either immersed in oil or solidly imbedded in insulating compound and the whole is enclosed within grounded metal casings which form the exterior covering. Disconnection is provided by withdrawal, in a horizontal direction, of the carriage type oil circuit breaker.

The field of truck mounted breakers has been extended and high interrupting capacity outdoor breakers, up to circuit voltages of 154,000, are now being built with this type of mounting.

Working toward a better interchangeability of breakers of the smaller indoor type, single-pole elements are now being mounted on trucks and arranged for installation in a uniformly constructed steel housing; this will serve in place of the usual cell construction and will allow a more liberal interchange of elements and, because of the single- rather than triple-pole element, will permit a smaller stock of spare units to be carried. Each element may be controlled by a separate protective relay, allowing one pole to trip while the other two remain closed, continuing a single-phase supply over the circuit which the switch controls.

Another step toward universality is being made by one manufacturer who is arranging to build certain high-voltage breakers with provision for interchanging manual, solenoid, and motor operating mechanisms.

The application of motor mechanisms has been considerably widened to cover a greater number of breaker capacities and to meet a larger diversity in control circuits as to a-c. voltage, and frequency, and varying d-c. voltage.

Another manufacturer employs high-speed arcing contacts in high-voltage oil breakers. In the 110,000-, 132,000-, and 187,000-volt breakers the arcing contacts are of the high-speed bayonet type. A cam in the guide mechanism of the arcing contacts provides for a straight line motion of the arcing contact latch until the main contacts have parted a pre-determined distance, when the cam releases the arcing tips from the latch of the moving contacts. The release of the arcing tip is followed by a quick return to the normal position. The 25,000-, 37,000-, 50,000- and 73,000-volt breakers employ finger type high speed arcing contacts. The main contacts open at a moderate speed and when they reach a pre-determined separation, the arcing contacts are released at a high rate of speed. The contact parts are so arranged as to take advantage of the magnetic blow-out action of the current-carrying loop of the breaker. Another class of breakers, used for central station service, employs the double tank feature, the purpose being to prevent oil throwing and to provide additional assurance that a tank will not be burned

through. Breakers with interrupting ratings up to 1,500,000 kv-a., of the indoor type, are being provided with the resilient double tank and also each pole unit is designed in two sections so as to reduce the area which might be exposed to high gas pressures.

The multiple series break principle for 4, 6, 8, and 10 breaks is being employed on breakers from 15,000 to 220,000 volts.

Considerable interest has been manifested by a number of companies in the interrupting capacity of both high- and low-voltage fuses. Several companies have tested fuses in the 250- to 600-volt class.

In one series of tests on open-link fuses in sizes from 100 to 1000 amperes, with the fuses both initially hot and cold prior to test, it was found that in every case the fuse operation was selective between two fuses of adjacent current rating, the two fuses being in series for each individual test.

A series of tests conducted on renewable and one-time enclosed cartridge fuses indicated that the rupturing capacity of the fuse is largely a function of the length of the fuse element and the volume of the cartridge fuse case. The time for interrupting a circuit was found to be very selective between fuses of different sizes. The melting time of the fuse was a direct function of the thermal capacity of the element and inversely to the heating effect of the short-circuit current.

Tests have been made by a number of companies on high-voltage fuses for protection of transformer banks, sectionalizing lines, and similar service. Standards have been fairly well established on the liquid types of fuses. On the open link expulsion type fuses, a wide variety of results has been secured.

Protective Relays

In view of the recent publication of the Relay Handbook, this year's report of the relay subcommittee consists principally of a resumé and analysis of the present status and trend of protective relay practise.

As the publication of the Relay Handbook has given to the industry a comprehensive picture of the relay art in detail, this report will refer in detail only to developments which have occurred since the Handbook went to press, and only generally to developments occuring prior to that date.

Present State of Protective Relay Practise. A "relay" in the electrical art is an automatic device whose function is to receive information and initiate action in response thereto. It is estimated that the total number of types of such devices used in the electric power and telephone industries alone is in excess of 60,000. However, this subcommittee, being a branch of the Committee on Protective Devices, deals primarily with relays for the protection of power circuits and apparatus. The function of the relay as a protective device is to receive information of some abnormal condition and initiate action to correct the abnormal condition, or to disconnect the apparatus or circuit involved, from the source of energy.

Probably the oldest form of protection in use on electrical circuits is the fuse. From this developed the so called "overload" relays designed to act in response to excessive flow of current. At first these acted instantaneously, but as power systems, protected by "overload" relays, grew in magnitude and complication, it became necessary to differentiate between relays in different parts of the circuit by introducing the element of time. We therefore have today, as our fundamental system of protection against faults producing abnormal currents, a system depending on overcurrent relays with differing time adjustments, such time adjustment, in general, becoming longer the closer the generating station is approached. This has resulted, with the enormous and complicated power networks now existing, in the appearance of various limitations to the use of this system, due to the fact that the time differentials between relay settings cannot be reduced below a certain minimum on account of the inherent time required for relays and circuit breaking devices to function.

To meet this objection, a second general system of protection against abnormal current producing faults has developed, based upon the principle of balancing out of relay circuits all current except the fault current, thereby causing the protective relays to function in response to the fault current alone.

This general idea has crystallized in the system of protecting individual pieces of apparatus by balancing out of the relay circuits all current except that resulting from a fault within the particular piece of apparatus. There are two methods of applying this principle, first, by means of a series differential connection in which the two ends of a circuit are balanced against each other, and second, a parallel differential system which may be used where a circuit consists of parallel paths which may be balanced against each other.

In addition to systems of protection using current alone, we have a number of systems which depend upon the use of both current and voltage. Some of these systems, such as directional ground relaying systems, use both the fault current and the fault voltage; others, such as directional current and directional power systems, utilize the circuit voltage and total current, and certain other devices, such as the impedance relay, utilize the total current and fault voltage.

It should be observed that we have in the above, in general, two systems of current relaying, one depending upon total current and time for selective action, the other depending upon fault current and location for selective action.

In addition to protection against faults involving current, many other abnormal conditions are now protected against specifically by means of relays, such as abnormal voltage, temperature, speed, etc., single-phase operation of motors and generators, cessation of

flow of oil, water and air for lubrication or cooling purposes, and other conditions too numerous to mention. Development of many of these additional protective devices has been largely accelerated by the advent of the automatic station, in which, there being no operator to act in case of trouble, it is necessary to provide automatic devices.

Trend of Protective Relay Practise. The above outline of the types of protective relaying systems now in use, together with the chronological order of their development, indicates certain quite definite trends in the protective relay art. These may be briefly stated as follows:

First: With the development of large interconnected power systems supplied from numerous generating sources of varying efficiencies, there appears to be a growing trend towards the integration of all such sources into one comprehensive system so interconnected and relayed that its integrity shall not be broken by the occurrence of faults.

Second: Since the system of relaying which depends upon differential timing for selective fault isolation has not proved sufficiently flexible to promote the maintenance of the maximum integrity of such systems, there appears to be a strong trend towards obtaining such fault isolation through the use of balanced relay systems, or systems responsive to the location or specific nature of the fault.

Third: There also seems to be a rather strong trend towards the use of what may be called "back-up" protection, or a second line of defense, in the form of a second system of relays to function in case of failure of the first system, applied either to the same circuit breakers as the primary defense, or to others nearer the sources of energy.

Fourth: There also seems to be a strongly developing tendency toward the development and use of devices for the detection of abnormal conditions and approaching faults before such faults actually occur.

Summarizing the apparent trend of relaying practise in general, therefore, it would appear that the tendency is towards the maintenance of system integrity by the setting up of three lines of defense:

1. Relays which will detect and give warning of approaching faults or conditions which may cause faults,
2. Relays which respond to the abnormal conditions resulting from the occurrence of faults to isolate the particular piece of apparatus or circuit at fault,
3. A back-up system (consisting in its commonest form of overcurrent relays) adjusted with such time delay as to function only upon the failure of the first and second lines of defense.

The relay art has played an important part in the evolution of the modern superpower system and has itself evolved in sympathy therewith. This evolution is still going on and must continue to do so. We are confident that it will go on until every requirement for continuous electric service has been met.

Developments During the Past Year. A number of new developments have occurred during the year, most of which are in the nature of detail improvements devised to keep abreast of the evolving art. The following specific developments are noted for the purpose of recording the advances in the art and as information as to new devices available.

1. Speed indicating relay for application to automatic stations. Makes separate contacts at definite per cent under-speed, at synchronous speed and at definite per cent over-speed.

2. Automatic network relay. For the control of alternating current network breakers. Connects transformers to network when capable of supplying load and disconnects them on reversal of energy flow. Will operate on magnetizing current of a transformer.

3. Ratio differential relay. For the differential protection of a-c. generators and transformers. Tripping current varies with load, allowing the relay to be set for close protection at normal loads. Does not require balancing auto-transformers for transformer protection.

4. Direct-current polarized relay. Has inverse definite minimum characteristics. A complete line is available including over-current, under-current, over-voltage, under-voltage, reverse power, polarized potential, and resistance measuring relays.

5. Duplex impedance relay. A combination of a directional impedance relay and a ground relay in one case.

6. Automatic reclosing relay. Has been modified to permit any desired duty cycle. Time intervals may be varied between five seconds and two minutes.

7. Over- and under-voltage relays. Have been modified by the addition of a voltage adjusting resistor controlled by a pointer and scale. Permits relay to be adjusted for any voltage within a definite range.

8. An over-voltage relay. The same as existing over current relay except that a voltage winding has been substituted for the current winding and certain other minor alterations.

9. A power directional over-current relay, offering power directional protection against ground faults, and against phase-to-phase faults where for any reason single-phase directional elements are preferred to a polyphase relay.

10. A network relay for protecting low-voltage a-c. networks against a faulty distributing transformer or feeder.

11. Power directional relays for sensitive protection against ground faults in grounded neutral circuits.

12. Differential frequency relay consisting of two induction frequency elements arranged in opposition on a single shaft. For application in connection with

two circuits that are interlinked by means of a rotating machine.

13. A phase unbalance relay for use in a polyphase circuit for protection against faults producing an unbalancing of currents in the several phases.

14. Synchronism indicating relay comprising an induction type differential element for preventing interconnection of two systems at one point unless they are already connected at some other point.

15. Motor-operated timing-relay for controlling the time elapsing between certain operations. Intended primarily for use with automatic reclosing of circuit breakers.

16. Auxiliary relay. A plunger type relay particularly adapted to automatic switching for introducing time in starting up and in shutting down machines. Can also be used in any a-c. or d-c. circuit where instantaneous pick-up and long time drop-out are required.

17. Electrically-reset instantaneous over-current and auxiliary relays. Equipped with a solenoid for resetting.

18. Flashing protective relay. Has a heavy winding for connection from d-c. machine frame to ground to protect against flashing or grounding of winding to frame. Instantaneous.

19. Plunger type trip free relay for use with electrically operated circuit breakers to prevent the breaker being held closed with over-current in the circuit.

20. Locking relay plunger type. Primarily for preventing a circuit breaker from opening on an excessively heavy over-current.

21. Locking relay. Primarily for preventing the opening of one circuit breaker due to surge conditions resulting from the opening of another circuit breaker.

Recommendations. Since the efforts of Institute Technical Committees are directed towards research, standardization, and publicity, it is believed that this subcommittee can be of most service this year by suggesting a few subjects on which research, standardization, or publicity appear desirable.

As to research, the following studies are recommended:

A. Study of pilot wire transmission line relay systems employed in Europe, to determine their proper field of usefulness. It is understood that many successful installations are in use and it is thought that American practise may benefit by the investigation thereof.

B. Study of characteristics of current transformers at very high overloads. The characteristics of current transformers at very high overloads are of importance in many relay applications, and the information at present available is somewhat meagre. It is recommended that the manufacturers be urged to investigate this matter and present the information to the industry in the form of papers, or otherwise.

It is recommended that standards be formulated and adopted for the following:

1. Relay operation nomenclature. The selection of terms to define the characteristics of relay operation are very chaotic at the present time, probably no two companies having the same conception of what is required, or using exactly the same terms. In order that material for publication regarding operating experience may have a common language of expression it is recommended that standard nomenclature for relay operation be adopted.

2. Relay acceptance tests. At the present time there are no Institute standards of overpotential tests, temperatures, etc., for relays. It is recommended that such standards be established.

3. Relay designs and ratings. At the present time there is no purposeful coordination of standard relay designs among the different manufacturers. This fact imposes considerable hardship upon the relay users, in view of the difficulty introduced thereby, of making relay applications involving relays of different manufacturers. It is therefore recommended that, in so far as appears feasible, standard ratings and operating characteristic curves be established for the more common types of relays.

4. Current transformer characteristics. A. Coordination between transformers of different types and voltages: Considerable difficulty arises in the application of balanced protection where transformers of more than one type or voltage rating are involved. It is recommended that in so far as possible the designs of transformers of different types and ratings be so coordinated that differing types can, without serious difficulty, be used for differential protection.

B. Coordination of characteristics as between different manufacturers: It is also recommended that in so far as may be practicable, current and potential transformer designs of different manufacturers of the same general type and voltage ratings, be so coordinated that like types will have like characteristics.

As to papers for publication, due perhaps to the above noted confusion as to nomenclature for relay operation, there has been little published information regarding the operation, successful or otherwise, of existing relay systems. It is therefore recommended that at a future general Institute meeting, an appropriate amount of time be alloted for the presentation of relay operating experience. It is suggested that this presentation might well be made under three general divisions:

Time differential systems, or systems in which selectivity is obtained principally by timing.

Current differential systems, or systems employing various current balancing plans for selective operation.

Voltage differential systems in which the abnormal voltage conditions resulting from a fault are utilized to assist selective operation, such as impedance relay applications.

In the advancement of the above suggested program the following sub-subcommittees have been appointed:

1. On Relay Operation Nomenclature and Experience.
2. On Relay Acceptance Test Specifications and Standards.
3. On Current and Potential Transformer Characteristics.

These subsubcommittees have not had time to complete their work this year, but it is hoped that they will be continued next year and continue their work to a useful conclusion.

Appendix

Report of Subcommittee on Automatic Stations

Since the presentation of the Automatic Stations Subcommittee Report this year, three points have developed on which is submitted supplementary information, including points as follows:

1. Minimum safe protection of power apparatus in automatic stations.
2. Device function numbers for use in automatic stations.
3. Device symbols for use on automatic station wiring diagrams.

Minimum Safe Protection. In its reports of 1925 and 1926, the subcommittee presented its recommendations for the protection of synchronous converters of railway, Edison, and industrial types; synchronous motor generators of Edison and industrial types; synchronous generators (in automatic hydroelectric applications) and synchronous condensers. These recommendations have been tabulated and are presented herewith. It is urged that they be transmitted to the Committee on Standards with the recommendation that they be accepted and incorporated in the Standards of the Institute.

MINIMUM PROTECTION
FOR POWER APPARATUS IN AUTOMATIC STATIONS

Protection	Synchronous Converters			Syn. Motor Gen.		Gen.	Cond.
	Rwy. 600-volt	Edison 250-volt	Mining & indust.	Edison 250-volt	Mining & indust.	Synch. hydro.	Synch.
A-C. Under-voltage	x	x	x	x	x	x	x
A-C. Over-voltage						x	x
Incorrect Polarity	x	x	x				
Single-Phase Starting	x	x	x	x	x		x
Single-Phase Operation						x	x
Loss of Field, A-C. Machine	x	x	x		x	x	x
Loss of Field, D-C. Machine				x	x		
D-C. Reverse Power	x	x	x	x	x		
D-C. Overload	x	x	x	x			
Excess Temperature (Sustained Overload)	x	x	x	x	x	x	x
Imperfect Start (Lock-out)	x	x	x	x	x	x	x
Machine Overspeeding (Lock-out)	x	x	x	x	x	x	
Severe A-C. Overload (Lock-out)	x	x	x	x	x	x	x
Grounding Protection (Lock-out)	x	x	x	x		x	x
Excess Bearing Temp. (Lock-out)	x	x	x	x	x	x	x

Device Function Numbers. During the year 1924 the subcommittee submitted a set of device function numbers for use in automatic stations. Through the efforts of the subcommittee, this was accepted by the principal manufacturers and users and is now almost universal. This idea has practically standardized itself, but it is felt that these device function numbers should be transmitted to the Committee on Standards, who should be urged to accept and incorporate them in the Standards of the Institute.

Device Symbols. The subcommittee also submits a set of device symbols for use on automatic station wiring diagrams. These have just been accepted by the two principal manufacturers and will be used by them in the future. It is urged that these wiring diagram symbols be transmitted to the Committee on Standards for acceptance and incorporation in the Standards of the Institute.

Walter H. Millan,
Chairman.

ELECTRIC CARS FOR STEAM RAILROADS

Electricity for local passenger service is going to the aid of steam railways that are not yet ready to completely electrify their systems. The Boston & Maine, after a summer's experience with seven passenger cars operated by electricity generated on board by a gasoline engine, is now installing seventeen more to make runs of 250 and 300 miles a day covering most of the main line of the railroad and many of the branch lines.

The new cars are 73 feet long and can seat 88 people in passenger, smoking and baggage compartments. The generators on each car are rated at 275 horse power. Car warmth in winter is provided by water electrically heated. Quick starting and high speed enable these cars to run on main lines to do local work between fast through trains. They reduce the cost of branch line service markedly.

SEMINARS FOR PRACTISING ENGINEERS

In the October Journal a paper by Edward Bennett bears the title "Excellent Seminars for Practicing Engineers." "Excellent" should be omitted. The word was inadvertently so affixed to the manuscript by a reviewer that it appeared to be part of the title.

Status of Electric Lighting in 1926

Report of Committee on Production and Application of Light*

PRESTON S. MILLAR, Chairman

To the Board of Directors:

As required by provision of the By-laws, this report constitutes a brief resumé of of the progress of the lighting art, including recent developments in electric lighting which appear to have significance as indicating an actual trend in the art.

Illuminants

In electric illuminants there have been no new developments of a radical character during the past year. Among tungsten filament incandescent lamps there has been developed a new standard line in which the gas-filled type has been introduced in the 50- and 60-watt sizes heretofore generally of the vacuum type. These lamps, standardized thus far from the 15- to the 100-watt sizes of the 115-volt range, are characterized by

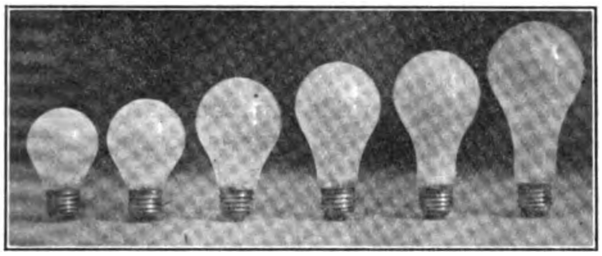

Fig. 1—New Standard Line of Tungsten Filament Lamps

bulbs of a pleasing contour (Fig. 1), lightly frosted upon the inner surface, providing a measure of diffusion of light, while retaining the cleanly, smooth surface heretofore had only in the clear bulb and "natural glass" lamps. The adoption of this new standard line of lamps in place of a variety of types heretofore employed is a conspicuous example of the principle of simplification which the Department of Commerce has urged successfully and constructively upon industry in this country.

Arc Lamps. The employment of arc lamps in this country for general illumination is confined largely to the magnetite lamp which continues in successful operation in some localities, and which in its higher powered form has been utilized in several recent installations where high-intensity street lighting is desired.

For the projection of motion pictures in large houses, the high-intensity arc is quite generally used. In medium-sized theatres carbon arcs, both alternating and d-c., operating at currents from 30 amperes to 80 amperes, are quite generally in use. A 10- to 30-ampere, horizontal carbon arc used with a reflector instead of a lens as a condenser has entered into use recently.

Practically all interior motion picture photography is now done with the aid of electric arcs for illumination. Four types of arc are used: the high-intensity arc (150 amperes), the white-flame arc, the ordinary carbon arc, and the mercury vapor arc. There is steady improvement in all forms of studio arc-lighting apparatus.

The high-intensity arc has been brought to its highest degree of perfection in military searchlight work and is now used universally by both the Army and Navy.

White-flame arcs are still quite generally used in photo-lithography and color reproduction work. Improved units are occasionally appearing in this field.

The use of white-flame arcs in portrait photography is increasing and several small, efficient arc mechanisms are now being used in this field.

Small Gaseous Conductor Lamps. A distinctly new development is the small gaseous conductor lamp[1] devised by Moore for indicator or marker purposes rather than for purposes of illumination. These lamps operate at 115 volts alternating-current or direct-current. They consume about one-half milliampere for the T-4 bulb size, and one milliampere for the G-10 bulb size, and have an efficiency of about one-third lumen per watt. The life is said to be 3000 to 5000 hours. One form of the lamp, fitted with a G-10 bulb, has an over-all length of two in. and a diameter of one to one-fourth in. This is provided with a wire resistance of about 35,000 ohms in the base, which is of the medium screw type. Another form has a T-4 bulb, an over-all length of about one to one-fourth in., and a diameter of one-half in. This is fitted with a candelabra screw base in which there is a composition paste resistance of about 70,000 ohms. The lamps are said to contain neon, helium, and argon in certain proportions. When excited by electric pressure at the electrodes, the gas becomes luminous at the cathode. On direct current, the gas around only one electrode glows; on alternating current the gas glows near both electrodes at a frequency depending upon the supply current.

The lighting and extinction of these lamps is practically instantaneous. They thus have properties which are peculiarly desirable for such instruments as strobo-

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W. T. Dempsey,	H. H. Higbie,	B. E. Shackelford,
H. W. Eales,	A. S. McAllister,	C. J. Stahl,
F. M. Feiker,	G. S. Merrill,	G. H. Stickney.

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, June 21-25, 1926.

1. "Recent Developments of Moore Gaseous Conductor Lamps" by Moore and Porter, *Transactions*, Illuminating Engineering Society, Feb. 1926, p. 176.

scopes, synchroscopes, etc. If 230 volts be applied, they merely glow a little more brightly than on 115 volts.

The two forms of this lamp are illustrated in Fig. 2. Application of the lamp to an electric flat iron is shown in Fig. 3. The small power consumption makes it practicable to use the lamp in a wide variety of service to indicate that the circuit is alive, or to indicate loca-

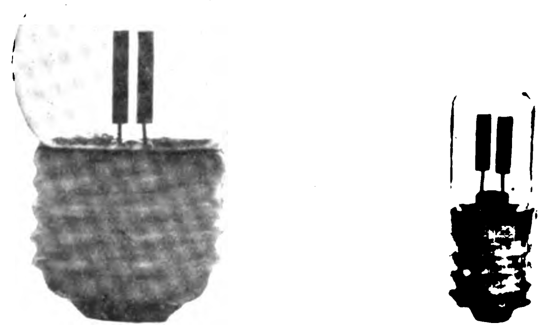

FIG. 2—GASEOUS CONDUCTOR LAMPS FOR 115-VOLT CIRCUITS

tions of switches, polarity of d-c. circuits, etc. For other applications see paper to which reference has been made.

Double Filament Automobile Lamp. The past year has witnessed the rather extensive introduction of the double filament automobile headlight lamps. In ordinary practise the lower filament provides the principal driving beam. When the upper filament is

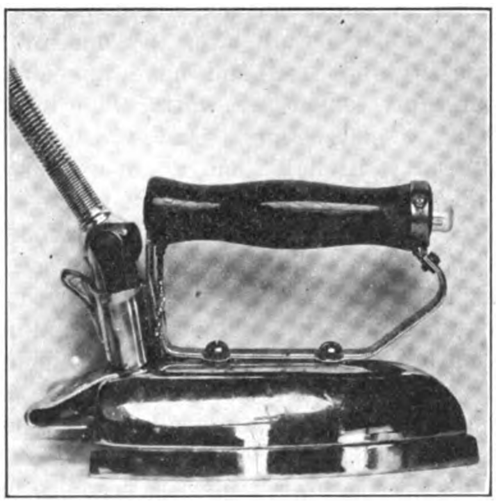

FIG. 3—GASEOUS CONDUCTOR LAMP TO INDICATE CLOSED CIRCUIT ON FLATIRON

switched into circuit the beam is depressed by two to three degrees. A further discussion of this development in relation to headlight practise appears under a later section of this report.

Prefocusing Lamp Socket. To meet the requirements for precise location of filaments of incandescent lamps used in motion picture machines, stereopticons, signals, etc., there has been developed a special type of base and socket which insures correct operating position for the filament in such apparatus. Each lamp is based in an optical jig to secure exact filament location with respect to both axial alignment and light center length once the projection apparatus is properly fitted. This device eliminates the necessity of refocusing on renewing a lamp, and procures for users of projectors maximum screen illumination. While this equipment is not regularly listed by manufacturers it is understood that it can be procured when desired.

LIGHTING EQUIPMENT

For Residence Lighting. The trend in luminaries for home lighting in recent years has been largely in the direction of the candelabra type of equipment employing frosted or coated incandescent lamps which in large part have been without shades and wholly exposed to view. In illuminating engineering circles this trend has been regarded as contrary to the public interest in that it has brought within the field of ordinary vision sources of excessive brightness which have produced glare. With a view to correcting this condition much educational work is being done by central stations and other branches of the industry to impress the public with the desirability of properly shading light sources, and new types and finishes of shades are being made available by some manufacturers to encourage this practise.

For Street Lighting. In street lighting equipment there has been a pronounced trend in the direction of employment of directive equipment, usually of prismatic glass, surrounded by lightly diffusing outer glass envelopes. The purpose has been to secure a considerable measure of favorable redirection of light while keeping brightness and glare within bounds. A variety of equipment of this kind has been placed in service. In some cases effort is confined to redirection into the lower hemisphere of some of the light flux which otherwise would be directed upward. In other cases this has been combined with a latitudinal redirection along the street of some of the light flux which otherwise would fall upon building fronts.

ORGANIZED STUDY OF ILLUMINATION

Illumination and Production. Under the aegis of the National Research Council an effort is being made to ascertain some of the relations between changes in illumination and changes in industrial production. Investigations to date[2] have indicated that improved illumination has secured industrial advantage in the way of increased production, diminished shrinkage, and more favorable working conditions. The purpose of the present investigation is, if possible, to ascertain under independent auspices the facts in certain representative industries. Thus far, the committee having

2. Report of Committee to Promote Central Station Illuminating Engineering, Lighting Bureau, Commercial National Section, Presented at National Electric Light Association Convention, May, 1924. (Table III)

this enterprise in charge, and operating under the chairmanship of Professor D. C. Jackson, has engaged largely in developing methods with a view to the formulation of a procedure and the establishment of systems of control which when applied to an industry which is largely dependent upon vision, may be expected to determine the facts of relationship between illumination and industrial production.

Street Lighting. A committee of the Illuminating Engineering Society is endeavoring to develop a method of appraising the effectiveness of street lighting which will make it practicable to determine, at least approximately, the relative merits of two different street lighting systems. It is an interesting and notable fact that despite the extensive attention which has been devoted in recent years to the subject of street lighting, there is today nothing like consensus among the leaders of the art as to the best manner of locating and equipping street lamps and of distributing the light for purposes of street illumination. If the present attempt fails in its ultimate object, it may at least succeed in diminishing the divergence of views among street lighting engineers. There is included in the program a project for study of the elusive subject of glare in street lighting.

Organized Movements for the Improvement of Lighting Practise

Electric lighting is receiving proportionately more attention at the hands of electric service companies throughout the country than has been the case in recent years. The potentialities of revenue from increased lighting load and a growing sense of responsibility for making available to the public the benefits of improved illumination have combined to command a greater degree of specialized attention to illumination.

Training Course for Lighting Men. At the 1924 Convention of the National Electric Light Association, a Committee to Promote Central Station Illuminating Engineering reported upon the importance of the opportunity in the lighting field afforded central stations, and described a training course for prospective central station illuminating engineers then in course of preparation. This course, under the joint auspices of the National Electric Light Association and the Illuminating Engineering Society, was arranged for the autumn of 1924 and was carried through with success. It made available to a training group the kind of instruction which in recent years had been given lighting students in training courses by the larger manufacturers of incandescent lamps, and supplemented this by the experience of central station companies who have pioneered in the organization and operation of lighting service departments and by a carefully chosen inspection trip.

Selection of Lighting Equipment. A further indication of central station concern for the improvement of electric lighting is furnished by action of the Lamp Committee of the Association of Edison Illuminating Companies, which heretofore has functioned successfully in connection with incandescent lamps themselves, but has not concerned itself with lighting equipment. It is understood that this Committee has taken cognizance of unsatisfactory lighting conditions in residences, and has requested the Illuminating Engineering Society to formulate a statement of principles and perhaps some simple specifications which may be looked to for the guidance of central stations which desire to select satisfactory lighting equipment for sale to the public. It is further understood that the Illuminating Engineering Society is endeavoring to comply with this request and has a committee at work formulating such a statement of principles which may govern the selection of residence lighting equipment.

Central Station Lighting Departments. Whereas in the spring of 1924 only nine central station companies were known to have lighting service departments, today there are 42 central stations which have such departments and the number is fast growing. The principal limitation is the unavailability of trained men competent to organize and operate such activities.

This awakening of central stations to their opportunities and responsibilities in lighting is of large significance to the country. Most classes of illumination, and particularly residence, industrial, and street lighting, suffer needlessly from ineffective and inappropriate lighting which fails to take advantage of recent advances in the art. The light and power industry can contribute materially to the welfare of the country by lending its great influence to betterment of these conditions. It is a matter of gratification to this Committee that definite progress in this direction is indicated by the developments of the past year.

I. E. S. and Central Station Lighting Men. During 1925 the National Electric Light Association, in reorganizing its Commercial Section for greater effectiveness, dispensed with its Lighting Sales Bureau. In September, 1925, on the day preceding the opening of the Illuminating Engineering Society's annual convention, there was a gathering of central station lighting men out of which there was evolved a plan for greater activities in connection with central station lighting under the auspices of the Illuminating Engineering Society. In this connection it is understood that there is in course of preparation a Lighting Service Department Manual which will make available the experience of central stations which have assumed the lead in such work. This will include a brief survey of the lighting field and chapters on the organization of a lighting service department, its scope, needed equipment, and engineering and commercial features of its work.

Lighting Demonstrations. Interest in electric lighting has been enhanced and in all probability practise has been much improved as a result of demonstrations made in the elaborate Lighting Educational Centers

of the incandescent lamp manufacturers at Nela Park and Harrison. So successful have these been that less elaborate demonstrations have been set up and operated in a number of cities. Notable among these are demonstrations in Boston, Chattanooga, Cincinnati, Detroit, Kansas City, Knoxville, Louisville, Nashville, Philadelphia, Pittsburgh, and Providence. Others are understood to be in preparation.

Motor Vehicle Lighting

Specifications for automobile headlamp and rear-lamp performance have been prepared by the Illuminating Engineering Society and revised as of 1922. These headlamp specifications cover laboratory tests for headlamps and headlighting devices and prescribe candle power limits for different parts of the beam. The headlamp specifications were endorsed in 1922 by the Society of Automotive Engineers, which organization, however, supplemented its endorsement by promulgating, within such limits, recommended practise calling for a higher maximum beam candle power and a higher candle power in the beam spread to the right and to the left than is stipulated in the specifications. The I. E. S. headlamp specifications were approved as a "Tentative American Standard" in 1922. They are in use by the Eastern Conference of Motor Vehicle Administrators in which are represented all the New England States, (except Massachusetts) New York, New Jersey, Pennsylvania, Maryland, Delaware, Virginia, District of Columbia, Ontario, and Quebec. The specifications are also in force, either wholly or in part, in Ohio, Wisconsin, Iowa, Utah, Nebraska, Texas, California, and Oregon. Also they are recommended in the "Uniform Act Regulating the Operation of Vehicles on the Highways" prepared under the direction of Secretary Hoover in the National Conference of Street and Highway Safety.

The rear lamp specifications developed by the Illuminating Engineering Society cover the general relation of the lamp and license plate holder and the quantity and uniformity of illumination upon the license plate. At the present time the rear lamp specifications used by the State of Massachusetts are substantially in accord with those prepared by the Illuminating Engineering Society.

During the past year the Automotive Lighting Association has prepared specifications covering stop and direction signals and the depressed beam from controllable headlights or auxiliary driving lights. Subsequently somewhat different specifications for depressed beam lighting have been formulated tentatively by the Illuminating Engineering Society's Committee on Motor Vehicle Lighting. The matter also is understood to be under consideration by the Eastern Conference of Motor Vehicle Administrators.

A further advance made in the practise of the Eastern Conference of Motor Vehicle Administrators is a requirement for excellence of headlamp construction not formerly imposed. Another forward step was taken by the National Conference on Street and Highway Safety in formulating a Uniform Vehicle Code intended to promote uniformity of regulatory action in the several states.

The depressible beam, fast coming into use in motor car lighting, is a step in the direction of securing the advantages of the desirable headlighting characteristic required by the specifications now in general use with the element of advantage otherwise secured through dimming. It is a step further in the direction of doing away with the disadvantage inherent in each practise, measurably avoiding the glare to which the approaching driver is subjected under the first practise and the hazard of passing vehicles with lights dimmed involved in the second.

The depressed beam has become a practicable device through the development of a lamp having twin filaments, one placed 9/64 in. above the other and suitably coordinated with lens or reflector elements. By switching from one filament to the other, the beam is depressed by from two to three deg. in a simple, positive, and easily applied manner.

Although but few of these devices as thus far developed are understood to have been approved by the Eastern Conference, more than 20 car manufacturers have adopted such equipments for their new cars.

Research. As a result of discussion following the 1925 Conference on Street and Highway Safety, a joint Steering Committee on Headlight Research has been formed by the Society of Automotive Engineers and the Illuminating Engineering Society.

The first objective of the Committee is to stimulate and guide experimental research directed toward the determination of the most satisfactory methods of automobile headlighting and, in accordance with the results of research, to formulate a code of recommended practise with respect to headlight equipment, adjustment, and use.

A program has been projected by the Committee including collection of data on visibility of objects under various conditions, experimental studies of visibility under conditions of actual driving, collection of data on quality and condition of lamps as used and the possibilities of bettering them, and a demonstration of the lighting which various automobile manufacturers consider most satisfactory for all-around use.

Relation to Street Lighting. In this connection it may be interesting to observe that the Committee on Street Lighting of the Illuminating Engineering Society is of the opinion that urban streets ought to be sufficiently well lighted to make it practicable to do away entirely with powerful headlights on automobiles, as is the practise in New York City, and to a limited extent in some other cities. It is held that streets which support considerable traffic ought to be sufficiently lighted to make this practicable, and that where such condition exists, the safety and convenience of all

concerned will be promoted. The Committee is engaged in establishing street lighting minima above which it can feel confident in recommending the abolition of headlights.

Residence Lighting

One of the serious obstacles to the provision of better lighting in the home is the general lack of adequate outlets and the apparent difficulty and expense of making additions.

In the 1925 report of this Committee, reference was made to the Red Seal Campaign which undertakes to establish a minimum limit of adequacy of wiring according to the needs of each community. This plan has been adopted by nineteen different local electric leagues operating in six hundred and seventy-six communities and reaching nearly ten million people. One manufacturer is undertaking to establish a nation-wide standard of quality and adequacy, and it is probable that others will follow along similar lines. It is therefore becoming the fashion to provide suitable wiring.

Although home-lighting equipment is still being selected with the main emphasis on the artistic features of metal working, with inadequate attention to the artistic and utilitarian values of the illumination itself, there yet seems to be a slow but general progress toward a better understanding of the merits of good lighting. The more common use of such terms as "shaded lights" indicates the trend.

School Lighting

Preliminary tests have been made for the city of Newark, New Jersey, to secure an indication of the quantity and character of artificial light desirable for special public school classes of pupils having defective vision.

Observations of reading and writing suggested 15-ft. candles, or about 50 per cent more than ordinarily recommended. Comparison seemed to show semi-indirect and direct lighting, with large diameter diffusing glassware, to be equally acceptable, when supplementing daylight.

Railway Lighting

The first edition of a Manual of Lighting Practise for Railroads has been practically completed by the Association of Railway Electrical Engineers.

The following topics have been covered: Fundamentals of Illumination and General Design, Design Data, Railway Shop and Roundhouse Lighting, Office and Drafting Room Lighting, Freight and Passenger Station Lighting, Warehouse and Pier Lighting, Yard Lighting, and Car Lighting.

Bus Lighting

The 12- to 16-volt systems are rapidly displacing the six- to eight-volt systems formerly used in bus lighting. A 21-c. p. incandescent lamp in an S-11 bulb designed for 300 hours of life has been standardized particularly for this purpose. It is interesting to note that some of the modern double-deck motor coaches have as many as 42 lamps for interior lighting. Special types of enclosing units and opal glass reflectors have been developed for motor coach lighting. Enclosing units are being used in the majority of new buses.

Illumination of Railroad Classification Yards

The employment of flood lights for illumination of railroad classification yards is becoming general. The Committee on Illumination of the Association of Railway Electrical Engineers reported that in 1924, 35 railroads had 90 yards equipped with an aggregate of about 2100 flood lighting units. Since that time the practise has been extended, notable recent installations being in the Selkirk Yard of the New York Central Railroad and the Markham Yard of the Illinois Central Railroad.

The necessity for adequate and proper illumination is enhanced by the introduction of the so-called mechanical car-retarder system for controlling the speed of cars in the gravity type of classification yard since the operators of such equipment must have a good view of the entire yard from their control towers.

The above mentioned Committee has received a report from one railroad covering operating records of yards for several months before and after equipment with flood lighting, there previously having been no artificial illumination in the yard. This showed an increase of 15.5 per cent in number of cars handled at night with a decrease of 21 per cent in the average cost of damage suffered by cars and with entire elimination of personal injuries attributable to inadequate illumination during the months in which the records were studied.

Lighting for Advertisement

Electric signs and illuminated displays are a constantly growing factor in the advertising field. There has been within the last year a noted increase in the diversity of form of such displays together with a more rational design of the illuminated pattern based upon new engineering information.

Signal Lighting

Traffic Signal Lighting. With the large increase in the use of electric traffic signals, there has come fortunately an approach toward uniformity of practise in their use. Red quite generally now means "Stop" and green means "Go". Amber signifying "Caution" is employed in many cities for the assistance of the pedestrian.

A lens, a glass reflector, and an incandescent lamp are the usual equipment for each signal. Styles of signals are becoming more nearly uniform. Flexibility of control for isolated units and for large interlocked installations is a feature of the latest developments. A centrally controlled progressive system of signal operation has been developed and placed in operation in Chicago, which is greatly expediting the flow of traffic through the "Loop" district. Many of the signals

installed in the past have not been sufficiently bright to have the necessary attention value when seen against the sky near the sun. Experience indicates that this is a subject to which considerable attention must be given to insure the efficacy of the signal under all conditions.

The proper solution of the traffic problem in any given case requires real engineering analysis.

With the multiplication of traffic signal lights, there comes a possibility of confusion which merits further study. Red traffic signal lights are sometimes placed at elevations of not more than 10 ft. above the roadway; there are red tail lights; and sometimes red stop lights on street cars and port running lights on motor buses. In some districts there is also a red signal at fire alarm boxes. Police patrol stations and building exit markers further complicate the situation. This is a matter which clearly requires care and attention if we are to avoid complexity of signal lights which may result in confusion and increase the accident hazard.

The 1926 Conference of Street and Highway Safety, taking cognizance of the above described situation in regard to traffic signals, adopted by majority vote a recommendation that yellow be employed as a rear lamp signal for motor cars.

Railway Signal Lighting. Progress is reported in the development of electric signals both to replace the kerosene lamp for night use and to serve as a full color signal both day and night. The development has involved specialized design of lamp filament and bulb, of optical system, of a universal accurate focusing mechanism, and of means for directing the light as desired.

Aviation Lighting. After much experimentation, particularly on the part of the United States Air Mail Service, it appears that the following is likely to become general practise in aviation lighting: a 500,000,000-c. p., high-intensity arc searchlight, visible in clear weather for 150 mi., is located every 250 mi. along the route. Every 25 mi. between these beacons are located 60-ft. steel towers supporting a 24-in. rotating beacon, employing a 30-volt, 900-watt, tungsten filament lamp. This beacon has a beam c. p. of approximately 7,500,000, and in clear weather is visible for 75 mi. The beam is elevated at an angle of one to one-half deg. above the horizon, and rotates at a speed that provides a flash every 10 seconds. In very hilly or mountainous sections, routes are marked with smaller beacons consisting of four automobile headlamps equipped with 12- to 16-volt, 21-c. p. tungsten filament lamps. These beacons are rotated at a speed of 10 rev. per min.

The boundaries of the principal landing fields are marked by 60-c. p. series lamps spaced 150 ft. apart around the edge of the field. Emergency landing field boundaries are marked by two-c. p., three- to four-volt lamps, 28 of these being connected in series around the boundary of the field. They are operated from gasoline-electric equipments. Each fitting has a relay which introduces an equivalent resistance into the circuit in case of a lamp failure. It is usual to place a number of flood-lighting equipments along two sides of the field to illuminate it for landing purposes. These have 120-deg. Fresnel lenses and are equipped with 900-watt, 30-volt, tungsten filament lamps. To some extent 10-kw. ribbon filament lamps are also used in very large Fresnel type lenses for flood lighting landing fields.

With the development of commercial flying it is probable that there will arise requirement for well defined routes and landing fields. The total lighting load at a typical air mail field is 38 kw.

A New Application of Light

The transmission by wire or wireless of actual scenes or so-called "television" is understood to have been accomplished experimentally. With the aid of the photoelectric cell and the Moore gaseous conductor lamp it has been found possible to use relatively simple apparatus for the transmission and reception of pictures within the interval imposed by the human eye as a requirement for sustained vision. It is expected that this new art will be brought to commercial development at a relatively early date.

Illumination Nomenclature and Symbols

Nomenclature, abbreviations, and symbols in the illumination field are now fairly well fixed in this country. The report of the Committee on Nomenclature and Standards of the Illuminating Engineering Society, having been submitted some time ago to the procedure of the American Engineering Standards Committee, was adopted as an "American Standard."

Illumination Items in the Proceedings

Under the auspices of this Committee there have appeared in the proceedings from time to time brief articles designed to keep the membership posted as to significant developments in the lighting field. Evidences of appreciation having been received, this practise is being continued and may be recorded as a supplementary activity of this technical committee.

Conclusion

The Committee on Production and Application of Light, having thus reviewed the field of lighting within its purview, is in a position to report to the Institute that electric lighting is undergoing a sound and wholesome development under the influence of forces largely commercial in character but greatly beneficial from a public point of view.

The Illuminating Engineering Society is intent upon developing the science and the art of illumination and is making measurable progress in its activities. Associations of manufacturing and operating interests are contributing notably through progressive engineering and business development which derives adequate sanction from the fundamentally favorable consideration that every improvement in equipment and practise in the lighting field is mutually advantageous to the commercial interests and to the public.

Fire Protection of Water-Wheel Type Generators

BY J. ALLEN JOHNSON[1] and E. J. BURNHAM[2]
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Synopsis.—*In recent years, much attention has been given to fire protection of turbo generators, resulting in a trend towards closed ventilating systems and the use of inert gas to smother combustion. Water-wheel type generators are not so well adapted to this method of protection. In water-power plants, water is the most readily available means for fire extinguishment, but its indiscriminate use through perforated pipes or nozzles may cause damage equal to that of the fire.*

The present paper describes a system of fire protection for water-wheel type generators which is designed to limit both fire and water damage to the section of the generator immediately adjacent to the point of origin of the fire. This is accomplished, first, by air baffles which control the flow of ventilating air around the armature end projections, and second, by the use of fusible sprinkler heads which permit the application of the water solely to the region of the fire. The means for preventing and detecting fires in such generators are also outlined. Tests made during design to establish the effectiveness of the scheme and devices used are also described.

THE problem of protecting generators against fires of internal origin is closely associated with that of their ventilation. This is obvious from the fact that the cooling medium ordinarily employed, namely, air, contains the oxygen required to support combustion. This fact has been recognized in that one method employed for extinguishing fires in generators is to control the composition of the atmosphere within the ventilating system. In closed ventilating systems, such as are now becoming standard for steam turbo generators, this may be accomplished in various ways. For instance, the fire may be permitted to burn until enough of the oxygen contained in the closed ventilating system is used up so that the remaining gases will no longer support combustion, or an inert gas such as carbon dioxide may be admitted to the ventilating system in sufficient concentration to lower the free oxygen content to a point where combustion will stop. A third method which has been proposed is to maintain at all times in the closed ventilating system an inert gas, such as hydrogen, as a cooling medium instead of air. Methods of protection, however, which have been worked out for steam-turbine-driven generators are not in general applicable without modification to water-wheel type generators.

The purpose of this paper, therefore, is to point out certain factors involved in the problem of fire protection of water-wheel type generators, and to record the principles and devices employed in the fire protection of the 65,000-kv-a. Niagara generators.

Let us therefore first catalog some of the essential points in which water-wheel type generators differ from steam turbo generators from the standpoint of fire protection.

1. Water-wheel type generators are of relatively large diameter. This means that the armature windings occupy a considerable circumferential length. For instance, in the 65,000-kv-a. generators to which reference was made, the circumferential length of the armature windings is approximately 75 ft., whereas in turbo generators the diameters are small and the windings concentrated into a much smaller space. The significance of this fact is that it ought not to be necessary to burn up a whole winding, say 75 ft. long, on account of a fire starting at one point.

2. Water-wheel type generators are usually of open construction and employ an open system of ventilation as contrasted with the closed systems now usually employed with turbo generators. It is, indeed, becoming more common to employ semi-enclosed systems of ventilation for water-wheel generators in which either the air inlet or air outlet is enclosed, but it is seldom that both inlet and outlet are enclosed, and no case is known to the writer where a completely closed system of ventilation with air coolers is employed with a water-wheel generator, although such a case may exist.

3. In turbo generators it is now usual to employ forced ventilation in which the air is moved by an external fan and directed in definite paths through the generator ventilating ducts. In water-wheel type generators, however, a natural system of ventilation is usually employed in which the air is moved by means of the natural blower effect of the generator rotor, sometimes assisted by fan blades attached to the rotor, and sometimes, also, by an external blower the only function of which, however, is to bring the air to, or remove it from, the generator. This method usually results in a considerable circumferential motion of the air around the armature windings, particularly about those portions of them which project beyond the iron core. These end projections are frequently insulated with inflammable materials, and on account of this and their extent and exposure to the whirling air currents, they constitute the principal element of fire hazard in the generator. In many cases of fires which have occurred in generators of this type, it has been the experience that a fire originating at one point of the circumference has been communicated very quickly throughout the entire circumference of the generator through the agency of these whirling currents of air. When this occurs, it usually results in the loss of the entire winding, if, indeed, damage does not also result to other parts of the

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structure. In large machines this involves a very considerable direct loss which, however, is usually exceeded by the cost of the loss of use of the machine while repairs are being made. The latter is of especial significance in hydroelectric plants where it is unusual to find spare capacity available.

Figs. 1 and 2 are cuts made from photographs of the results of fires in the armature end projections of two horizontal-shaft water-wheel type generators. Both of these started from faults in the armature coils, and within a few seconds after starting, the flames had been swept completely around the circumference of the machine. Eye-witnesses state that within one minute after these fires started, the iron shields covering the end projections of the armature windings were at white heat. One of these fires occurred in a machine with completely closed ends and the other in one with partially closed ends, but the results were the same in both cases.

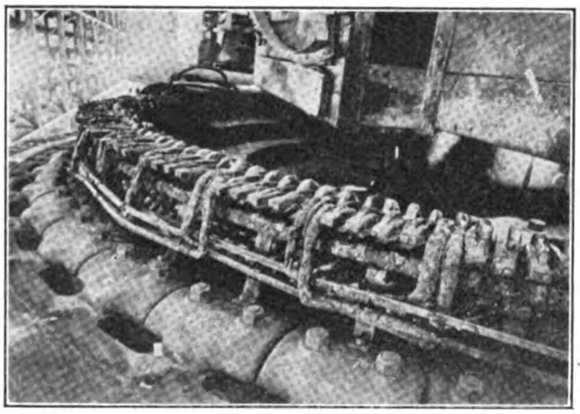

Fig. 1

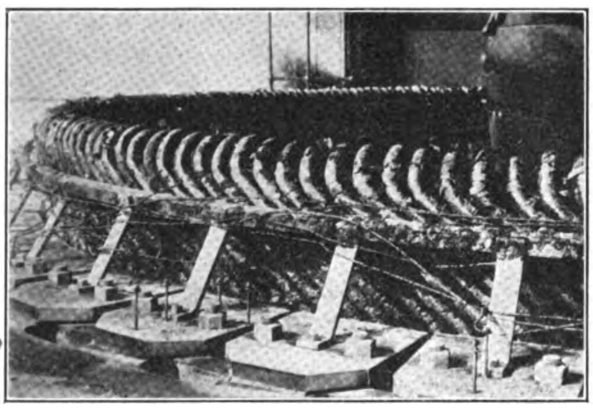

Fig. 2

Figs. 1-2—Effect of Whirling Air Currents on Fire in End Windings of Generators

In view of these considerations, it would appear that, whereas in steam turbo generators the most promising element with which to work for fire protection is the *composition* of the ventilating atmosphere, in water-wheel type generators the *directing* of the ventilating atmosphere in its passage through the machine appears to offer the most promising opportunity for the control of fire.

In any complete system of fire protection there are four necessary elements:

1. Prevention; that is, means should be provided to prevent, whenever possible, the starting of a fire.
2. Control; that is, assuming that a fire has started in spite of preventive methods, means should be provided to confine the fire to as small an area as possible.
3. Detection; means should be provided for promptly detecting the presence of a fire, and it is desirable that such means should also give an indication of its location.
4. Extinguishment; a fire having occurred, means for its prompt extinguishment should be provided.

Prevention

The only inflammable material built into a generator is the insulation. The use of non-combustible insulation, if that were possible, would therefore be the best fire preventive. Even Class "B" insulation as now employed, however, contains a considerable amount of inflammable material used as a binder, and the requirement for flexibility often dictates the use of fibrous or Class "A" materials on the armature end projections. Generator windings often also accumulate, between cleanings, considerable quantities of oily dirt of an inflammable nature, so that even the use of fire-proof insulation cannot always be depended upon to make a fire impossible.

Generator fires are usually caused by insulation breakdown. One obvious means of fire prevention, therefore, is to use a high factor of safety in the insulation of the windings.

Should a failure occur, however, the next obvious thing to do is to disconnect the generator from the system and remove its excitation as quickly as possible. This is best accomplished by means of differential relay protection in a manner now well understood and almost universally used. Such a differential relay system should be sensitive, and, from the fire prevention standpoint, should be arranged to de-energize the machine as promptly as possible. Reference is made to the recently published Relay Handbook for details of such applications.

Control

In spite of all that may be done in the use of fire-resisting nsulation, in preventing insulation failures and in de-energizing the machine in the event of a failure, a fire may nevertheless occur. In one case known by the authors, a stubborn blaze was initiated in a mica-insulated generator winding by an insulation breakdown on over-potential test with a 50-kw. testing transformer equipped with an instantaneous trip. Owing to the energy stored in the magnetic circuits of the generator, it is impossible to de-energize a machine instantaneously, and the writer therefore sees no reason

to believe that even the differential relay system will necessarily prevent the starting of a fire.

Assuming, therefore, that a fire may be started, the next problem is to prevent such a fire from spreading, or in other words to confine it to the smallest possible zone. Here appears the virtue of controlling the direction of flow of the ventilating air as it passes the generator windings. The minimum fire-spreading effect will result if the air currents are directed radially through the generator winding with complete suppression of the circumferential component of the movement. The requirements for cooling, of course, necessitate that some air shall be allowed to pass through and around the armature windings. Through the core, ventilating ducts are provided for this purpose. It has been customary, however, to permit the air to flow about the projecting ends of the armature coils in any manner which might result from the chance arrangement of the parts without any specific provision for guiding it in any particular direction, radial or otherwise. The result has been the production of a large circumferential component of air velocity in the neighborhood of the armature end projections.

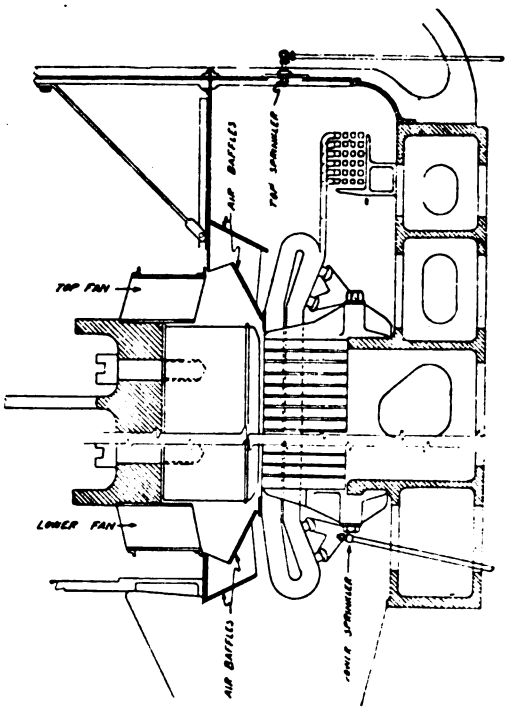

Fig. 3

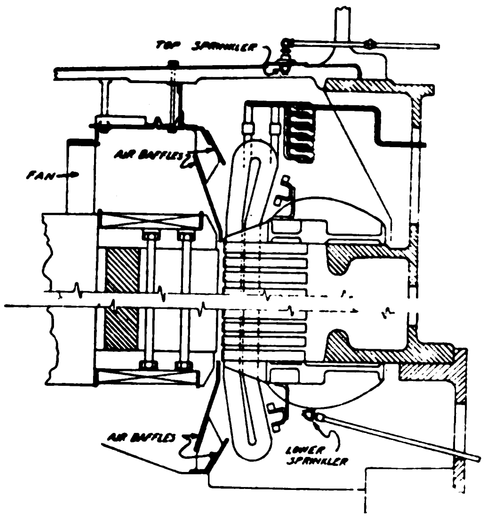

Fig. 4

Figs. 3-4—Cross-Sections Showing Applications of Fire Baffles to Two Designs of 65,000-Kv-a., Vertical Shaft Generators

To rectify this condition, the idea was conceived of placing between the rotating field and the armature end projections a stationary structure of some sort for the purpose of guiding the air currents in a radial direction through and between the armature end projections. Such a structure might be of a number of different forms, such as, for instance, a perforated wall, or a series of vanes which might be of any required shape, or an arrangement of baffled passages. After considerable study of these three alternatives, an arrangement of passages between two inclined walls was adopted for the 65,000-kv-a. generators. Figs. 3 and 4 show the application of this scheme of air control to the two makes of 65,000-kv-a. generators installed by The Niagara Falls Power Company, and Fig. 5 is a reproduction of a photograph showing the baffles installed at the lower ends of the coils in one of the generators. In order to prevent the generation of eddy currents in these baffles due to their presence in a strong varying magnetic field, they are made of insulating material.

The effectiveness of these baffles in directing the air through the end windings is very marked, the hurricane of air usually found about the armature end projections in conventional machines of this type being entirely absent from the machines equipped with these baffles.

The effectiveness of the radially directed air currents in preventing the spread of a fire was demonstrated by means of tests on a full scale model of a small section of one of these generators. These tests will be hereinafter described, and seem to indicate that by this means a fire may be confined to a circumferential length of not over two ft.

Detection

A fire having been started, it is, of course, desirable to detect its presence immediately, and since we have now found means of confining a fire to a small section of the winding, means of locating it in the machine are also desirable. In the case of the 65,000-kv-a. machines, the heated ventilating air is collected in a steel housing which surrounds the armature frame and is thence blown out of the building by means of separate motor-driven blowers. This arrangement would lend itself very readily to a system of smoke detection involving the use of a photo-electric cell. Such a system has not, however, been installed. Various detectors based on

abnormal temperatures might also be employed; one device suggested consists of a fuse wire carried around the generator and arranged to give an indication upon being fused at any point. Another possible device would be a vapor tension thermometer with its bulb in the form of a long slender tube extending completely around the machine. This would indicate the maximum temperatures at any point throughout the length

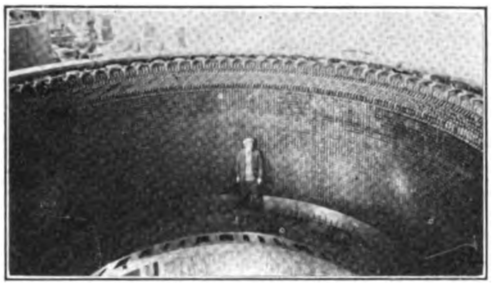

Fig. 5—Fire Baffles Installed at Lower end of Armature of 65,000-Kv-a. Generator

of the tube. A third system of giving the indication of the presence of a fire is the use of sprinkler heads in which case the means of detection and of extinguishment are combined. With any system the provision of hand holes at frequent intervals about the circumference of the machine is desirable both for the purpose of locating the fire and for allowing access to it by means of hand extinguishers or a fire hose. The combination of sprinkler heads and hand holes was used in the 65,000-kv-a. generators (Fig. 6).

Extinguishment

A number of mediums are now available for extinguishing fires in electrical apparatus, the principal ones

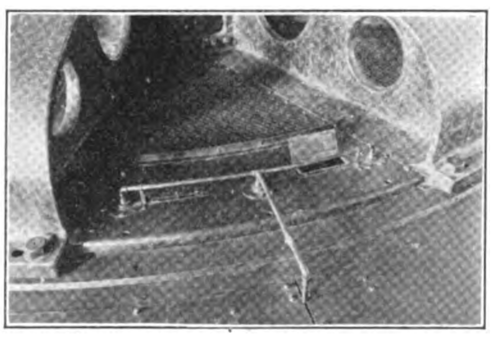

Fig. 6—Hand Holes and Sprinkler Heads at Top of 65,000-Kv-a. Generator

being water, steam, carbon dioxide, carbon tetrachloride, "Fire Foam," and the well-known soda acid extinguisher. These may be applied in various ways; for instance, soda acid, "Fire Foam," and carbon tetrachloride are usually applied by hand or portable tank extinguishers. Water or steam may be applied through a hose; or water, steam, "Fire Foam," and carbon dioxide may be applied through permanent piping.

In the case of the 65,000-kv-a. generator at Niagara, the means provided for extinguishment consist, first, in a series of hand holes giving access to the windings for the use of hand or portable extinguishers or water hose. There is also installed at suitable points near the armature end projections, a series of sprinkler heads connected by piping through a manually-operated lever valve to a source of water under pressure. This sprinkler pipe is arranged to be maintained under air pressure with a contact-making gage adjusted to sound an alarm upon the reduction of this pressure through the blowing of a sprinkler head (Figs. 7, 8, 9, and 10).

It has been ascertained by means of tests upon the above mentioned model that a fire can be maintained for a considerable length of time under the system of air control installed in these machines without spreading appreciably beyond its point of initiation, so that upon

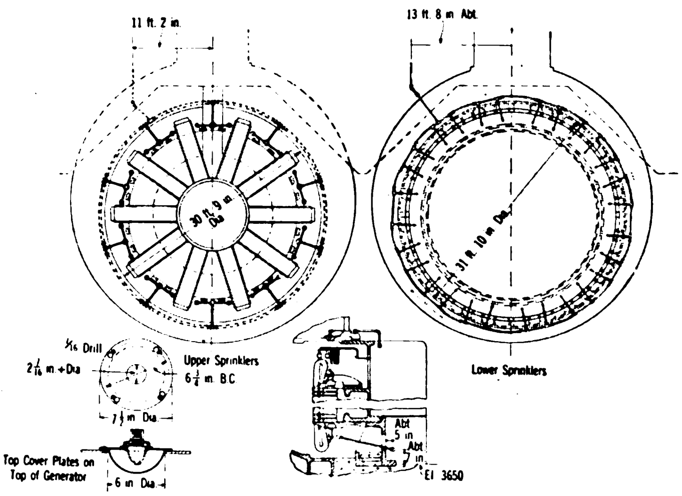

Fig. 7—Details of Sprinkler Head and Piping Installation in 65,000-Kv-a. Generator

occurrence of a fire, the operator has ample time to determine its location by inspection through the hand holes. Having located the fire, the operator is instructed to attempt its extinguishment first by means of hand or portable extinguishers using carbon tetrachloride or "Fire Foam." Should these prove insufficient, he can employ the soda acid extinguisher, or if his judgment indicates the necessity, he can turn on the water in the sprinkler system by means of the above mentioned lever valve. In this event the application of the water will be limited to one or two sprinklers which will have opened immediately adjacent to the fire, so that the water damage will be confined to as small a portion of the machine as possible.

If the use of carbon dioxide for fire extinguishment is perfected to a point where it is applicable to machines of this type, there would appear to be no reason why the general system of protection installed in these machines would not be readily adaptable to its use. It would appear that the baffles between the rotor and

armature coils might be of material assistance toward the effective use of carbon dioxide.

Details of Installation on 65,000-kv-a. Generators

These are shown in Figs. 7, 8, 9, and 10. The air baffles are constructed of bakelized canvas or asbestos supported by suitable castings with radial vanes forming passages for the cooling air.

The sprinklers are of modified standard design and are enclosed in baskets of sufficiently fine wire mesh to retain the loose parts resulting from a blow-off.

Separate piping systems are provided for the top and bottom ends of the armature windings with separate alarm signals so that a fire may be immediately located with respect to the two ends of the generator.

The manually-operated control valves shown in Figs. 9 and 10 are normally sealed in the closed position and are so arranged that any leakage of water into the sprinkler piping which may take place is caught in a sump and may be periodically drained off. The opening of the valve for draining the sump will automatically test the alarm system by lowering the air pressure in the sprinkler system.

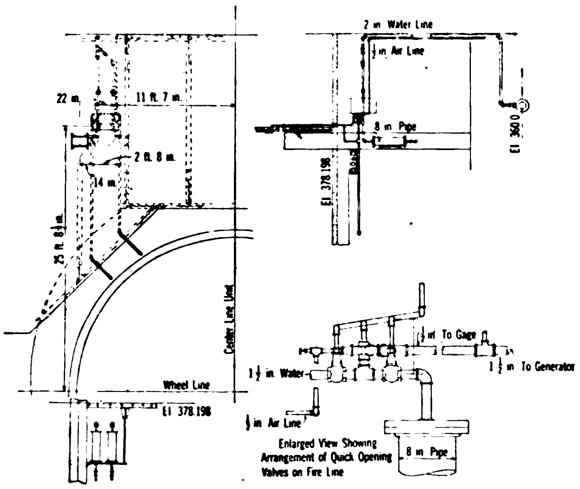

Fig. 8—Layout of Air and Water Piping, Three-Way Valves, Sumps and Contact-Making Gages

The air valves through which compressed air is supplied to the sprinkler pipes are of the needle type and may be kept slightly open so as to automatically maintain the air pressure so long as all sprinkler heads are intact. Upon the blowing of a head, the pressure will drop due to the throttling effect of the needle valve and the alarm will be given.

The contact-making pressure gage is of standard design arranged to close a contact upon a drop in pressure to a predetermined value. Any desired form of alarm can be used.

Tests

Before adopting the above described system of protection for the 65,000-kv-a. generators, a series of tests was made to determine the best type and arrangement of sprinklers, to determine whether the temperatures produced by a fire would be sufficient to operate standard sprinkler heads, and whether the air control devices proposed would be effective in confining the fire to a small area.

The first series of tests was taken to determine the following points:

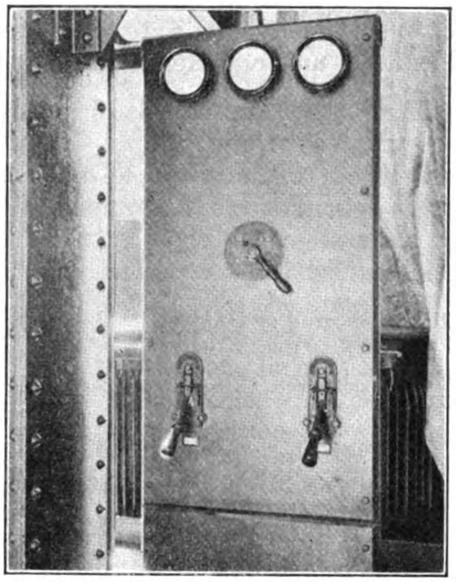

Fig. 9—Arrangement of Handles of Three-Way Valves and Contact-Making Pressure Gages

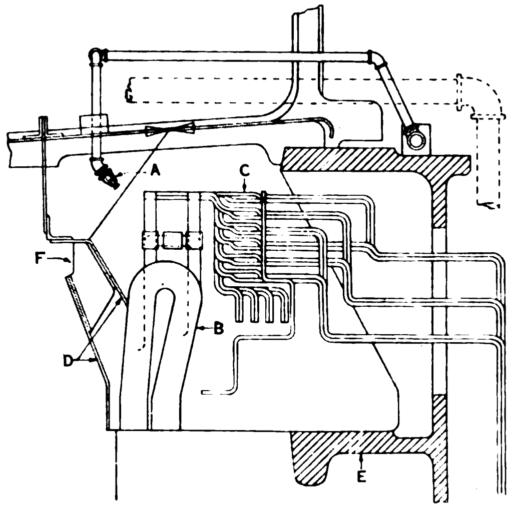

Fig. 10—Sectional View of Generator

Showing relative location of end windings, connections and sprinkler. A—sprinkler, B—stator coil, C—stator connections, D—fire bafflers, E—stator frame, F—air inlet

1. Location of sprinkler heads with respect to generator windings.

2. Design of sprinkler-head deflector.

3. Design of screen to catch links or parts which fly out from sprinkler heads when they operate.

It was impossible to make the proposed tests on one of the 65,000-kv-a. generators; therefore it was desirable

to make the conditions under which the tests were to be taken as near like actual conditions as possible.

Fig. 10 shows a section of the generator with location of sprinkler head as originally estimated to be approximately correct. Fig. 10 also shows the relative locations of the stator-coil end windings, stator connections, and fire baffles, and also shows the relatively small amount of space above the electrical parts in which to locate the sprinkler heads.

In order to see exactly how water would spray from the sprinkler heads under different conditions, a dummy

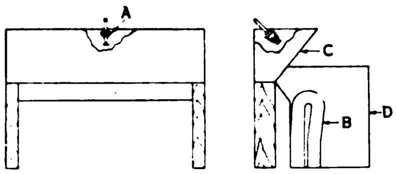

Fig. 11—Dummy Section of Generator Used in the Water-Spray Tests

A—Sprinkler, B—stator coil, C—screen, D—beaver board

section of the generator was made up in the form of a wooden box as shown in Fig. 11. This box represented at full scale one of the generator sections in which a sprinkler head was to be located. The length of the box represented the length of one of these sections measured on the circumference of the generator at the air-gap. On account of the size of the 65,000-kv-a. generators, the air-gap did not vary far from a straight line in the length of a section being considered; therefore for our test purposes, the box was made without curvature.

The ends of the box represented the barriers to be placed between sprinkler heads. Side pieces made of beaver board were fastened to the ends of the box, and on each a stator-coil end projection was drawn in its relative position as shown in Fig. 11.

A screen was placed across the front of the box as some such protection would be needed in actual practise to keep the links of an operated head from dropping down into the generator windings. Medium-weight wire screening was used, having five wires per in. each way, it being found by trial that links from the sprinkler heads would not go through mesh of this description, while they would go through mesh having wires of the next greater standard spacing.

In this first set of tests no fire was used, as the principal object was to determine how well water would be sprayed into the generator windings and connections under different conditions. As fires in generators usually occur in the stator-coil connections or stator-coil end projections, it was necessary in the tests to find an arrangement in which water would reach these parts effectively.

Before taking the tests it was quite obvious that water could be sprayed in large quantities on the stator windings and connections directly in front of the sprinkler, but it was not certain just what position of sprinkler head and type of deflector would give the best water distribution over the entire area to be considered. From Fig. 11 it can be seen that the area to be covered was much longer than it was wide, but it was just as important that the water reach the coils at the ends of a section, or in other words, that it reach coils midway between two sprinklers, as it was to reach the coils directly in front of the sprinkler.

In the sprinkler tests, over two dozen different special deflectors were used, and several locations of sprinkler and angle of spray were tried. The water pressure, also, was varied to determine the effect of such a change on the water distribution.

Under each test the water distribution was observed and rated in five ways as follows:

1. Distribution and distance water sprayed directly in front of sprinkler head.
2. Amount and distribution of water sprayed onto beaver boards at side.
3. Amount and distribution of water backward into box.
4. Amount of water to reach upper corners at each side of box.
5. Spray of water in general.

Regarding the location of sprinkler head and angle of spray, the best results were obtained with the sprinkler head tilted down 45 deg. from horizontal and located in the box so that the center of the sprinkler-head deflector was five in. from the back and three in. from the top of the box.

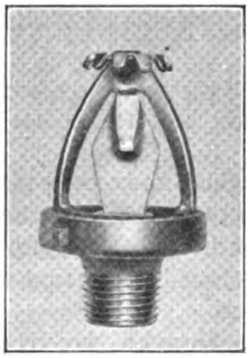

Fig. 12—Standard Sprinkler Head Used in Fire Protection of Buildings

If the sprinkler head was tilted more than 45 deg. from horizontal, an undue amount of water was sprayed into the box; and if the angle was made less than 45 deg., a larger portion of water than necessary was sprayed out directly in front.

Fig. 12 shows a common type of sprinkler head as generally used in fire protection of buildings. It will be noted that the deflector used at the top of this sprinkler has projections or ears around its outer edge which are bent downward. It was quite obvious that this type of deflector would not meet our needs, as the bent

ears have a tendency to spray a larger portion of the water backward.

After many tests were made in which a large number of different deflectors was used, it was found that a deflector as shown on sprinkler head in Fig. 13 gave the best results. This deflector, which is approximately 13/16 in. in diameter and is cupped upward slightly, happens to be a deflector which is used on many sprinkler heads in mills where the projecting ears of the standard sprinkler are objectionable. When used in mills, however, the deflector is cupped downward instead of upward.

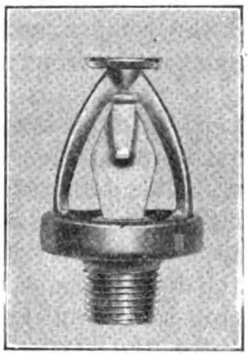

Fig. 13—Sprinkler Head Used in 65,000-Kv-a. Generators

In order to show how the design of a deflector affects the water distribution, a few of the deflector tests will be described.

1. Deflector in accordance with Fig. 13. The water was sprayed a distance of six ft. out in front of the box, and the beaver boards at the sides were well covered. Some water was sprayed backward into the box. With this deflector, the water was discharged in a fine spray which almost resembled a fog. The distribution of water over the desired area was very good.

2. Same as (1) except that deflector of larger diameter was used. Water was sprayed farther out in front than in case (1), but the spray was not as fine and the general distribution was not as good as in case (1).

3. Deflector in accordance with Fig. 12 except that all but two ears on opposite side were cut off. (It was thought that the two remaining ears might help throw more water out to the sides.) Water was sprayed farther out in front than in case (1). Water spouted up at ears, but distribution at sides was not as good as in case (1).

4. Same as (3) except that all ears were cut off. Results were about the same as those of (3).

5. Same as (1) except that deflector was inverted and therefore cupped down instead of up. Less water was sprayed out in front than in case (1). Practically no water reached the beaver boards at the sides. Large amount of water discharged back into the box.

The deflector tests such as described above were taken with a medium water pressure of 43 lb. per sq. in. With deflector used in case (1), the water pressure was increased to 100 lb. per sq. in. With this pressure the spray became extremely dense, and the distribution of water remained good.

By decreasing the water pressure it was found that the quantity of water and the distribution of water was satisfactory down to a pressure of 30 lb. per sq. in. With a pressure of 25 lb. per sq. in. the results were only fair; therefore it was felt that in practise the water should be held up to at least 30 lb. per sq. in. This matter of water pressure can be easily taken care of in case of the 65,000-kv-a. generators, as the normal water pressure in the station is approximately 80 lb. per sq. in.

The principle of operation of the sprinkler heads used may be seen from the construction shown in Figs. 14 and 15. Fig. 14 shows the cross-section of a sprinkler head and position of links before the head has operated, and Fig. 15 shows the same head with position of links shortly after the head has operated.

It may be noted that the links of a sprinkler head are small levers so assembled that they can be held together in the normal position before operation by a very small amount of solder. By using solders of different melting points, the sprinkler heads can be made to operate over a wide range of temperatures.

Ratings of sprinkler heads have been standardized so that a head may be obtained having a rating of 155,212,286 or 360 deg. fahr. For each different rating the composition of the solder is such that the heads will operate at a temperature corresponding to the rating.

In order to make sure that sprinkler heads located in the 65,000-kv-a. generators as previously determined would operate satisfactorily in case of a generator fire, further tests were considered.

Actual fire tests seemed desirable, as it was not certain that heat sufficient to operate the sprinkler heads would have a chance to reach them in case of a generator fire. The ventilation of these generators is such that a current of air passes in a horizontal direction through the stator connections and end windings and then out through openings in the stator frame. It seemed possible that in case of a fire in the end windings or con-

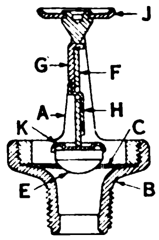

Fig. 14—Cross-Section of Sprinkler Head

Showing position of links before operation

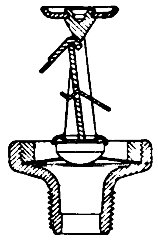

Fig. 15—Cross-Section of Sprinkler Head

Showing position of links after operation

A—Yoke. B—body. C—diaphragm. E—glass valve. F—main strut piece. G—hook link. H—key link. J—deflector

nections of one of the generators, sufficient heat to operate a sprinkler head might not pass up through this current of air.

Another point in question regarded the wire screen which was to be used to keep the links of an operated head from dropping down into the generator windings. It is known that a wire mesh offers some resistance to the passage of heat, and it was thought desirable to check this point in a test to find out if heat sufficient to operate a head in case of a generator fire would pass through the proposed screen.

In order that the second series of tests could be made

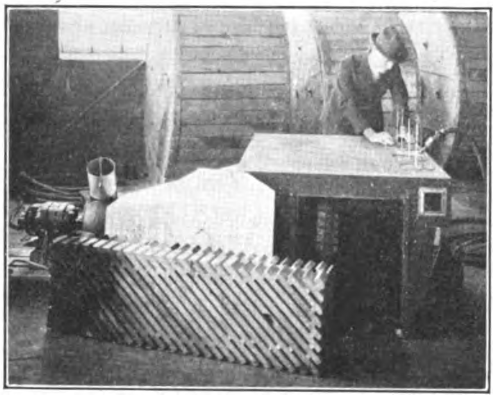

Fig. 16—Dummy Section of Generator Used in Fire Tests

conveniently, a dummy generator section was made of sheet metal. The construction of this compartment was such that, turned one way, it represented a section of the generator at the top of the machine, and inverted, it represented a bottom section of the generator. Dummy stator connections and stator-coil end projections were also constructed, these being made of wood. All parts were made to full scale.

Fig. 16 shows the dummy compartment in a position representing a top section of one of the generators. It may be noted that the door has been removed and the dummy coils taken out of the sheet metal compartment and placed in the foreground so that the construction may be seen. In the same figure, an end view of the dummy stator-coil connections may be seen in position in the compartment. The dummy connections and coils were made of boards one in. thick and spaced ½ in. apart. With this construction the wooden parts could be easily ignited for the fire tests.

A motor and exhaust fan were connected to the sheet metal compartment as shown in Fig. 16, in order that air might be circulated through the stator coils and connections in the normal way.

Provision was made for the mounting of a sprinkler head in the test compartment as previously determined. Four thermometers having 150-deg. cent. scales were suspended through small holes in the top of the compartment as shown. With the use of the thermometers, temperatures could be read at time intervals between the starting of the fire and the operation of the sprinkler head. By means of a hose, air pressure was placed on the sprinkler heads so that the operation of a sprinkler head would be known immediately by the rush of air.

Fig. 17 shows a cross-section of the test compartment described above with door removed and the dummy connections and stator end projections in their normal position. The location of the wire screen and fire baffles is also given. The small glass window in the end of the dummy section was provided so that the intensity of the fire could be watched with the metal door in place and the compartment entirely closed except for the air inlet in the front and the air outlet in the rear.

Shutters were placed in the air inlet and a damper in the air outlet so that the flow of air through the compartment could be regulated if desired.

With the test equipment arranged as shown in Fig. 17, the first set of fire tests was made. Fire was started at different places in the dummy connections and coils by means of a small rag soaked in kerosene. After a sprinkler head operated, the wooden parts were taken from the compartment and the fire was put out by means of steam.

In Fig. 18 some representative temperature curves are given showing the results of a few of the tests made with the fire started in the dummy coils. In these curves, temperature in degrees centigrade is plotted against time in minutes. In the first four tests shown, the shutters in the air inlet and the damper in the air outlet were open and the fan was running. In the last test shown, the fan was shut down. The four different curves for each test represent the readings of the four different thermometers which were numbered one to four from right to left facing the front of the

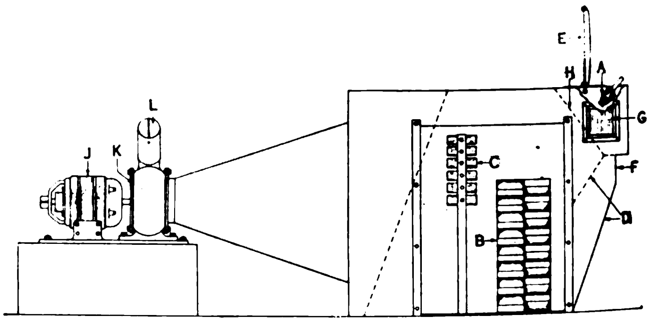

Fig. 17—Cross-Section of Sheet-Iron Dummy Compartment Used in Fire Tests

dummy compartment. Temperature readings were taken every quarter of a minute.

In tests 2, 5, and 7, 100-deg. cent. sprinkler heads were used and in tests 3 and 6, 68-deg. cent. heads were used. Facing the front of the compartment, the fire was started in the left end of the dummy coils in tests 2 and 3, and in the middle portion in tests 5, 6, and 7.

It should be noticed that in these tests the temperature curves become very steep close to the time of head operations. In fact, the temperature increased so

fast that the thermometers were raised out of the compartment in order to keep them from going off scale and breaking. This accounts for the fact that the curves do not in all cases extend to the vertical line which indicates the time of head operation.

As would be expected, the curves show that under similar conditions the 68-deg. heads operate sooner than the heads rated 100 deg., although the difference in time is small. By comparing test 2 with test 3, it may be seen that with the fan running and with the fire started in the left end of the dummy coils, the 100-deg. head operated in three min. and the 68-deg. head in 1¼ min.

Tests 5 and 6 show that under conditions similar to those described above except that the fire is started in middle of the dummy coils, the 68-deg. head operated in 2½ min. and the 100-deg. head in 3⅛ min.

It may be noted that in some of the tests the fire got started a little sooner than it did in other tests. This was due to the fact that steam was used to extinguish the fire and in some cases the dummy coils were left more moist than in others. By comparing tests 5 and 6, it may be seen from the curves that soon after the fire was started it required ½ min. longer in test 5 than it did in test 6 to reach a certain temperature. By making correction for this difference, the 100-deg. cent. head of test 5 would have operated about ½ min. sooner, or in approximately 2 ⅝ min., had the fire developed to raise the temperature as in test 6 where a 68-deg. cent. head was used. In other words, the difference between 2 ⅝ min. and 2½ min., or ⅛ min., gives approximately the difference in time between operation by a 100-deg. cent. head and a 68-deg. cent. head, under such conditions as existed in test 6.

In all cases it may be noted that the temperatures as measured with the thermometers exceeded the sprinkler head ratings before the heads operated. This does not mean that the heads were rated incorrectly but rather that with the temperature increasing rapidly, the time lag is greater in the sprinkler heads than in the thermometers.

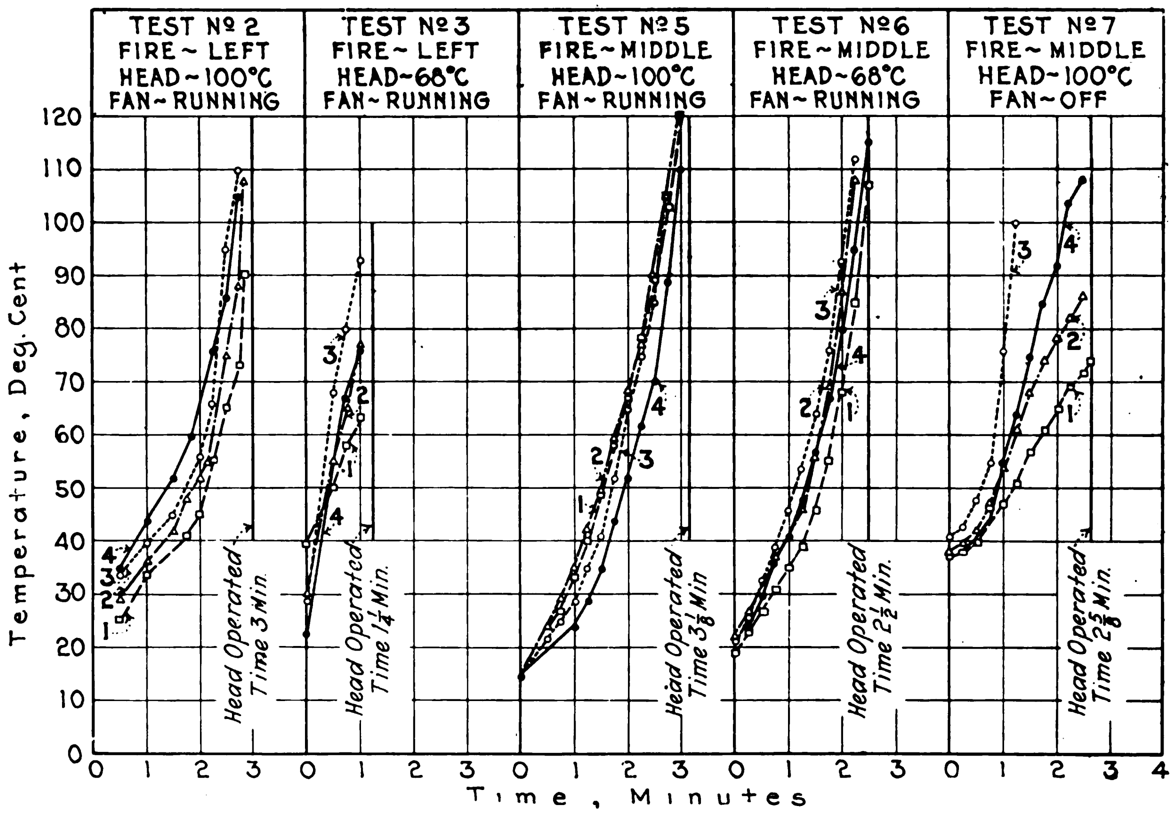

Fig. 18—Representative Temperature Curves

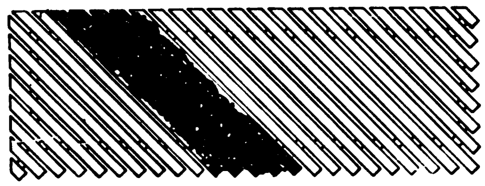

Fig. 19—Dummy Coils Showing Burned Portion

Fig. 20—Dummy Connections Showing Burned Portion

Fig. 19 shows the way the dummy coils were burned and charred in Test No. 5, this being a typical case. In this test the fire was started in the middle of the dummy coils, and it should be noted that the fire followed up the diagonal wooden members, but due to the strong current of air that was being blown through the dummy coils, the fire did not spread to the right nor to the left appreciably. Fig. 20 shows the way the dummy connections were burned in the same test. Later a similar test was made in which the fire was allowed to burn for 15 min. in the dummy coils. The results were about the same in that the fire spread very little. This is a very important point since the fire damage can be reduced to a minimum if the fire in coils of generators can be prevented from spreading.

In test No. 7 the fan was not running; otherwise the test is the same as test No. 5. By comparing tests Nos. 7 and 5, it may be seen that the operating time is 2 5/8 min. in one case and 3 1/8 min. in the other, which shows that the current of air passing through the compartment has very little effect in the operation of the sprinkler heads.

Another set of tests was made with the fire located in the dummy connections. By moving the sprinkler heads back slightly from their first position, very good operation of the sprinkler heads was obtained. The operating time was approximately 1 3/4 min. for the 68-deg. head and approximately 2 1/2 min. for a 100-deg. cent. head.

With the dummy sheet metal compartment inverted, an additional set of tests was made to determine the effectiveness of the sprinkler heads in protecting the stator-coil end projections at the bottom of one of the 65,000-kv-a. generators. For this case, the operating time was about 2 1/4 min. for the 68-deg. cent. heads and approximately 3 1/2 min. for the 100-deg. cent. heads.

Conclusion

The tests proved conclusively that the proposed scheme of fire protection as described would be very satisfactory for the 65,000-kv-a. generators for the following reasons:

1. Sprinkler heads arranged in the generator as shown and properly spaced would operate for a very small fire in the stator end windings or stator connections.
2. Sprinkler heads would operate in spite of the air currents, which, in case of the coil projections and connections at top of generator, would tend to carry the heat from a fire away from the sprinkler heads.
3. With current of air flowing radially through the end windings and connections, a fire started in these parts is confined to a small section even after the fire has burned for as long a time as 15 min.
4. If a fire started in the generator windings cannot be extinguished easily with hand fire extinguishers, the operator can then turn a valve which will allow water to be sprayed effectively in the region of the fire only, thereby doing minimum damage to the remainder of the machine.

The authors wish to acknowledge the valuable assistance given by Mr. Ira Knight of the General Fire Extinguisher Company, who furnished equipment and helped to carry out the water spray tests.

Power Generation

Annual Report of Committee on Power Generation*

VERN E. ALDEN, Chairman

To the Board of Directors:

Last year's report of this Committee reviewed the many important developments in the art of power generation and dealt particularly with advances in steam station design and operation. As a committee we were just a little prone to believe that there could not be the advance during 1925 that had taken place during 1924. Nevertheless, substantial progress has been made.

Important Technical Achievements of the Last Year

1. The 3000-kw. turbine designed for operation with a steam pressure of 1200 lb. per sq. in., which was referred to in last year's report, was placed in operation in the Edgar Station of The Edison Electric Illuminating Company of Boston in December 1925. This turbine, receiving approximately 125,000 lb. of steam per hr. from a single high pressure boiler, exhausts its steam first through a reheating superheater built into the same setting with the high pressure boiler. The steam is then delivered to the main steam header of the station at a pressure of approximately 350 lb. per

*Committee on Power Generation:

Vern E. Alden, Chairman, Consolidated Gas & Electric Company, Baltimore, Md.

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E. T. Brandon,	H. A. Kidder,	M. M. Samuels,
H. W. Eales,	J. T. Lawson,	F. A. Scheffler,
Louis Elliott,	W. H. Lawrence,	R. F. Schuchardt,
N. E. Funk,	James Lyman,	A. R. Smith,
C. F. Hirshfeld,	W. E. Mitchell,	Nicholas Stahl,
Francis Hodgkinson,	I. E. Moultrop,	W. M. White.

This report published in pamphlet form includes an extensive bibliography.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

sq. in. The most annoying trouble encountered in connection with this unit has been vibration incident to double winding on rotor and possibly undue flexibility in the rotor shaft of the generator which runs at 3600 r. p. m.

The rotor was originally of the built-up type with squirrel-cage winding in addition to the usual externally excited field. This arrangement was adopted as a precaution in case there should be governor trouble arising from the use of extremely high pressure steam. As the governing and synchronizing have proved to be perfect, however, the generator has been equipped with a solid field and all vibration has been entirely eliminated.

The action of the unit is perfectly normal and indicates that equipment of this character is suitable for regular commercial service, where economically justifiable.

This unit has had over 1800 hours of commercial operation including one run of over three weeks' time without a shutdown.

The performance of the Edgar Station has been highly satisfactory. Operated with a favorable load factor and good coal, the 350-lb. pressure plant has a record of one lb. of coal per kw-hr. which means practically 14,000 B. t. u. per kw-hr.

With the single high-pressure boiler and the 3600-kw., 1200-lb. pressure turbine in service, the average coal consumption per kw-hr. for the whole station is reduced three per cent. This indicates that if all four boilers were of the high pressure type, the fuel consumption per kw-hr. would be reduced 10 per cent, to a value of 0.9 lb. of coal per kw-hr.

2. With the exception of moderately high outages of the generating units, the operation of the Philo Station of the Ohio Power Company, the Twin Branch Station of the Indiana and Michigan Electric Company, and the Crawford Ave. Station of the Commonwealth Edison Company, all at a pressure of 550 lb. per sq. in. and a steam temperature of 725 deg. fahr. with the reheating cycle, has been quite satisfactory. The troubles encountered have been of a nature not entirely chargeable to the use of the higher steam pressure and temperature and the use of the reheating cycle. The indications are that these stations may be counted upon for thoroughly satisfactory and reliable service.

3. The Columbia Power Company's new 90,000-kw. station designed for operation with steam at a pressure of 550 lb. per sq. in. and a temperature of 725 deg. fahr. and for operation on the reheating cycle was started in December of last year.

4. Two more turbines have been purchased for the Crawford Ave. Station in Chicago, and a turbine has been purchased for Waukegan Station of the Public Service Company of Northern Illinois, all for operation at a steam pressure of approximately 550 lb. per sq. in. Two new stations have been designed for operation with this same pressure. There is accordingly either in operation at a pressure of 550 lb. per sq. in. or now projected a total of 925,000 kw. of power station capacity.

5. The Milwaukee Electric Railway and Light Company is installing in its Lakeside Station for operation at 1200 lb. pressure a boiler of modified Stirling type which will deliver steam to a 7000-kw. turbine, the steam temperature at the throttle being 720 deg. fahr. The steam will be exhausted through a reheating superheater into the main steam header of the station, maintained at a pressure of approximately 315 lb. per sq. in.

6. Of particular interest has been the increase in the size of turbo generator units as exemplified by the purchase during the last year of the following machines:

a. A 77,000-kw. and a 90,000-kw. unit purchased from the General Electric Company for the Crawford Ave. Station in Chicago.

b. An 80,000-kw. Westinghouse turbine for the Hudson Ave. Station in Brooklyn.

c. A 160,000-kw. turbine for the Hell Gate Station of the United Electric Light and Power Company of New York.

This trend towards the use of still larger units is further indicated by the projected use of turbo generator units of 200,000-kw. capacity in the New State Line Station near Chicago. It is to be remembered that the largest machine which we had to report upon twelve months ago was of 60,000-kw. capacity.

7. The first large furnace of the Fuller Well type designed for pulverized fuel firing with turbulent mixing of coal and air has been placed in operation under a 11,400-sq. ft. boiler in the River Station of the Buffalo General Electric Company. Three more boiler and furnace units of the same design are now being installed in the River Station.

8. The Combustion Engineering Corporation is advocating the use of an entirely new type of boiler which will completely surround a furnace built for pulverized fuel firing. It is proposed to transfer to an air preheater an extraordinarily large percentage of the work usually performed by the last passes of the boiler in scrubbing heat from the flue gases. This will result in the boiler itself being of relatively small area. Brickwork with its troublesome problem of maintenance is to be almost entirely eliminated.

It is reported in the technical press that the Combustion Engineering Corporation has contracted to install a total of 15 of these new boiler and furnace units in the stations of eight different companies. Each unit will be capable of evaporating approximately 100,000 lb. of steam per hour.

9. As indicative of the trend towards the use of very large boiler units we have the operation of one of the 26,470-sq. ft. Ladd boilers in the River Rouge Plant of the Ford Motor Company. The furnace for this boiler was rebuilt during the last year, water-cooled walls were installed, the pulverized coal feeders and

burners were revamped, and the boiler was equipped with air heaters and induced draft fans of ample proportions. Since being rebuilt this boiler unit has evaporated a total of 480,000 lb. of water per hr. which would correspond in a well designed steam generating station to a gross generation of 45,000 kw. in the turbine room.

10. The Milwaukee Electric Railway and Light Company has built a plant for the processing of coal, prior to its use in the boiler plant of the Lakeside Station. Coal in pulverized form while falling through two vertical retorts will mingle with rising currents of hot air and gas which will drive off a considerable amount of gas including the valuable by-products of the coal. The coke residue still in pulverized form, after being cooled in the hopper at the bottom of the lower retort, will be pumped to the pulverized fuel bunkers in the boiler house and burned in the furnaces. Equipment has been provided for removal of tar and benzol from the gas.

Experimental work extending over almost a year's time has indicated that no major difficulties will be encountered in operation. This installation in Milwaukee is well beyond the laboratory stage and provision is made for the expansion of this processing plant so as to take care of all the coal burned in the station.

This installation is of interest, as the successfulness of its operation will indicate the advantages which will accrue from the joint operation of our steam stations and low-temperature carbonization plants by means of which coal may be processed before being burned.

Trends in Steam Generating Station Design

Aside from the individual achievements referred to above there are certain definite trends in power station design and operation which should be noted:

1. The heating of the feed water to a temperature of from 350 to 400 deg. fahr. by means of steam bled from three or more stages of the turbine.
2. The removal of the heat in the flue gases after they leave the boiler by means of an air heater which returns this heat to the furnace.
3. The elimination of the economizer.
4. The wide-spread use of steaming surface for furnace walls and the elimination of a considerable part of the furnace brickwork.
5. The use of automatic control in the boiler house with consequent improvement in day-in and day-out operating efficiencies.
6. The use of separate ventilating fans in connection with very large generators of 62,500 kv-a. and higher capacities.
7. The use of relatively smaller surface condensers made possible by more careful design of the condensers themselves and by a better understanding of the relation of turbine performance to condenser performance.

Developments Immediately Ahead

The present combination of boilers and water-cooled furnaces which are, as one engineer expressed it, "fearful and wonderful jobs of plumbing," probably forecast certain changes in boiler and furnace design which will result in simplification and decreased investment, while at the same time maintaining what appears to be the most logical development of the boiler surrounding the furnace.

We are probably on the verge of being forced into the use of higher voltages in connection with the very large generators now contemplated.

Auxiliary Power Supply

Two phases of the auxiliary power supply problem are worthy of study by the members of the Institute:

1. Is the use of 2300 volts for distribution to the station auxiliaries the best choice, involving as it does the use of expensive oil-immersed switching equipment occupying expensive space? The alternative is a voltage of the order of 440 and the substitution of carbon circuit breakers and contactors for oil switches. This alternative offers distinct advantages from the standpoint of reduced investment in equipment and in building, and in greater ease of inspection and maintenance.
2. What is the best solution for variable speed drive of the forced and induced draft fans in our new stations? The difficult nature of the problem is exemplified by an installation in one of the new stations now being built: Two 200-h. p. motors drive the forced draft fans of each boiler and two 550-h. p. motors drive the induced draft fans for each boiler. The speed of the fans must be varied by 50 steps through a range from seven to one and the total h. p. input to the four fans varies from 1500 to 15. In this case the motors for the fans in connection with one boiler cost approximately $12,000 and the electrical control equipment for these motors cost approximately $20,000 and occupied a considerable amount of rather expensive space. If electrical engineers can not work out a simpler and less costly solution for this admittedly difficult problem, power station designers may have to return to the use of steam turbine drive for these fans, much as they may wish to avoid this solution, with its attendant use of reduction gears.

Use of Steam at Higher Temperatures

The use of higher steam temperatures of the order of 800 deg. fahr. and perhaps as high as 900 deg. fahr. is being forecasted by scattered operating experience, most of it unpremeditated. Due in the main to errors in superheater design the steam temperatures have been higher than anticipated in connection with some of the new stations. Some of these stations have operated for appreciable periods of time with steam temperatures in excess of 775 deg. fahr. One turbine operated for a time with steam at a temperature of approximately 1000 deg. fahr. There have been no serious indications of distress as a result of operation at these high temperatures. It has recently been reported in the technical press that a 40,000-kw. turbine in the Gennevilliers Station in France operated for 135 hr. during the

months of October, November and December of last year with steam at temperatures ranging from 775 to 914 deg. fahr. An inspection made December 25th showed no indications of deterioration of the parts in contact with high-temperature steam. The turbine was returned to service and has continued to operate satisfactorily with steam at temperatures varying all the way from 700 deg. to 900 deg. fahr.

These experiences together with the experience gained in the operation of oil stills tend to show that we can avail ourselves of the attractive possibilities incident to the use of steam temperatures considerably in excess of the present accepted limit of 750 deg. fahr.

Joint Use of Steam Stations and Water-Power Plants

Worthy of attention are three examples of the broad general solution of power supply by the combined use of steam generating stations and water-power plants in:

1. The construction of the 350,000-h. p. hydroelectric plant at Conowingo for joint use with 520,000 kw. of capacity in steam stations of the Philadelphia Electric Company.
2. The construction of a new 70,000-kw. steam generating station by the Southern Power Company.
3. The completion of a 128,000-kw. addition to the Long Beach Steam Station of the Southern California Edison Company and the starting of work by this same company on a new station of at least 600,000-kw. ultimate capacity with an initial development of 94,000 kw. The Southern California Edison Company has approximately 350,000 kw. installed in water-power plants.

Operating Reliability and Margin of Spare Capacity

The results of studies made jointly by a number of the operating companies of this country having for their purpose the determination of the operating reliability of our large generating units, are of considerable interest.

An analysis of the operating records covering the calendar year of 1925 for 191 steam turbines aggregating 5,627,000-kw. capacity showed that on an average these machines were in service 65.1 per cent of total hours in the year and that they generated 44 per cent of the maximum possible number of kw-hr.

These machines were idle because not needed 21.25 per cent of the hours in the year. For 13.63 per cent of the hours in the year, however, they were out of service for overhauling, inspection, maintenance work and cleaning, these outages being allocated as shown below:

Turbine outage	— 7.29 per cent
Generator outage	— 1.85 per cent
Surface condenser outage	— 3.51 per cent
Other causes	— 0.98 per cent
Total outages	—13.63 per cent

Comparing the foregoing results with the results of similar analyses made during previous years covering operation for the period from 1914 to 1923 inclusive, three things stand out in striking fashion:

1. There is little if any evidence to indicate the decrease which we would like to see from year to year in turbine outages.
2. Prior to 1923 the generator outage averaged 2.8 per cent of the hours in the year. For 1923 and 1925 the generator outage has averaged 1.8 per cent. These statistics are concrete evidence as to what the generally adopted closed system of ventilation has accomplished.
3. The surface condenser outage has increased from 1.2 per cent to 3.51 per cent of the total hours in the year. This increase serves perhaps as an index of pollution of the water in our rivers and harbors.

A study of the fact referred to above, that the outages due to causes other than the turbine, the generator and the surface condenser, aggregated only 0.98 per cent of the total hours in the year and that this item is of only seven per cent of the relative importance of the outages due to other causes, is cause for reflection. It is not recorded that Oliver Wendell Holmes was an outstanding engineer but any one of us would have been proud to have been the designer of as perfectly proportioned a piece of equipment as his "One Horse Shay." On an average the investment in the turbine room with its equipment is only 40 per cent of the total investment in the station, yet 93 per cent of the outages of station capacity are chargeable to the turbine room. Perhaps we have been failing to strike the proper balance between installed capacities, with their corresponding investments in the turbine room and in the boiler house with its related coal handling equipment.

Turning to a consideration of water-wheel driven generators, an analysis made by the Hydraulic Power Committee of the National Electric Light Association shows that the total outage time on these units is appreciably less than on steam turbines. The analyses covered the operating records for 1924 on 56 water-wheels aggregating 950,000 h. p.

These machines were in operation 77 per cent of the hours in the year and generated 48.1 per cent of the maximum possible number of kw-hrs. They were idle because not needed for service 17.62 per cent of the total hours in the year and were out of service for 5.4 per cent of the total hours in the year for reasons indicated below:

1. General hydraulic causes	—0.64 per cent
2. Water-wheels and auxiliaries	—3.01 per cent
3. Generators and appurtenances	—1.55 per cent
4. Electrical causes beyond the generator, related to switching equipment and outside transmission	—0.2 per cent
Total outages	—5.40 per cent

Outage time is related directly to the need for spare

capacity and the fixed charges on spare capacity constitute perhaps as much as 10 per cent of the total annual cost of power generation in steam generating stations. It behooves us to find ways of reducing this item of cost. A major responsibility in this connection lies with the equipment manufacturer. He must build equipment that will be capable of operation for all except a very few hours per year. Particularly must the manufacturer guard against any inherent weakness which will cause trouble involving unexpected shutdowns even though these outages be of short duration. Much can be accomplished by the engineer who designs the power station in foreseeing and eliminating certain features which may constitute the cause of an outage. The operating engineer can do much to control the necessary margin of spare capacity by the choice of the best operating methods, the careful training of personnel and by the careful scheduling of inspection, preventive maintenance and cleaning. With careful planning, a large percentage of outage time can be made to occur when the capacity is not needed for service.

Probable Useful Life of Steam Stations now Being Built

One of the most troublesome problems facing the executives of our large electric light and power companies today is "what to do with the old steam generating stations." Many of our large companies have sizeable blocks of capacity in steam generating stations in connection with which the coal consumption per kw-hr. generated is two pounds or higher. The costs of labor and maintenance are high. Viewed from the standpoint of operating costs (not including fixed charges), it seems nothing short of a crime to generate power in these stations, bearing in mind that the modern stations being operated by these same companies will generate power at a fuel consumption slightly in excess of one pound of coal and with much lower costs for operating labor and maintenance.

There is, of course, the possibility in some cases of rebuilding in part, at least, in order to improve the station performance. Notable examples of such programs of rebuilding are exemplified by the substitutions of unit coal pulverizers for the obsolete stoker equipment in the Brunots Island Station in Pittsburgh and in the Ashley Street Station in St. Louis. Some executives raise the objection, however, that such a procedure would, in connection with their stations, be sending good money after bad.

It is not our purpose to discuss this question of "What shall we do today with our old stations?", but rather to ask "What of the stations being built today in relation to our operating problems of 20 and 30 years from now?"

Assume, for example, that a company which had a system load of 400,000 kw. in December 1925 places in operation this year the initial 50,000-kw. unit of a new 300,000-kw. steam generating station. We will assume that the average annual load growth is nine per cent, that the yearly load factor is 56 per cent, and that the shape of the load duration curve is typical of load conditions in almost any one of our large cities on the Atlantic seaboard. An additional 50,000-kw. turbine must be installed each year until 1931 when the station will be completed. Since the station will be half completed in 1929, we may take the beginning of its useful life from that date. If we follow conventional lines of thought, we will consider the useful life of this station to extend from 1929 to 1949. What shall we do with this station in 1949? Conceivably the new stations being built in 1949 may generate power for 9000 B. t. u. per kw-hr., whereas the very best our hypothetical station, started in 1926, can do, even on the basis of a good load factor, is 14,000 B. t. u. per kw-hr.

The system load has grown, however, from 400,000 kw. in 1925 to 3,185,000 kw. in 1949. As the result of the inevitable law which pushes the old station a little higher each year into the peak of the load duration curve, we find that our 300,000-kw. station will generate in 1949 only 300,000,000 kw-hr. corresponding to an annual use factor of 11.4 per cent. As the result of the low load factor, the B. t. u. per kw-hr. has been pushed up to 17,000. The annual coal consumption is 190,000 tons and the annual fuel cost is, let us say, $1,300,000. By scrapping this station and substituting in its place a modern station of the 1949 vintage, we can reduce the annual fuel cost in connection with the 300,000,000 kw-hrs. of generation carried by this station from $1,300,000 to $800,000, with an annual fuel saving of $500,000. Few of us would dare to predict that this 300,000 kw. of new capacity built in 1949 will cost less than $18,000,000, or that the investment bankers of that day will be willing to finance new construction work at rates which would permit the increase in fixed charges incident to the construction of the new station to be less than $2,200,000.

The major increase on load on most of our large systems comes about as a result of increase in load density. Consider therefore the strategic position which the station built in 1926 will probably occupy with respect to the load as of 1949 or 1959.

It would appear that the engineers and executives of 1949 are going to have a very difficult time justifying the scrapping of our 300,000-kw. station of 1926 vintage. Such a step will be even more difficult to justify in 1959, for by that time the annual fuel cost in connection with this station will have dropped from $1,300,000 as of 1949 to approximately $125,000 per year corresponding to an annual station use factor of one per cent. The function of this station will have changed from that of generating kilowatt-hours to one of supplying kilowatts of capacity. It is to be understood that the foregoing analysis is based not on this station being held merely in reserve but on its carrying its proportionate share of the system peak load.

This analysis rather places the burden of proof on us to show good reasons why we should not design our stations on the basic assumption that they will be used and useful not merely for a period of 20 years but for 100 years, 200 years, or until such a time as the use of electrical energy as related to the life of our large cities and our nation has become no longer necessary.

This statement is not to be construed as an argument for the doing away with renewal reserves. Sound business principles indicate the advisability of accumulating ample renewal reserves.

It is intended to make the engineer who lays down the design of a new generating station ask himself certain questions:

1. Is the equipment well adapted to the load conditions which will obtain in connection with this station after it has become 20 or 30 years old? These load conditions will involve starting and stopping all turbines in the station twice each day, and the picking up of large blocks of load at a rapid rate. The boilers must be banked frequently and they must be able to pick up load quickly.

2. Is the design of the station such that the costs of operating labor and maintenance will be reasonable?

In the example outlined above, after 1955, the costs of operating labor and maintenance will exceed the cost of coal and in 1959 will be at least five times the cost of the fuel.

During its first 100 years of life, our hypothetical station will probably burn $90,000,000 worth of coal and require the expenditure of $80,000,000 for operating labor and maintenance.

Consider the tremendous advantage in connection with this type of operation which a station of consistent design with duplicate units of interchangeable parts, would have.

3. Will it be necessary, solely from a standpoint of being able to install more kw. of station capacity on the available ground area, to do a costly job of rebuilding in the future? Perhaps the very policy now being pursued by some companies in building stations in which extra space is provided in the initial section of the station, so that later units installed may be increased in size, is laying the ground work for an expensive rebuilding job 20 or 30 years from now.

4. With changed conditions which will exist fifty or one hundred years from now, and with the city pressing in on our station from all sides, will we still be able to live peaceably with our next-door neighbors?

5. Is the station design such as to form the proper economic balance between fixed changes and operating costs on the basis of one hundred or even two hundred years' life?

These and a host of other questions press for answers the moment you admit the possibility that the foregoing analysis may be correct. Perhaps those of us who are power station engineers and the executives making decisions bearing on power station design, had better try to find the answers to some of these questions. If we don't, we will probably be damned cordially by the men of the coming generation who will carry on our work.

WHY GOOD HEADLIGHTING IS DIFFICULT

Lack of sufficient light is a much more common cause of accident than is glare, statistics show, asserts the October issue of the *Journal* of the Society of Automotive Engineers. It defines the ideal headlight as one that shows with sufficient clearness all that a driver needs to see when the road ahead is free from approaching vehicles, and that projects very little light to the spot occupied by the eyes of an approaching driver.

Obviously no system of lighting can accomplish both objects at the same time. As roads are neither level nor straight, the eyes of an approaching driver may occupy almost any position in the pattern of light thrown by the lamps, hence no adequate lighting is possible that will not at times cause glare. Any practical system, therefore, must be a compromise.

The light beams thrown by lamps mounted rigidly on the car can be adjusted to any desired angle with the horizontal, but when once adjusted all changes in direction, both horizontal and vertical, of the axis of the car must be followed by the axis of the light beams. The requisite compromise in angle of tilt lies between an axis high enough for illumination of the road and low enough to avoid the eyes of an approaching driver.

A compromise effected by devices for tilting or dimming the lamps involves changing the light pattern when meeting other cars. The driving light may give the best pattern for open road driving and the meeting light the best possible illumination compatible with the interests of both drivers.

On all roads where touring speeds are safe very little light is needed or desirable on the road surface within 50 to 100 feet, but when meeting other vehicles bright illumination is needed in this area and on the shoulder and righthand side of the road. This makes it imperative that practically no light should be projected above the horizontal at any time, and the driver, in self-protection, is forced to depress his own lights, thus automatically protecting the other driver from glare.

The safety feature might be enhanced by arranging the system so that switching from one adjustment to the other would be accomplished by pressure of the left foot of the operator, the depressed beam being the one in use except when the driver holds the button down.

The Space Charge that Surrounds a Conductor in Corona at 60 Cycles

BY JOSEPH S. CARROLL[1] and HARRIS J. RYAN[2]

Synopsis.—*An exploring potential wire was used to locate the radial position and to determine the potential of the space charge that surrounds a conductor in 60-cycle corona. The familiar concentric cylinder set-up was used. The potential of the exploring wire due to the applied voltage and its position in the electric field between the conductor and cylinder was maintained at zero so that the potential on the wire was due only to the presence of the space charge. The cyclic potentials of the exploring wire at various radial distances from the conductor in corona at the center of the cylinder were observed with an electrometer of low capacitance connected through a phase-shifting synchronous contactor to the exploring wire and through its own capacitance to ground. The location of the space charge and the potential it sets up in the electric field in the space surrounding the conductor in corona were thus determined. The paper contains four sections: I—The Problem and Results, II—Description of the Apparatus Used and the Method of Application, III—Discussion, IV—Conclusions.*

* * * * *

I. The Problem and Results

When 60-cycle voltage is applied to a conductor high enough in value to produce corona, a corresponding *space charge* is formed and maintained about the conductor.[3,4,5,6] The *existence and magnitude* of the space charge have been studied heretofore[4,5]. The present studies were made with a potential exploring wire *to determine the radial position* of the space charge with respect to the conductor about which it was formed. The conductor was mounted at the center of a half-in. wire-mesh cylinder (see Fig. 1). Parallel thereto a potential exploring wire was mounted at various radial distances from the conductor, between it and the cylinder. Sixty-cycle corona-forming voltage was applied between the conductor and cylinder. In order that the potential to ground of the potential exploring wire would be due to the presence of the space charge only, the following arrangement was adopted: The high-voltage source-circuit was grounded at a point having the same potential as that of the position that was occupied by the potential wire in the electric field between the conductor in corona and the cylinder. By this strategy an electrometer of low capacitance could be used to measure the potentials of the wire caused only by the presence of space charges. It was thus necessary that the neutral of the high-voltage source-secondary could be changed through all intermediate values from zero voltage-to-neutral on the conductor and maximum voltage-to-neutral on the cylinder to maximum voltage on the conductor and zero voltage on the cylinder. This was accomplished by means of a potentiometer. The isolated secondary of the high-voltage source-transformer was loaded with a water column resistance containing a grounded floating electrode. The electrode could be passed freely from either end to any desired point in the water column.

When a space charge is formed about a conductor in corona a few of the ions constituting the charge go astray and diffuse widely through the air. The voltage is alternating and so is the space charge. Following the application to the conductor of a corona-forming positive voltage crest, the charge is made up of positive ions. The next voltage crest will be negative; it will discharge the positive ions in the space charge and set up in their place a corresponding charge of negative ions. The net result of the diffusion of the alternating positive and negative charges is a small but very real rectifying effect, negative at the start of corona and positive when fully established[7]. This rectifying effect may be due to the differing mobilities[8] of positive and negative ions in the atmosphere.

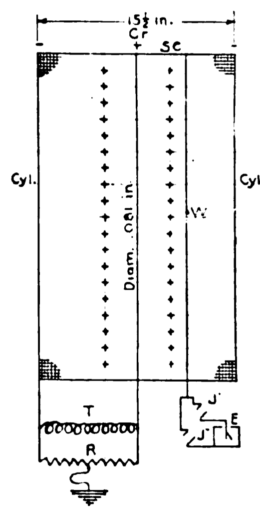


Fig. 1

1. Instructor and Graduate Student, Stanford University, California.
2. Professor of Electrical Engineering, Stanford University, California.
3. Franklin and McNutt, Lessons in Electricity and Magnetism, 1919 Ed., p. 148.
4. Ryan and Henline, *Hysteresis Character of Corona Formation*, Trans. A. I. E. E., Vol. XLIII, p. 1118, October 1924.
5. Hesselmeyer and Kostko, *On the Nature of Corona Loss*, A. I. E. E. Journal, Oct. 1925, p. 1068.
6. Ryan and Carroll, *On the Nature of Corona Loss*, Discussion. A. I. E. E. Journal, Feb. 1926, p. 175.
7. J. B. Whitehead and T. Isshiki, Trans. A. I. E. E., Vol. XXXIX. Part II, p. 1091.
8. R. A. Millikan, The *Electron*, 2nd Ed. (1924), p. 36.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

To obtain the cyclic relation of the voltage to the corresponding potential of the wire as affected by the presence of the space charge, a gold leaf electrometer having a small capacitance was connected to the wire by means of two synchronous contactors. The phase of one contactor could be shifted conveniently throughout a complete cycle. It connected the wire to the leaf deflector of the electrometer. The phase of the other contactor was fixed at an instant whereat the voltage

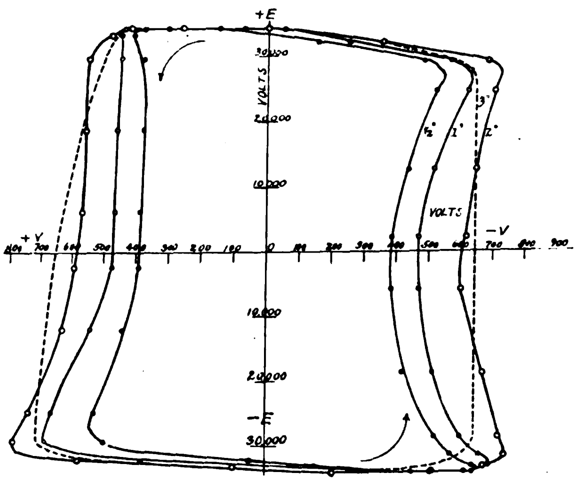


Fig. 2

applied between the conductor and cylinder was zero and the wire due to the space charge was not changing, or was changing very slowly. Thus the rectifying effect was eliminated. When the phase-changing contactor only was used and the leaf of the electrometer grounded, a positive charge on the electrometer was accumulated that varied with the change of the air currents through the open-mesh cylinder and about the conductor. This troublesome correction was avoided by the use of the two contactors just specified. The 60-cycle power supply for the high-voltage transformer was taken from a large power supply system. As the work progressed some inconsistencies in results were traced to variations in the supply voltage crest and the air density factors. In an intermediate stage of the work th' voltage was, therefore, controlled by crest corrected for barometric-temperature variations in lieu of effective values. Other inconsistencies developed and were found to be due to the shifting neutral in the water column and stray capacitances attached to the column and its connections. The remaining inconsistencies were found to be due to the corona-aging effect on the conductor whereby the voltage required to produce a given magnitude of space charge had to be increased. The voltage was increased slowly, of course, but nevertheless rapidly enough to require a corresponding control of the voltage so that in whatever radial position the potential exploring wire was being used and however long the time required to run through an entire series, the space charge had the same value throughout.

Corona began when the crest voltage applied between the clean conductor and cylinder reached 32,800. Visual corona was well developed over the wire with fair uniformity by the application of 34,400 crest volts. The corresponding "reading" on the space charge control electrometer was "23." By this control reading "23," the applied voltage was held to produce a constant space charge while the observations for six voltage-potential $(E-V)$ cyclograms were obtained corresponding to six different radial positions of the potential exploring wire. The following radial distances of the potential wire from the surface of the conductor were used, 0.5, 1.0, 2.0, 3.0, 4.5, and 6.0 in. The corresponding cyclograms obtained with the potential wire at these radial positions are reproduced in Figs. 2 and 3.

The character of the cyclograms changed decidedly as the radial distance of the potential wire was less or greater than about 2.8 in. A study of such changes reveals the fact that they are due to the inevitable shift in the space charge radially outward caused by repulsion during the quarter-cycle that followed the last voltage crest and again radially inward caused by attraction during the second quarter-cycle in which the voltage developed the next crest having an opposite sign to that of the potential of the space charge formed by the preceding crest. From inherent dimensional relations, such shift in the radial position of the space charge

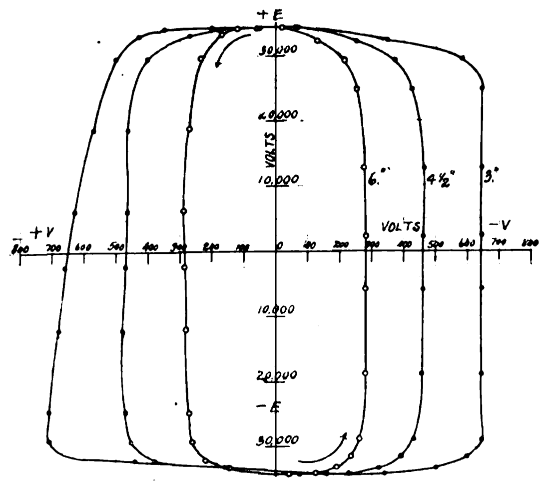


Fig. 3

affects the character of the cyclograms much more when the potential wire is inside the space charge and much less when outside. This change in the form-character of the voltage-potential cyclogram taken from the potential wire as the wire was shifted through the space charge was found to be as good a criterion for the location of the charge as the magnitude of the potential caused by the presence of the charge, which must be maximum when the potential exploring wire is located in its center.

If the space charge was placed in a fixed radial po-

sition as the voltage passes crest and falls below critical value, the voltage potentials due to the direct and reversed space charges would form approximately a rectangular cyclogram having straight parallel potential sides and slightly curvilinear voltage ends. Such was the case for the cyclograms taken from the potential wire when placed outside the space charge, while those taken from the wire mounted inside the space charge had decidedly concave sides due to the outward and inward movement of the space charge.

The understanding hereof is facilitated by the study of the curves in Fig. 4. Curve $I\ V^1$ was located by using the radial positions of the potential wire as abscissas and the corresponding observed potentials V_Q, due to the presence of the alternating space charge, as ordinates, occuring at the instant when the negative voltage crest has been completed. This curve locates a maxi-

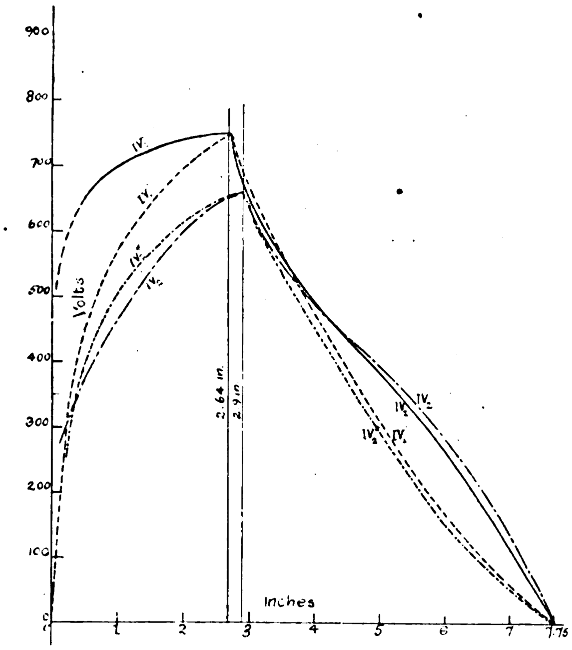


Fig. 4

mum for potentials for the wire placed at a radial distance from the conductor of 2.67 in. As a criterion for understanding the factors that determine the character of Curve $I\ V^1$, Curve $I\ V^2$ was located by commonly adopted theory on the assumption that the entire space charge is uniformly distributed about the conductor at the radial distance of 2.67 in.

At positions within the space charge, the potentials were observed to be well above those obtained by calculation on the assumption that this region was free of ions. The differences may be taken as a measure of additional potentials due to the presence of negative charges in such space. The direct inference is that not all of the space charge is located at the radial distance of 2.67 in., and that a small portion thereof is distributed through the intervening space.

At corresponding positions without the space charge, there is a close agreement between potentials by measurement and by calculation at first as the radial distance of the potential wire extends beyond 2.67 in. Beyond four in. the values of the observed potentials due to the presence of the space charge are higher than those by computation. The difference attains a maximum well out toward the surface of the mesh cylinder, let us say at a radial distance of about 6.5 in. This difference clearly indicates that while most of the charge occupies the cylindrical location at a radius of 2.67 in., some of it located in a broad zone at the 6.5-in. central radial position.

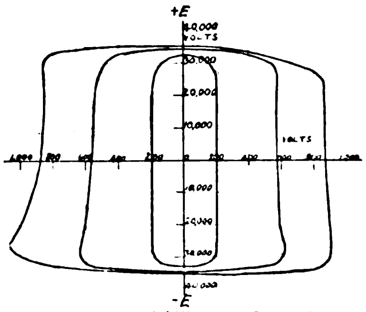
A quarter of a cycle, or 1/240 of a second later, the voltage was zero and curve $I\ V_2$ was correspondingly located by the $E - V_Q$ values taken from the cyclograms at that phase. It will be noted that the maximum potential in the charge had dropped from 750 to 666 volts and that the central position of the charge had been repelled from the radial position of 2.67 to 2.90 in. Curve $I\ V_2''$ was computed as the criterion to accompany Curve $I\ V_2$ on the assumption that all of the space charge was located at the radial distance of 2.9 in. from the conductor. A comparison of the two curves, the one observed and the other calculated for the phase whereat the voltage is passing through zero from minus to plus, reveals the fact that the observed potentials through the region within the main space charge at the radial distance of 2.9 in. are now less everywhere than the corresponding values by computation. The inference is that only a small distributed vagrant charge remains in such space and that its sign is positive whereas the sign of such vagrant charge was negative as the voltage was falling from a negative crest.

Radially beyond the 2.9-in. position, corresponding observed and calculated values have scarcely been changed by the migration of the space charge. All of this is in complete agreement with the characteristic difference in the cyclograms taken from the potential wire when located within and without the space charge. The curves show that the cyclograms should have the concave sides when observed within the space charge and straight parallel sides when observed without such charge.

It was shown by Hesselmeyer and Kostko[5] that voltage-charge $(E - Q)$ cyclograms obtained for a line in corona change only slightly in character as the frequency is changed from 60 cycles upwards to 120 and downwards to 10.5 cycles. Substantially the same must be the case for voltage-space charge potentials. It follows, therefore, that in all ordinary study of these phenomena cyclograms, giving the direct relation of voltage and potential due to space charge with time omitted is particularly helpful. However, there are many who are not accustomed to the study of these phenomena without their relation to the times at which they take place. To assist them and for those considerations wherein the time factor is of definite importance, all of the values occurring in the cyclograms are re-

peated in waves reproduced in Fig. 8, using times for abscissas and voltages or potentials as ordinates. The radial distances of the potential exploring wire are marked on the waves to facilitate their comparison with corresponding cyclograms.

A further study of the voltage-potential cyclograms through the second quarter-cycle after the voltage has passed a negative crest similar to that which was made with the contents of Fig. 4 reveals the fact that at the close of the first half-cycle, just before active ionization is resumed and before the process of reversing the negative space charge has begun, the potentials at the several radial positions within the space charge have again increased and returned nearly to their original values obtained at the beginning of the cycle. There is, however, much less difference between the potentials by measurement and by calculation, showing that the vagrant charges of opposite signs are nearly equal and generally distributed through the region with the space charge. So much for the fact. One may also infer that many positive and negative ions which are vagrant within this region have disappeared by recombination.



Potential Wire at 2.8 in. Radius

FIG. 5

To check this understanding as to the cause of the change in the form of the voltage-potential $(E - V_Q)$ cyclograms taken from the exploring wire when located within and without the main body of the space charge, the potential wire was kept at the 2.8-in. radial distance from the conductor, while three cyclograms were obtained each at a different value of corona-forming voltage. The values were so chosen that one was low enough to place the space charge between the wire and the conductor, another that would place it in the same radial position as the wire, and the third voltage high enough to place the charge well beyond the wire. The first or inner cyclogram thus obtained (Fig. 5) had the flat parallel sides indicating as anticipated that the exploring wire was located radially beyond the space charge; the second or middle cyclogram in Fig. 5 showed but slight departure from that of the preceding rectangular cyclogram; the third or outer cyclogram, Fig. 5, showed a well developed distortion of the rectangular form;—each, therefore, showed characteristics that had been anticipated.

With the potential wire left in the 2.8-in. radial position, the relation between the excess of crest over critical voltage, $E - E_0$, taken at the phase at which the value of the voltage E was zero and the potential of the space charge as given by the potential wire, was found to be *linear* between the limits used in this study, *viz.*, $E_0 = 32{,}800$, and $E = 35{,}200$ volts crest. The relation is given by the equation:

$$(E - E_0) = 2.80\, V_Q \tag{1}$$

Since V_Q is the value of the voltage to which the condenser between the space charge and the cylinder was charged as determined by the exploring wire, it follows that the drop in voltage through the ionized air when it was conducting the space charge to such condenser was

$$(E - E_0) - V_Q = 1.80\, V_Q \tag{2}$$

For example, when the value of E was 34,400, $(E - E_0) = 1600$, the space charge was located 2.8 in. from the conductor and its potential was observed to be $V_Q = 572$ volts; the measured difference that applies for conducting the space charge through 2.8 in. of ionized air was, therefore, $1600 - 572 = 1028$ volts, to check with $1.80 \times 572 = 1030$ volts, as given in (**2**).

For those who are interested in the equipment used to obtain these results, and the manner in which it was employed, Part II follows. It contains a complete description of the apparatus, connections, and procedure in making the observations.

II. DESCRIPTION OF THE APPARATUS USED AND THE METHOD OF OPERATION

In this description very little will be said of the "99 things" that were tried and did not work; however, it may be stated in passing that the only parts of the original set-up which were left were the wire-mesh cylinder, the copper conductor at its center, and the potential exploring wire.

Unfortunately, in the diagram of connections the relative importance of the various elements cannot be indicated by the amount of space they occupy on the paper. The cylinder of ½-in. mesh was 15.5 in. in diameter and 15 ft. long. It was mounted vertically, the lower end being four ft. above the floor of the laboratory. The No. 12 B. & S. G. copper conductor stretched tightly at the center of the cylinder was supported by hard rubber rods across the ends of the cylinder. Vibrations in the conductor were suppressed by means of silk thread guys in four directions to the cylinder at two points along its length. Both potential wires shown in the diagram were No. 20 B. & S. G. copper. The end supports were hard rubber. To keep the wires free from vibrations, ¼-in. hard rubber rods were extended, through wood blocks on the cylinder, radially inward until they just touched the potential wire.

The source of high voltage was a 60-kv. transformer, the secondary of which had no permanent ground. A high-resistance water column potentiometer was con-

nected across this secondary in such a manner that the ground could be made any place between the two high-voltage terminals of the transformer. This potentiometer consisted of two sections of ¾-in. garden hose each about 12 ft. long. These were mounted vertically on a steel tower just outside the laboratory. The total resistance across the secondary of the transformer remains constant at about 250,000 ohms. With this arrangement the exploring potential wire can always be kept at ground potential due to its position, *i. e.*, the voltage across the right side of the potentiometer is made equal to the voltage between the exploring wire and cylinder; likewise the voltage across the left side

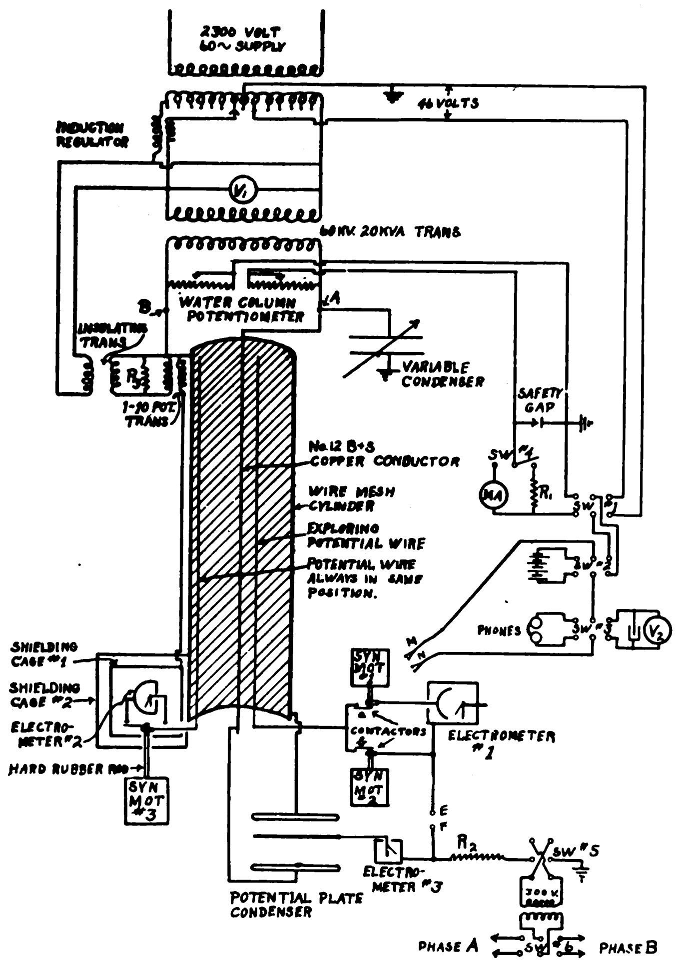


Fig. 6—Connections for Space Charge Study

is made equal to the voltage between the exploring wire and the conductor at the center of the cylinder. Since the potentiometer is grounded at the center, the exploring wire must therefore be at ground potential due to its position when there is no corona present on the center wire.

The correct position of the ground on the potentiometer is found as follows, after the exploring wire has been moved to the desired position. No one of the three synchronous contactor motors is running, contact (a) is left closed, (b) is opened, terminals E and F are connected together and the quick-acting, double-pole double-throw switches No. 5 closed either up or down, also switch No. 6 is open. The voltage on the 60-kv. transformer is slowly raised from zero by means of the tap transformer and induction regulator. Electrometer No. 1 will then indicate the voltage between the exploring wire and ground. The ground on the potentiometer must then be shifted until the electrometer shows zero voltage. Since the electrometer is not sufficiently sensitive at low voltages, a voltage is added to the circuit by closing switch No. 6 to phase A. This voltage is in phase with that applied between the No. 12 conductor and cylinder. The voltage used for this purpose is 300, which puts the electrometer leaf up into a sensitive position. If the potentiometer ground is not in the correct position, the exploring wire will have a voltage above ground that will increase the electrometer reading with switch No. 5 in one position and decrease it in the other position. The proper place for the ground on the potentiometer is that which gives the same electrometer reading for both positions of switch No. 5. With a little care, this ground can be set to within one volt in 25,000.

Since the position of this ground must be set below a voltage that will start corona on the conductor, some means must be established whereby it may be known when the position is correct at the operating voltage when the conductor is on corona. An arrangement must also be made to keep watch of this ground to see that it does not change on account of air bubbles in the water column, obstructions in the nozzles, shifting of the chain, or any other cause. To accomplish this, the potential plate condenser was built and connected in parallel with the conductor and cylinder. The condenser consisted of two cast iron disks 12 in. in diameter with amply rounded edges mounted parallel to each other about seven in. apart with a 12-in. aluminum disk as a potential plate ⅛ in. thick arranged to float between the two iron disks by means of a hard rubber rod and screw adjustment. This potential plate is connected to the leaf of electrometer No. 3, the case being connected to ground through the 300-volt transformer. When the position of the ground on the potentiometer is correct as shown by electrometer No. 1, the potential plate is raised or lowered until electrometer No. 3 shows no change on reversing switch No. 5. This means that the potential wire and the potential plate occupy the same electrical positions. Since there is no corona in the vicinity of this potential plate up to the highest voltage used, the correct position of the ground can be maintained by observing electrometer No. 3. This potential plate must obviously be reset each time the exploring wire is moved to another position.

There is another adjustment that must be made before the exploring wire is exactly at ground potential. If the charging current to ground from the apparatus and leads on one side of the high voltage transformer is not equal to the charging current to ground on the other side, the difference between these currents will flow

through one side of the potentiometer, thus shifting the phase of the voltage across this side with respect to the other, and making it impossible to find the correct position of the ground. To overcome this, a variable condenser must be connected on the side of the transformer furnishing the least charging current to ground. The test for the right amount of capacitance to be added is made by throwing switch No. 6 to phase B, which is in quadrature with respect to phase A. The variable condenser is then adjusted until the reading of electrometer No. 1 does not change on reversing switch No. 5. This adjustment must also be made each time the position of the exploring wire is changed, but when the balance is once made it will "stay put" and does not have to be watched. It is necessary when making this condenser balance to follow it up with the correct

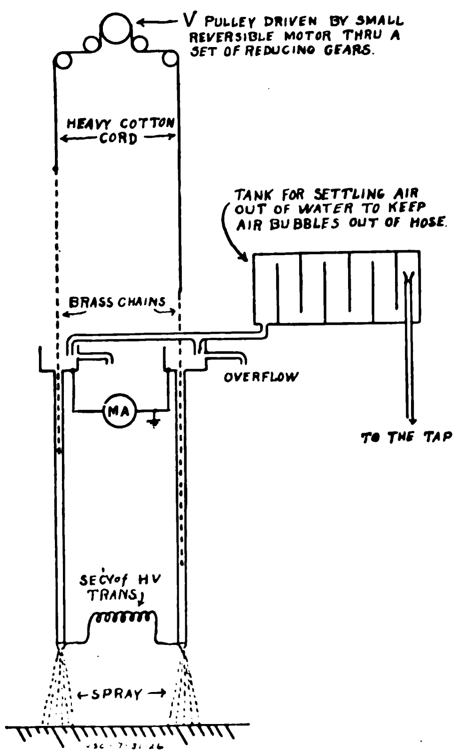


Fig. 7—High-Voltage Potentiometer

position of the potentiometer ground by occasionally throwing switch No. 6 to phase A. The exploring wire must truly be at ground potential when there is no change in the reading of electrometer No. 1 for phase A and phase B when switch No. 5 is reversed.

With the exploring wire at ground potential due to its position it will show no voltage until corona appears on the conductor; then the voltage it indicates on electrometer No. 1 will be that set up by the charge sent out by corona. The effective value of this voltage can be measured by disconnecting E from F and grounding E. However, we are not only interested in the amount of this voltage but also in its wave form. The latter was determined by means of synchronous contactors and the gold leaf electrometer No. 1.

The three synchronous motors shown in the diagram were four-pole, ¼-h. p. induction motors, the rotors of which had been slotted for salient poles. The motors were mounted vertically to eliminate end play, ball bearings being used for the upper bearing. The contactors consisted of a hardened steel pin and thin laminated steel spring, contact being made on the center lamination only. Synchronous motor No. 1 was supplied with voltage from a phase shifter consisting of a wound-rotor two-phase induction motor. The phase angle was read on a scale fastened to the frame with a pointer on the rotor shaft. Motors No. 2 and No. 3 were driven from a voltage supply having a fixed phase angle.

First, motors No. 1 and No. 2 are started up. To be sure that motor No. 1 has the same polarity each time it is started up, the clips M and N are connected across contact (a); E and F are not connected; and the double-pole, double-throw switches No. 1, No. 2 and No. 3 are all thrown to the right. The polarity of the motor must be such that the d-c. voltmeter V_2 reads positive when the phase shifter is on zero. To find the polarity of motor No. 2, the clips M and N are connected across the leads to electrometer No. 1, switch No. 1 is open, and switch No. 2 and switch No. 3 are closed to the left. By listening in the phones as the phase angle of motor No. 1 is shifted, a click will be heard at a certain position which means of course that contactors (a) and (b) are hitting at the same instant. The phase angle is then observed on the phase shifter scale.

Clips M and N are removed and voltage is applied between conductor and cylinder; when corona appears on the conductor, electrometer No. 1 will indicate a voltage due to space charge. The wave form of this voltage is determined by a step-by-step process. Contactor (b) was set so that it made contact when the applied voltage was zero; this was where the space charge was changing least rapidly. The phase angle of (a) was changed by means of the phase shifter and the angle read on the scale, the electrometer being read for each position. Readings were taken every 10 deg. where the voltage changed most rapidly and every 20 deg. on the flat parts. Suppose (b) is contacting at the point (x) on the curve taken at six in., and the phase shifter is set on zero; the difference in voltage of these two points on the wave, then, is 330 volts, which is read on the electrometer. The contactor (a) is set, say 10 deg. later, by means of the phase shifter and the voltage is found to be 420 and so on. When we get to, say, 240 deg., the voltage on the electrometer is practically zero, so that to get this half of the wave, motor No. 2 is slipped a pole, making the contactor (b) shift 180 deg. to (y), and then when the contactor (a) is on 240 deg. the voltage on the electrometer is 550.

In order to tie-in all the curves taken this way with the voltage wave, the exploring wire is disconnected from the contactors and the clips M and N are connected

across contactor (*a*). Switch No. 4 is thrown to the right, switch No. 1 left, switch No. 2 right, and switch No. 3 left. The phase shifter is then adjusted until there is no sound in the phones, which means that (*a*) is making contact when the voltage across R_1 is zero. The angle is then read on the phase shifter scale.

The potential wire at the left of the conductor, Fig. 6, was used in controlling the voltage. The distance between the conductor and this wire was six in. Motor No. 3 drove a contactor in which the two contacts connected to electrometer No. 2 were 180 electrical deg. apart, both making contact very nearly the instant when the voltage between the conductor and cylinder is zero. This charged the electrometer with the voltage due to the space charge, the plus crest on one side of the electrometer and the minus crest on the other side. Since the voltage due to position amounted to considerably more than the space charge voltage, it would be necessary to keep the contactors hitting exactly when the voltage due to position was zero. Practically, this could not be done with any degree of assurance. To overcome this difficulty, the voltage of this potential wire due to position was bucked out by surrounding the electrometer with a wire screen cage, No. 1, which was raised to the potential of the wire due to position by means of the transformers as shown in the diagram. R_3 was connected across the secondary of the insulating transformer to compensate for the shift in phase angle in the 60-kv. transformer caused by the water column resistance load. To prevent any variation in shielding as the ground on the water column potentiometer was shifted, cage No. 1 was surrounded by a wire screen cage No. 2 which was connected to the wire-mesh cylinder. Electrometer No. 3 was read by means of a telescope and the voltage held so that it read "23" throughout all the runs which gave the data for the curves in Fig. 8.

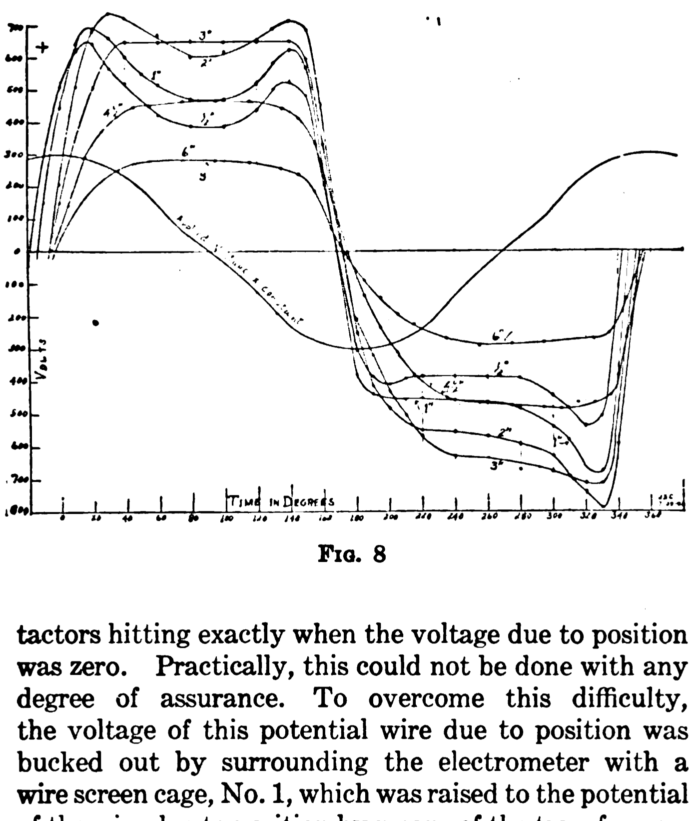


FIG. 8

III. DISCUSSION

From the results of the preceding and present studies, it is now known that corona at all ordinary voltage wave forms, frequencies, and air densities is due essentially to the formation of mixed ions in the air near the conductor where the electric intensity exceeds a certain critical value (30 kv. per cm., or 26.4×10^{-10} coulombs per sq. cm. in air at unit density, $\delta = 1$, which occurs at a temperature of 25 deg. cent. and a barometer of 76 cms.). The mixed ions include only atoms that have lost or gained electrons and have thus become positive or negative ions of low mobilities, 1.36 and 1.83 cms. per sec. per volt per cm., and *free electrons.* The last function as negative ions having mobilities hundreds of times greater and which, when the electric intensity falls to about *one-thirtieth* of that which caused ionization, attach themselves to neutral atoms to form negative ions with their corresponding low mobilities. This electric intensity at which free electrons form negative ions occurred in the present studies at about 1000 volts per cm., or 0.88×10^{-10} coulombs per sq. cm., the air density being near unity. Much experimental work will have to be done to determine the limits through which the electric intensity varies at which the free electrons combine with neutral atoms to form slow moving negative ions.

During copious ionization near the conductor the ions that carry charges having signs unlike the charge on the conductor due to the applied voltage are drawn to contact with the conductor and thus discharged; the ions of the same sign are repelled to a radial distance at which the electric intensity has fallen to the value whereat free electrons can no longer exist, as such, and must form negative ions of low mobility instead. Further details of the action are not as yet clearly defined and much further study is necessary. However the fact is now known that the presence of free electrons in the midst of mixed ions, in aggregate effect, greatly increases the mobility of all the ions, and when that region of the field is reached in which the free electrons combine with neutral atoms to form negative ions, both positive and negative ions are actuated only by the low mobilities above specified. So low are such mobilities that the further effects they produce at 60 cycles are nearly the same as though they did not move appreciably during the remainder of the half-cycle.

Thus it comes about that electric stress in the region surrounding the conductor, between it and the nearly fixed space charge, can be increased but a small amount, if at all, by raising the applied voltage above the critical value of the voltage. The increase in voltage, $E - E_o$, is consumed in two ways: (1) by the ionic conduction that delivers the space charge at the radial distance above specified, and (2) by the space charge itself. While this understanding of the nature of corona is now clearly indicated by the results of many observers to date, much experimental work will have to be done to know the amount and position of the space charge under

most circumstances in order that corresponding formulas can be derived and used reliably for practical purposes.

Something should be said in conclusion in regard to the background of the subject of this paper. There may be many causes of contributing factors that bring about the occasional unexpected flashovers of high voltage insulators that function in air, but among them must always be remembered three factors as follows:

I. Surface conductivity,
II. Surface charger,[9]
III. Space charge.

Surface conduction is a chaotic factor that nevertheless is much better known and understood than the other two. Nishi[9] found that when corona in air is present near an insulator, the surface of the insulator dielectric becomes heavily charged even when the voltage is alternating. There can be little doubt that the space and surface charges are related and that the nature of such relation qualitatively and quantitatively should be known. It is altogether likely that the zone of a comparatively heavy space charge standing well out around a transmission line conductor is a factor that will have to be reckoned with in various practical undertakings such, for example, as the coupling of carrier currents to power transmission lines. It may be that knowledge of the space charges due to the corona on insulator hardware, of surface charge, and of surface leakage will go far toward an understanding of the nature of things that requires the magnitude of tower clearances that practise is now slowly but surely discovering to be necessary.

The dimensional manner for many differing conditions in which the radial distance is related to the crest voltage in the production of space charge, and to the electric intensity of the field wherein the space charge is lodged, should be determined as soon as practicable. In the present study such radial distance was found to be at the average rate of 8.3 kv. (s. w. rms.) per in. and the corresponding electric intensity at the location of the space charge was found to be one kv. per cm. Our reconnaissance has revealed much evidence that the radial distance of the space charge from the conductor, cable, point or other high voltage electrode, is approximately equal to the distance through a needle gap that the corresponding voltage will discharge and, therefore, approximately at the distance-rate of one in. per 10 kv. (s. w. rms.). It must be remembered, however, that corona phenomena have always a strong tendency toward chaotic behavior and that few things can be taken for granted and that most of them must be determined by exact orderly procedure and measurement.

Until the values thus indicated have been reliably determined, it would be premature to write formulas for the power lost in corona due to the boundaries determined by the space charge and its capacitance. The temptation to do so is there, of course, because the energy in such charge is drawn from the source, is never returned and is, therefore, a measure of the loss produced by corona when due allowance has been made for the ionic conduction by which the space charge was placed in position.

9. T. Nishi, *Surface Charges on High Voltage Insulators*, A. I. E. E. Journal, November, 1920.

IV. Conclusions

1. A conductor in corona is surrounded by a free mobile space charge of the same sign as that on the conductor during the preceding voltage crest.

2. The sign of the space charge is reversed by the copious ionization that is produced during each succeeding voltage crest.

3. The mobility of the space charge is so low during interval between voltage crests that it behaves almost as though it were fixed in space about the conductor in corona.

4. The mobility of the mixed ions, positive, negative and free electrons, that reverse the space charge during the voltage crests is much higher than the mobility of the space charge during the interval between voltage crests.

5. For the most part, the space charge has an orderly relation in amount and space position to the voltage applied to the conductor and its dimensions and to the energy lost per cycle in corona at all ordinary frequencies used in the power industry.

A NEW CATHODE RAY TUBE

A vacuum tube which produces as many electrons per second as a ton of radium—and there is only a pound of that rare substance in the world—was announced by Dr. W. D. Coolidge of the research laboratory of the General Electric Company at a meeting of the Franklin Institute of Philadelphia, on the occasion of the award to him of the Howard N. Potts gold medal of the Institute for his outstanding work in the development of x-ray tubes.

Radium is constantly disintegrating, and in so doing is bombarding electrons—infinitely small particles of matter or electricity—into space at very high velocities. The rate at which radium disintegrates is beyond human control; nothing that man can do seems to affect the rate at which the element breaks down. The cathode ray tube likewise bombards high speed electrons into space, but at a rate that can be controlled by man, and in quantities far greater than by all the radium in the world. The electrons given off by radium are of higher average velocity than those so far produced with the cathode ray tube, but otherwise the two are alike.

So much more concentrated are the rays from the tube that many startling experiments have been conducted with the new device. Crystals of the mineral calcite apparently become red hot coals when exposed for a moment to the rays, but they are glowing with cold light; ordinary salt is turned brown, and considerable time elapses before it again becomes the colorless substance it usually is; bacteria and small flies are almost instantly killed by exposure to the rays; ordinarily colorless acetylene gas is transformed into a yellow solid which cannot be dissolved.

Unbalanced Conductor Tensions

Tests to Show Their Effects in a Long Span Transmission Line

BY E. S. HEALY[1] and A. J. WRIGHT[1]

Associate, A. I. E. E. Non-Member

Synopsis.—*Some interesting studies of the unbalanced tensions produced by heavy ice loadings on long spans supported by suspension insulators were made in the course of designing the recently completed Wallenpaupack-Siegfried 220-kv. line of the Pennsylvania Power and Light Company. These studies included investigations of the effects produced on suspension insulator construction by a broken conductor. Computations were verified in an approximate way by experiments on a one-mile section of the actual line. For the most part, results are given in diagrammatic form, in sufficient detail to allow both analysis and approximate application to similar problems.*

* * * * *

General Problem of Unbalanced Conductor Tensions

PREDETERMINING the effect of carrying long spans on suspension insulators has long been a perplexing problem. Span lengths have been gradually increased without any undue operating difficulties until several lines are now in operation with spans averaging well over 1000 ft. Studies for extra high-voltage lines show economies for even longer spans, especially when some of the very high-strength conductors are considered. Such construction requires careful attention to prevent unbalanced conductor tensions,—of no particular importance on shorter spans,—from assuming serious proportions, where combined with long insulator strings and heavy ice loading. In fact, the ice loading appears to be the most important factor.

The unbalanced loads caused by a broken conductor

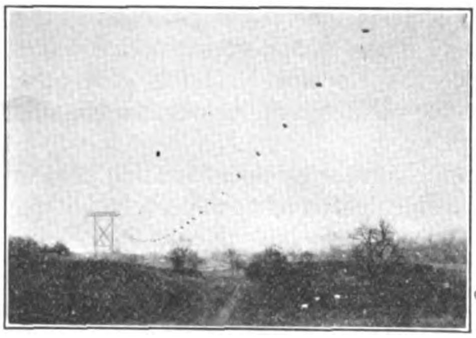


Fig. 1—Span Loaded with Sand Bags Between Tower No. 3 and Tower No. 4

are also of greater importance with the higher-strength conductors. The usual design for lines carrying comparatively small conductors, making each tower of sufficient strength to support one or more broken conductors, does not seriously affect the cost. The same assumption applied to very high-strength conductors so seriously affects the cost of the entire construction as to make a careful study of the character and amount of the loads caused by a break decidedly important.

In working out the designs for the Wallenpaupack-Siegfried line of the Pennsylvania Power & Light Company, both of these problems assumed considerable importance. The 1100-ft. spans and insulators with an effective mechanical length of over nine ft., located in a very bad sleet country, combined to create rather unusual conditions. Some tests and computations made of these problems on that line are given here in the hope that they may be of assistance in similar studies and in the consideration of extra high-strength conductors.

Problems Encountered on the Wallenpaupack-Siegfried Line

As a basis for certain features of design of the Wallenpaupack-Siegfried line, a rather extensive set of calculations was made of the effect of unbalanced conductor tensions. The computed results are summarized in two charts, Fig. 5 showing the unequal tensions caused by a heavy ice load forming on a series of spans of unequal length and Fig. 6, the effect of ice dropping off of all but one or two of a series of spans. Extensive calculations were also made to determine the effect of the longitudinal swing of the insulator string and of the resulting slack thrown into the adjacent spans following a failure of the conductor.

The calculations were intended to obtain results for a few general conditions which could be used as a basis of selecting specific tower locations and as an aid in judging whether special precautions were necessary to meet any particular conditions encountered. For instance, when extra long spans were required over rough country, these calculations gave a logical means of determining how long a span could safely be carried on suspension insulators.

Realizing the importance of a practical verification of the computed results, a set of tests was made as soon as the construction work had reached a stage where it was possible to string a test conductor over a typical section of the actual line. The results of the experiments and a comparison with some of the computed results are shown in the diagrams, Figs. 2, 3, 4, 7, 8 and 9.

1. Transmission Line Engineer and Asst. Transmission Line Engineer of the Electric Bond and Share Company, New York City.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

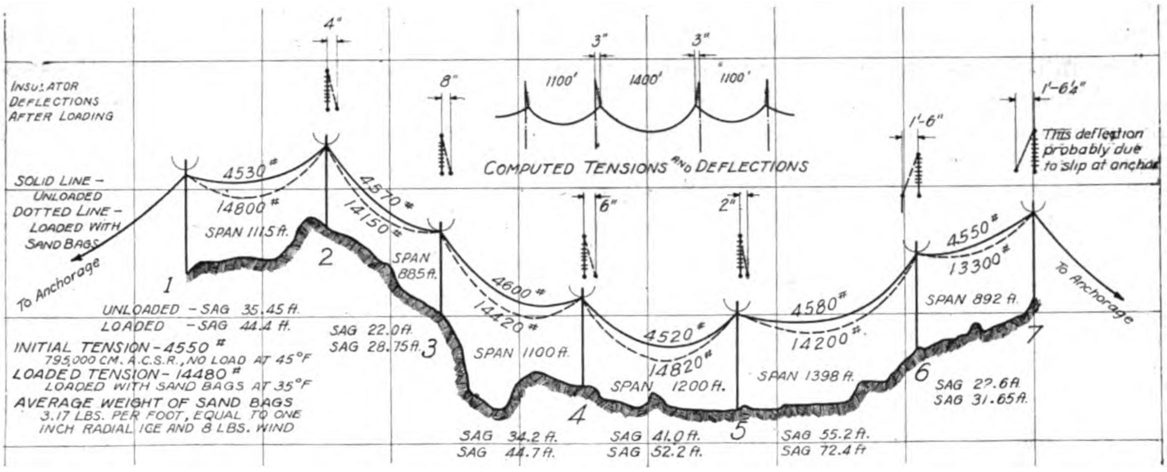


Fig. 2—Experimental Results of Artificially Loading all Spans of the Series

795,000-cir. mil steel-reinforced aluminum conductor sagged to 4550 lb. and then artificially loaded with sand bags representing one-in. ice and eight-lb. wind

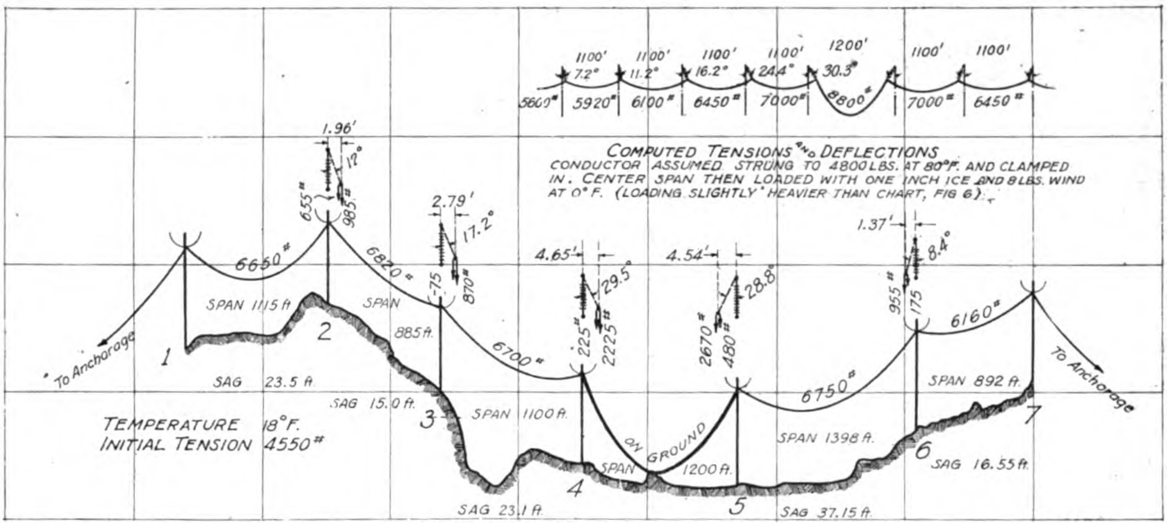


Fig. 3—Experimental Results of Artificially Loading the Center Span of the Series

795,000-cir. mil steel-reinforced aluminum conductor sagged to 4550. lb. and the center span then loaded with sand bags representing one-in. ice and eight-lb. wind

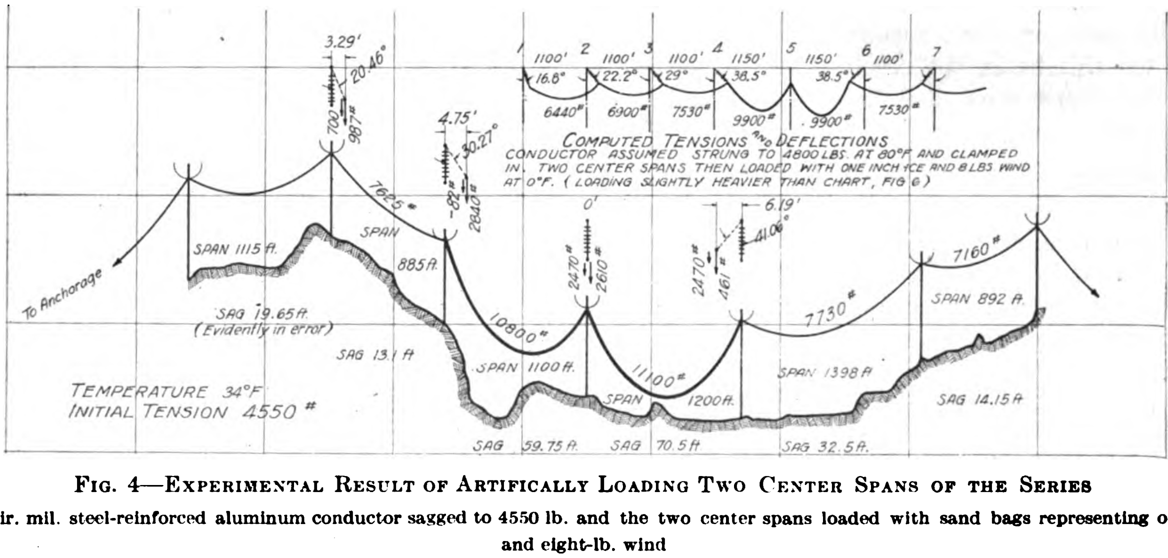


Fig. 4—Experimental Result of Artifically Loading Two Center Spans of the Series

795,000-cir. mil. steel-reinforced aluminum conductor sagged to 4550 lb. and the two center spans loaded with sand bags representing one-in. ice and eight-lb. wind

The irregular profile and unequal spans of the experimental section as compared with the equal-length level spans assumed in the computations, together with the difficulties of making exact measurements in the field, make it impossible to consider the experimental results an exact confirmation of the computed results.

The results should be viewed rather as a comparison of the actual conditions found on one particular section of the line with one of a series of conditions assumed to simplify computations and intended to approximate practically any condition encountered on the actual profile. On this basis, the result of the experiments and computations show deflections and tensions of reasonable consistency.

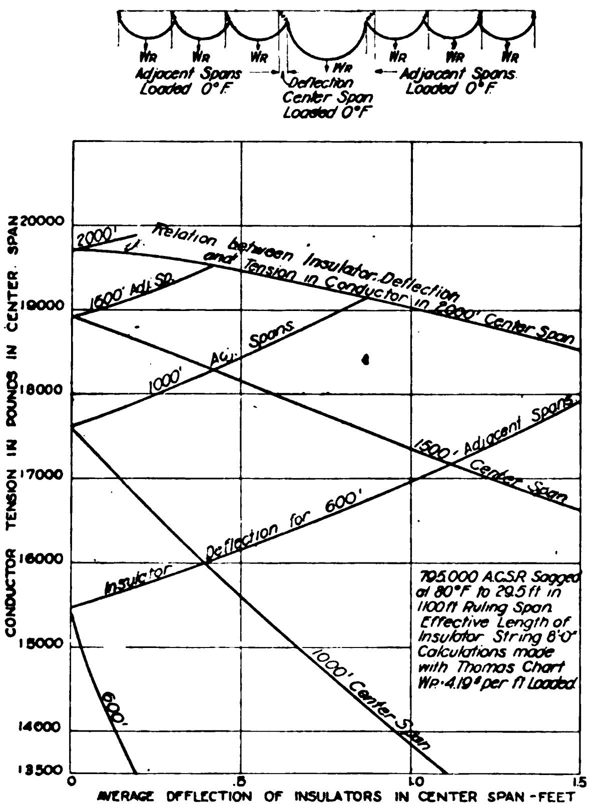


Fig. 5—Computed Effect of Loading a Series of Spans

Chart showing maximum insulator deflection and conductor tension for all spans of a series loaded with one-in. ice and eight-lb. wind at 6 deg. fahr. 795,000-cir. mil steel-reinforced aluminum conductor

Experiments with Artificial Loading

The tests consisted of two sets of experiments; one set to determine the effect of a one-inch radial ice load applied to a part or to the whole section with the conductors intact; and a second, to measure the impact on the tower and the tensions in the conductor caused by a broken conductor under various conditions.

A one-mi. length of 795,000-cir mil. steel-reinforced aluminum conductor was strung on snatch blocks over the section of line shown in the diagrams. The wire was dead-ended to ground pins about 600 ft. ahead of Tower No. 7, sagged to a tension of 4550 lb., and dead-ended about 900 ft. back of Tower No. 1. The insulators were then clamped in, and loading tests made by suspending sand bags from the conductor at about 20-ft. intervals. A reproduction of a photograph of the line, with sand bags in place, is shown in Fig. 1.

The impact tests were made by "cutting" the conductor at a point about 700 ft. back of Tower No. 1, and allowing the conductor to swing free, supported only by the suspension insulators. The resulting insulator deflections at each tower and the sag in each span were measured both with and without artificial load.

The diagrams showing test results are generally self explanatory. Figs. 2, 3 and 4 indicate the conditions

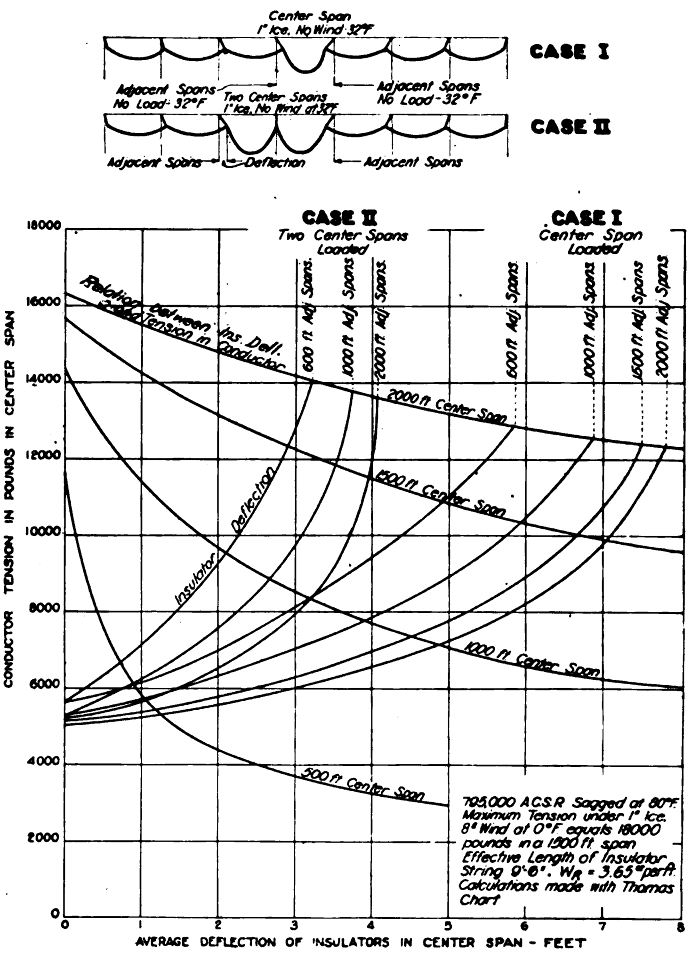


Fig. 6—Computed Effect of Loading Center Spans

Chart showing maximum insulator deflection and conductor tension with one and two spans of a series loaded with one-in. ice at 32 deg. fahr. No wind 795,000 cir-mil. steel-reinforced aluminum conductor

resulting from the artificial loading together with the results computed from a roughly similar series of spans on a level profile. The conductor tensions shown were computed from the measured sags. The vertical weights are obtained from the conductor lengths scaled from the profile with the sags drawn in to scale—the weight on an insulator being taken as the weight

of conductor from the insulator to the low point of the sag. All of these quantities show slight discrepancies due to small errors in the sag measurements, but more accurate methods of measurement would not have increased materially the value of the results.

These experiments may be considered as an approxi-

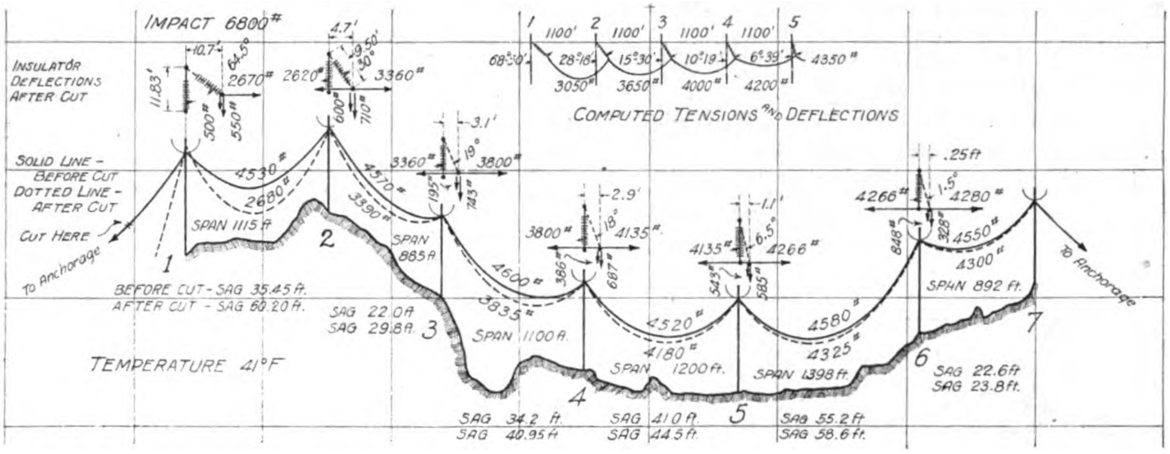


Fig. 7—Experimental Result of Breaking Conductor at Normal Tension

795,000-cir. mil steel-reinforced aluminum conductor "cut" when sagged to 4550-lb. tension. Clamps set to prevent slipping.

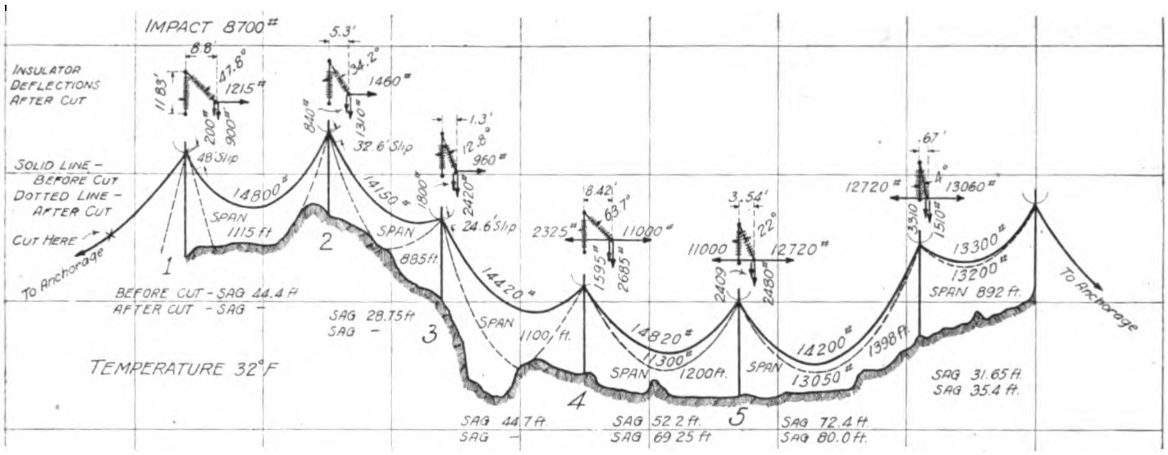


Fig. 8—Experimental Result of Breaking Conductor Upon Artificial Load

795,000-cir. mil steel-reinforced aluminum conductor strung to 4550 lb. and then an artificial load of approximately 3.17 lb. per ft. added equivalent to one-in. and eight-lb. wind. Clamps set to slip at 5000 lb.

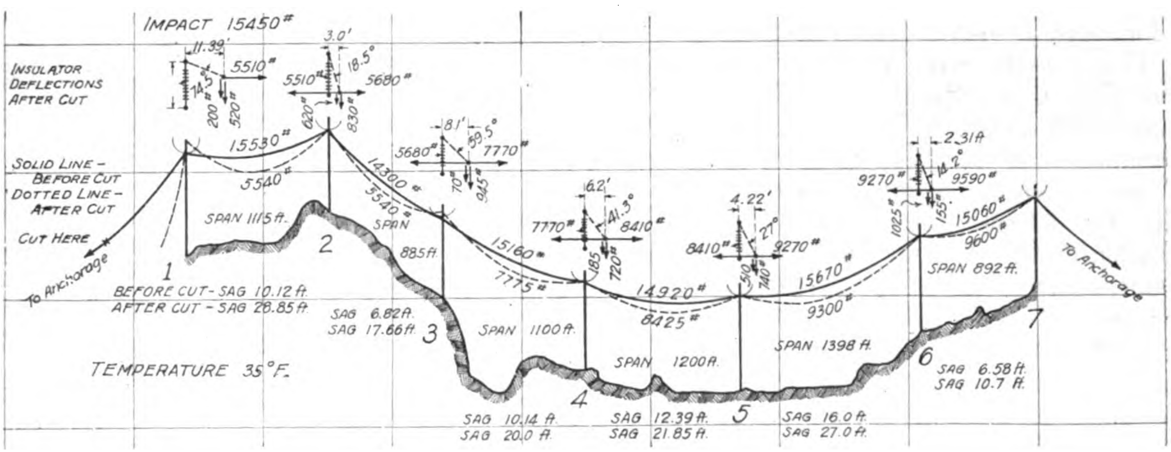


Fig. 9—Experimental Results of Breaking Conductor at 15,000-Lb. Tension

795,000-cir. mil steel-reinforced aluminum conductor "cut" when sagged to 15,000-lb. tension without artificial loading. Clamp on Tower No. 1 set with positive grip. Other clamps set to slip.

mate check of one of the many combinations of span lengths given by computation and shown in diagram in Figs. 5 and 6.

Explanation of Charts Showing Computed Results

Some explanation is required of the use of these charts and methods of making the calculations.

A series of spans was assumed with the insulator supports all on the same level and the conductor strung to the correct sagging tension at 80 deg. fahr. The series of spans consisted of a long "center span" or, in one case, two "center spans" and several equal-length shorter "adjacent spans" on each side of the center.

Fig. 10—Tripping Device Used to Give the Effect of "Cutting" the Conductor in Making Broken-Conductor Tests

A pull on the lower arm instantly releases the clamp, shown at right of the illustration, to which the conductor was attached

Fig. 5 shows the average deflection of the insulators on the center span and the tension in the conductor of the center span caused by dropping the temperature from 80 deg. to 32 deg. fahr., and adding a one-inch ice load to the entire series. The solution of each combination of adjacent and center span lengths was made by a series of trials, interpolating between trial results for the correct solution. In making up the chart, a separate set of computations was carried through for each of several combinations of span lengths. These results were plotted and connected by a curve again by interpolating, obtaining results of intermediate conditions. As an example it may be assumed that in a section of the line over which spans averaged about 1000 ft., a span of 2000 ft. was encountered. For this case, the effect of a heavy ice load may be read from Fig. 5, thus: Following the curve for a 2000-ft. center span to its intersection with the curve for 1000-ft. adjacent spans, we find an insulator deflection of 0.7 ft. and a conductor tension of about 19,300 lb. in the center span. In the same manner, we may determine the effect of one center span of any length loaded with ice if the adjacent spans are unloaded from Case I, Fig. 6, or for two center spans loaded from Case II, Fig. 6. Sags may easily be computed from the tension.

Considering the computations involved in solving the various combinations of span lengths shown on Fig. 5, it is evident that the heavy ice loading causes considerably more stress in the long center span than in the shorter adjacent spans, and that this causes the insulators to swing over until the horizontal component of stress in the insulator string is equal to the difference in tension between the two adjacent spans. This effect is, of course, complicated by the swing of successive insulators on each side. However, it was found that about the fifth insulator from the center has a swing of only a few degrees, and that (approximately) the tension in the next span beyond is unchanged. Cases involving very large insulator deflections or more accurate results require this assumption to take effect at a greater distance from the center span.

One other assumption was required—that the deflections of the two insulators at the opposite ends of a span had the effect of increasing or decreasing, as the case might be, the length of the wire in the span by the sum or difference of the insulator deflections. With this assumption, supplementary "deflection-tension" curves were made, showing the change in tension in any span of the particular conductor and loading under consideration, for any increase or decrease in the length of the wire or as assumed difference in swing of the supporting insulators. These curves are easily made by use of the Thomas Chart, treating changes of wire length due to insulator swing exactly as if due to temperature change.

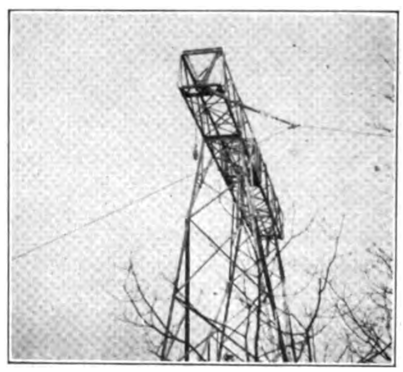


Fig. 11—Tower No. 1 after "Cut" Showing Dummy Insulator Embracing Spring Dynamometer and Impact Dynamometer

Conductor cut about 700 feet to the left

As a trial, the deflection of the fifth insulator was assumed at some definite amount from one to 10 deg. and the conductor tension and insulator deflection computed for each successive span by use of the "deflection-tension" curve for the "adjacent spans." On reaching the "center span" it was found that the deflection and tension thus computed generally corresponded more or less closely to the relation between deflection and tension shown on the "deflection-tension"

curve for the "center span." Two or three trials were generally sufficient to interpolate for the correct results.

The chart shown on Fig. 6 was made in a similar manner.

Incidentally, there is shown in Fig. 2 an interesting comparison between the experimental and computed tension resulting from adding an ice load to the steel-reinforced aluminum conductor. The computed tension resulting from loading a 1100-ft. span, sagged to 4550 lb. with an ice load of 3.17 lb. per ft., is 13,800 lb. The average tension from the artificial loading in the experimental span series was 14,480 lb.

The computations in this case assumed that the steel and aluminum strands, initially of exactly the same length, worked together, each taking load proportional to its respective area and modulus of elasticity up to the elastic limit of the aluminum strands. For tensions greater than this, it was assumed that the steel alone carried the increasing loads.

In this connection, it should be noted that the experiments were made under roughly constant temperature conditions and that while this temperature actually averaged about 35 deg. fahr., the tensions in the conductor corresponded to about 80 deg. fahr. These tensions were used to approximate usual summer conditions. Actually, therefore, the artificial loading experiments correspond to about one-in. radial ice and eight-lb. wind at 80 deg. fahr.

Tests on the Effect of a Broken Conductor

Computed results indicated that the tension in the span adjacent to a break would be very materially reduced by the swing of the insulator. There was, however, a great deal of doubt as to what relation this reduced tension bore to the maximum load thrown on the tower. This maximum load would be applied suddenly and, depending on the momentum developed and the elasticity of the parts absorbing this momentum, the load on the tower might be anywhere from a few per cent to several times greater than the final tension in the span.

The broken-conductor test results are shown in diagram in Figs. 7, 8 and 9. These tests were made to determine the effect of a broken conductor under normal tension, Fig. 7, under maximum ice load, Fig. 8, and under a heavy tension without ice load, Fig. 9. In addition to the insulator deflections and conductor tensions, these diagrams indicate the impact load recorded on the tower next the break. As a check on the impact readings, certain of these tests were repeated. A summary of the results is shown on Table I.

TABLE I
SUMMARY OF IMPACT TESTS

Description of test	Temp. Deg. Fahr.	Wind velocity ft. per min.	Initial tension in conductor, lb.	Final tension in span adjacent to break, lb.	Cylinder length, in.	Impact from calibration curve, lb.	Reading of maximum hand of dynamometer, lb.	See diagram
Conductor sagged to 4550 lb. Clamps tightened with positive grip.......	41	410	4550	2680	0.3850	6800	6850	Fig. 7
Conductor sagged to 4550 lb. Clamps tightened with positive grip......	45	..	4550	..	0.3935	6500	..	
Conductor sagged to 4550 lb. Clamps tightened with positive grip.......	45	..	4550	..	0.4028	6100	5800	
Conductor sagged to 4550 lb. Clamps tightened with positive grip.......	45	800	4550	..	0.3837	6900	8000	
Conductor sagged to 4560 lb. Clamps set to slip.........................	32	..	4500		0.3975	6300	..	
Conductor sagged to 15,000 lb. Clamp set with positive grip......	35	..	15,000	5540	0.423 0.426 0.427	15,450	21,500	Fig. 9
Conductor sagged to 4550 lb., then loaded with sand bags to give a total load of 4.19 lb. per ft. Clamps set to slip.......................	32	..	14,500	..	0.4719 0.4716 0.4713	8470	10,000	Fig. 8

The tests of a break under normal tension were made with the suspension clamps all bolted down firmly to prevent any slipping and to obtain actual impact readings. In the test of the conductor with artificial load, the suspension clamps were used as they were assembled in the completed line; that is, to allow slipping under an unbalanced tension of about 5000 lb. The third impact test was made without any superimposed load but under a tension of about 15,000 lb. The conductor was positively gripped at the suspension insulator Tower No. 1 but the remaining clamps were set to slip as before.

The specific values of insulator deflections recorded

in the latter tests are therefore of little general value. While quite aside from the scope of this discussion, it might be mentioned that this type of clamp effectively held down the loads on the tower as intended. Furthermore, the results left a serious doubt as to whether a slipping clamp can be so applied to a multi-layer cable of this type as to avoid injury to the strands when slipping takes place.

The impact values given in these tests were measured by an ingenious adaptation of the U. S. Ordnance Department's "Crusher Gage" designed and made by J. B. Thomas, Chief Engineer of the Texas Power & Light Company, and shown in Fig. 12.

The conductor tests were all made with this impact dynamometer used in place of insulator disks on the insulator string of the first tower. The impact dynamometer was attached directly to the suspension clamp. Directly above this was placed an ordinary spring-type dynamometer and the remainder of the "insulator string" consisted of an iron bar of a length and weight to make the whole the same length and about the same weight as the usual string of insulator disks.

A little consideration will show that it is an exceedingly difficult matter to measure the force exerted on a

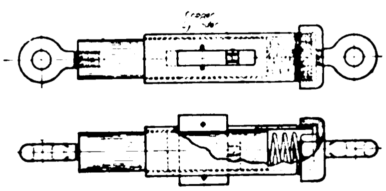


Fig. 12—Impact Dynamometer Used in Measuring Impact on Tower Resulting from a Broken Conductor

tower by the breaking of a conductor. The *crusher gage* method was devised for measuring the pressures developed in guns. As thus used, the device consists of a small steel cylinder with a light piston so arranged that the force of the explosion will compress a carefully calibrated cylinder of soft copper. The pressure is measured by the reduction in length of the copper cylinder. A description of the uses of the crusher gage is given in the U. S. Bureau of Standards, Technologic Paper, Paper No. 185. After consulting numerous authorities on the subject, it was concluded that even for the comparatively slowly applied loads resulting from these tests, the accuracy was well within practical requirements.

The spring dynamometer which was used in series with the impact dynamometer did not show consistent results. The impact was taken as the reading of the maximum hand. This hand is so arranged as to follow the indicating hand up to its maximum reading and remain at this point. The results indicated that the maximum hand was probably thrown beyond the proper reading as in only the first of the six tests made did the maximum hand approximately check with the crusher gage. It was also found in calibrating the dynamometer, that after tests had been completed, the dynamometer readings were over 1000 lb. lower than before the test.

A small moving-picture camera provided with a telescopic lens was used in the test of the broken conductors, and set up about 300 ft. on one side from the first tower. A time analysis of these pictures should give some interesting information and should be a real aid in solving the mechanics of the problem. Thus far, however, time has not been available for this analysis.

Conclusions

The results of these experiments and computations were derived only for application to the Wallenpaupack-Siegfried line and in this served as the basis for important decisions.

The results indicated that even with the extraordinarily heavy ice loading adopted for the line, seriously unbalanced longitudinal loads would not result when span lengths were reasonably uniform in length. On the other hand, they indicated that the maximum tension increased quite rapidly for spans materially longer than the average. Consequently an effort was made to equalize span lengths as far as practicable, and spans greater than 1750 ft. were not carried on suspension insulators without a suitable reduction in the sagging tensions.

Curves of Fig. 6 were used as a means of ckecking the safety of the conductors against coming in contact with the ground under the condition of heavy ice load on one or more adjacent spans, all other spans being unloaded. Two adjacent spans, fully loaded, were assumed as the limiting condition for ground clearance.

Broken conductor tests demonstrated that insulator deflection from the vertical, of magnitude for practical concern, did not extend back more than five towers from the break. Furthermore, these tests demonstrated the ability of the slipping clamp to successfully protect the tower against impact and other stresses from the conductor.

Recent surveys indicate that the farm power bill is greater than that of any other industry, about $3,000,000,000 per year. These surveys made by Stone & Webster, Inc., also indicate that of all the sources of power, animal power is most expensive, costing about 24 cents per horsepower-hour while electricity is probably the cheapest. The cost of the latter is rather variable because of local conditions but the average falls at about 5 cents per horsepower-hour.

Of the work to be done on a farm about 48 per cent is field work, 22 per cent hauling and 30 per cent stationary. It is to the last class of work that electricity is particularly applicable where savings up to 75 per cent in power costs are now made.

Variable-Voltage Equipment for Electric Power Shovels

R. W. McNEILL[1]
Associate, A. I. E. E.

ALTHOUGH the power shovel was developed and brought to a high state of perfection by using steam as a motive power, a constantly increasing number of power shovels is being supplied for electrical operation. These electric power shovels are being used for all sorts of work although they are in particular favor for projects of a permanent nature or for those requiring a considerable period for completion. In some cases the electric power shovel has been adopted when starting these projects, or in other cases it has replaced the steam power shovel because of its superior operating economies. This process of replacement is very active at the present time in connection with open-pit copper and open-pit iron mines. Other extensive uses for electric power shovels are found in "strip" coal mines, quarries with output used in crushed form (such as for blast-furnace purposes), road materials, cement manufacturing steel plants for rehandling ore and slag, and contract work on dams, canals, tunnels, etc.

This widespread use of the electric power shovel has led to a considerable development in connection with this type of machine not only in connection with the electrical equipment but also with regard to general mechanical design. While earlier experiences with electric power shovels had indicated that very good results were obtainable by taking the steam power shovel design and replacing the steam engines and boilers with electrical equipment, later experience has shown that in order to obtain the full advantage of benefits of electrical operation, the shovel must be designed with this point especially in view. Mechanical improvements have taken the form of better gearing, (double helical gears having been substituted for coarse spur gears in many instances), and of better systems of lubrication for gears, bearings, etc.

The latest development in the line of electrical equipment for power shovel operation is characterized by two outstanding features. First is simplicity of control, and second, sturdiness of the entire electrical equipment. Simplicity of control is secured by use of the *variable-voltage* system of motor speed control and durability by designing all the electrical equipment with the same high standards as characterize the rugged reliable d-c. mill-type motors used for operation of the shovel.

In the development of this latest type of electrical equipment for operation of power shovels, every advantage gained by experience in perfecting the steam power shovel has been utiliized and the equipment has been designed to duplicate the steam power shovel in performance and digging characteristics, for it is a well recognized fact that the power characteristics of the steam engine are practically ideal for power-shovel operation. The variable-voltage system of motor speed control as developed for electric power shovels employs an individual motor for drive of each principal motion, power being supplied to each motor from an

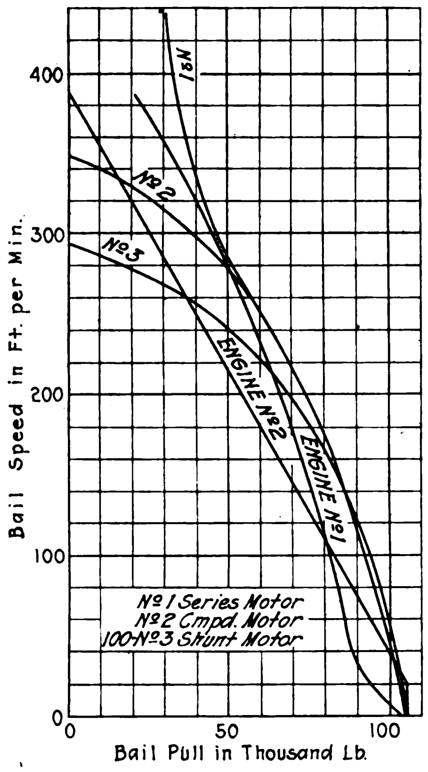


FIG. 1—COMPARISON OF STEAM-ENGINE AND VARIABLE-VOLTAGE-OPERATED MOTOR CHARACTERISTICS FOR POWER SHOVELS

individual generator of such design that the speed torque characteristics of the individual motors closely resemble those of the steam engines used on steam power shovels, as shown in Fig. 1.

Electrical equipment using the variable-voltage scheme of motor control is adapted to all sizes of shovels from the smallest to the largest, and its principle of operation is the same, regardless of the size of shovel. Where this system is used, a-c. power is usually supplied to the shovel from a central station system. This means that the complete electrical equipment for a shovel using the variable-voltage system will, of neces-

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sity, consist of the following principal items in the order of their location with respect to the incoming power line.

1. Starting equipment for a-c. motor.
2. Motor-generator set.
    a. A-c. driving motor.
    b. D-c. generators for supplying power to individual shovel motors.
    c. D-c. generator for furnishing excitation to above d-c. generators, shovel motors and a-c. motor, if same is of synchronous type. (This exciter may be separate-motor-driven, if physical limitations make it impossible to drive same from main set.)
3. Controllers and field resistors.
4. Shovel-driving motors.

Auxiliary equipment may consist of air compressors, magnet valves, solenoid brakes, etc.

Due to differences in size of equipment, type of driving motor, and voltage used, there will be considerable variation in the type of starting equipment furnished for the main motor-generator set. For the larger outfits using high-voltage synchronous driving motors, the usual practise will be to supply a combined synchronous motor and exciter panel of steel clad construction. If reduced-voltage starting is used, this panel or switch structure will include auto-transformer, double-throw oil switch, field rheostats, necessary current and potential transformers, and meter equipment. If full-voltage starting is used, the auto-transformer will be omitted, and if desirable, starting may be made automatic by using an electrically-operated circuit breaker. On the smaller sized motor-generator sets driven by induction motors, the equipment can be simplified and motor started at full-line voltage by use of an oil circuit breaker in case of high-voltage motors, and by means of an across-the-line type magnetic starter in case of low-voltage motors.

While the size of the motor-generator sets will vary with the different sizes and models of shovels, the general scheme will always be the same and the set will consist of an a-c. driving motor of either the synchronous or induction type, a d-c. generator for the hoist motion, a d-c. generator for the swing motion, a d-c. generator for the thrust motion, and a d-c. exciter. The exciter may or may not be part of the main motor-generator set, depending upon whether or not space limitations will permit the use of a five-unit motor-generator set. Where the exciter is separate-motor driven, it is usual to use a low-voltage driving motor, and, if power supply is at high voltage, to supply transformers for furnishing power to the exciter motor-generator set. Driving motors for the larger shovel motor-generator sets usually are wound so that by a simple change in connections they can be operated on either 2200 or 4000 volts. Smaller sets are wound for 2200, 550, or 440 volts. Lower voltages are not recommended on account of poor line regulation. Either synchronous or induction motors can be designed for full-voltage starting if desirable. In general, this will be the standard method of starting the smaller induction-motor-driven sets.

The individual d-c. generators used for supplying variable voltage to the various motions are of the differentially-compound-wound type, designed with three separate field windings, *viz.*, a separately-excited shunt-field winding, a self-excited shunt-field winding, and a series winding so connected as respects the armature that its effect on total field strength will be subtractive or differential under-load current on the generator. This type of generator will deliver variable-voltage power to the shovel motors, the exact voltage value at any instant being dependent on two factors: first, the value of the separate shunt-field excitation, and second, the value of the load current flowing in the

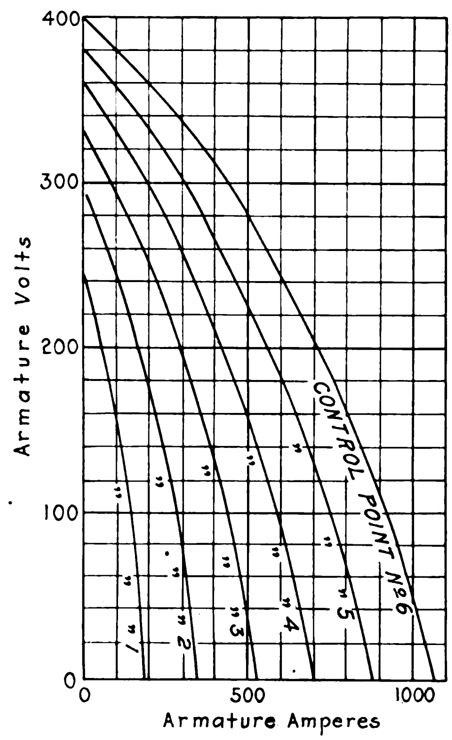


Fig. 2—Volt-Ampere Characteristics of Differential Compound Generator as Used Showing the Effect of Excitation Changes

armature and the differential series field winding. Fig. 2 shows voltage characteristics of a typical differential-compound-wound d-c. generator for power-shovel service under different conditions of separate-excited field strength and load currents. These characteristics are practically ideal for power-shovel operation, since by supplying power to the shovel motors from such generators, we are enabled to obtain motor speed torque characteristics closely resembling those of the steam engines used for power-shovel service. Actual practise in the design of these generators proportions the shunt-field windings so as to give the required light-load voltages and proportions the differential series winding so that the total field strength at heavy loads will be only

of such value as to force the maximum required current through the main circuit consisting of motor and generator armatures, series and interpole field windings and connecting cables between the machines.

The motors used for driving the individual motions on variable-voltage equipped electric power shovels are of the well known d-c. mill type, used so extensively for auxiliary drives in steel mills and on heavy-duty cranes, car dumpers, etc. Open or ventilated type motors are usually used on hoist and swing motions, and totally enclosed motors on the thrust motion. Mill motors have massive cast steel frames split horizontally so that the top half can be readily swung back or lifted off. Widespreading feet, cast integral with the lower half of the frame, insure stability and freedom from vibration when the motor is bolted to a firm foundation. Electrically, the design is of the very highest order. Mica and asbestos insulation is used throughout; all main and commutating field poles are of laminated construction and coils are supported and banded in such a manner that there can be no loosening in service.

There is some variation in the type of field windings employed on d-c. motors used for shovel operation. The swing and thrust motions are always operated either by straight shunt-wound, separately-excited, d-c. motors or by compound-wound motors having separately excited shunt fields. The hoist may be operated either by series-wound motors or by separately-excited, shunt- or compound-wound motors. As compared to the compound-wound or series motor, the straight shunt-wound motor, when controlled by the variable-voltage method, possesses the advantage of no reversal of main circuit connections being necessary to secure reversing of direction of rotation of the motor. As compared to the series motor it has the advantage of positive regenerative braking being easily secured. As compared to the series and compound wound motors it has the disadvantage of not being designed to deliver the same maximum torque for the same current value and its speeds are inherently lower at light loads.

On the swing and thrust motions, the necessity of regenerative braking for quick stopping practically eliminates the series-wound motor, so that choice must be made between the straight, shunt-wound motor and the compound-wound motor. This also applies to the hoist-motion on high-lift shovels which use regenerative braking in lowering the dipper. The main objection to the use of compound-wound motors is that their use complicates the control, as it is necessary to furnish means of reversing the series fields for reversed service. On the smaller motors this is easily accomplished by additional contacts in the small drum controllers used for governing the operation of each motion. But on the larger motors, it is necessary either to add magnetic contactors for reversing these fields or to provide a series exciter, or its equivalent, so that compound motor characteristics can be obtained with shunt-field windings in the motor. These schemes do not eliminate the reversing processes but do reduce the capacity required so that large magnetic contactors are unnecessary. The choice between straight-shunt and compound-wound motors for swing and crowd motions is not very clearly defined; in some cases the extra complications of the compound-wound motor will be justified, while in others the simplicity of control possible with the straight shunt motor will be the deciding factor in determining its use.

On the hoist motion the problem of proper type of motor is further complicated by differences in practise in operation, particularly on low-lift shovels. Some shovel manufacturers prefer to use the motors in lowering, using regenerative braking to obtain speed control, while other manufacturers prefer to lower the

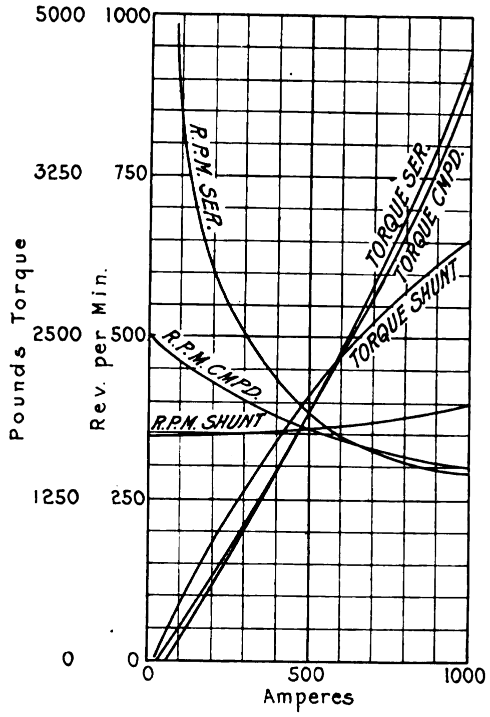


Fig. 3—Speed-Torque Characteristics of 170-H. P., 230-Volt, D-C. Mill-Type Motors for Power Shovel Service

dipper on a foot brake without operation of the hoist motor in the reverse direction. If the latter practise is followed there is little advantage in using the straight shunt or the compound-wound type of motor and advantage can be taken of the superior operating characteristics of the series-wound motor for the hoist motion. If, however, regenerative lowering is needed, a shunt or compound motor is used, control connections being so arranged on the compound wound motor that in lowering, it operates as a straight shunt-wound motor. Comparative speed torque characteristics of shunt, compound and series motors are shown on Fig. 3.

The control equipment necessary with electric power shovels operated by the variable-voltage system is of

the very simplest nature. Actual practise is to use small drum controllers and series resistors connected into the separately excited shunt fields of the individual generators in such a manner that operation of these controllers will direct the flow current and current strength in these fields. Additional contacts are regularly provided in this controller for weakening the self-excited shunt field of the generator in the off position for connection of field discharge resistors and for operation of brake and clutch circuits. Where straight shunt-wound motors are used, these controllers provide for the weakening of the motor shunt field in the off position and may provide for insertion of resistance into the motor field to secure high light-load speeds. When compound-wound motors are used, it is necessary to furnish not only the field weakening point in the off position for the separately excited shunt field, but also to furnish additional contacts either for reversing the series field direct through magnetic contactors or by reversing connections to a separate exciter used to secure compound-wound motor characteristics. Where series-wound motors are used on the hoist, it is not necessary to provide for frequent reversals, as the only time that reverse operation is required is when the hoist motor is used for propelling the shovel. This infrequent reversal is usually taken care of by a separate hand-operated reversing switch. Typical diagrams for shunt, compound-wound and series motors are shown on Figs. 1, 2 and 3.

Controllers used with the variable-voltage equipped shovels are all of the same general type and construction though they may differ somewhat as to drum development and method of operation. The currents to be handled by these controllers are small and the design is determined more by the demand for rugged mechanical construction and ease of operation than for current-carrying capacity. Full revolving shovels are built usually for one-man operation and for this reason there is some demand for a foot-operated controller to be used on one of the motions on these shovels. Standard controllers for variable-voltage equipped shovels are constructed with vertical operating handle. Thumb-operated auxiliary switches for operation of dipper-trip mechanisms, magnet valves, etc., are frequently added to the handle of standard controllers.

While the resistors used with the variable-voltage equipment are of small size and capacity, even on the largest shovels, they are quite an important feature of equipment and it is very essential that they be of ample capacity and rugged construction. Experience has demonstrated that these resistors should be wound on insulated metal supports and that special care should be taken to insure against connections loosening due to vibration. Practise in method of assembling resistor units varies with shovel design. On one type of shovel it may work out to advantage to assemble resistors all in one unit and provide this assembling with a terminal board which will serve as a distribution center for all control wiring. In other cases, space limitations can best be met by making up the resistors in unit assembly, that is, one unit for hoist generator separate excited field, one unit for hoist generator sets excited field, etc.

Air compressors, when used with shovel equipment, are usually of the industrial type with a-c. driving motor. Air pressure is maintained at a constant value by means of an automatic governor which stops and starts the compressor as the air receiver pressure varies. Compressed air is used for operation of brakes on the swing and thrust motions and for brake and clutch on the hoist motion.

Magnet valves are used to give electrical control of the air brakes, clutches, etc. Two types of valves are used; these are known as "straight" and inverted valves. Both types of valves are of three-way construction and the difference between the two is in the method of operation. The *straight* valve is provided with three openings for pipe connections; one from the air supply, one to the brake or clutch cylinder, and an exhaust opening. With magnet of valve energized, the exhaust opening will be closed, the air inlet will be open, and full air pressure will be exerted against the brake or clutch cylinder. Interruption of magnet circuit closes inlet opening, opens exhaust port, and relieves pressure in brake or clutch cylinder. Operation of "inverted" valve is just the reverse of above, as magnet coil is energized to exhaust brakes or clutch cylinder and circuit broken to apply air pressure. The straight valve is always used on brakes which are of the spring- or gravity-applied, air-released type. The inverted valve is used in connection with air applied spring released clutches where it might be dangerous to use a straight valve as interruption of magnet circuit might be the cause of accident.

Solenoid brakes are used on electric-shovel equipments where compressor equipment is not supplied. On variable-voltage equipments these brakes are of the d-c. type with shunt-wound operating coils designed to operate from the exciter circuit.

While the above has covered only the application of the variable-voltage system to power shovels of the conventional type, the system is equally adaptable to dragline excavators, dipper dredges, and to hoist and swinging motions on all types of cranes, dredges, etc. It provides a simple automatic method of limiting motor torques where serious damage to the mechanical equipment might result if motor torques were not limited, and it also provides a simple automatic method for obtaining high motor torques with low kw-input to the motor. This last factor is a valuable one where power is purchased on a peak-load basis or where the primary source of power is of limited capacity.

Discussion at Midwinter Convention

EXPERIMENTAL DETERMINATION OF LOSSES IN ALTERNATORS[1]

(ROTH)

NEW YORK, N. Y., FEBRUARY 9, 1926

W. F. Dawson: In an article published in 1920[2] I called attention to the fact that in many cases load losses indicated during short-circuit test were greatly reduced when the machine was run at full voltage and rated power factor.

I have since run many other tests and while I am not prepared to lay down any definite rule, I am prepared to suggest that the present A. I. E. E. rule (paragraph 470, No. 7) which charges all of the load losses measured during short circuit against the losses of the machine, is probably unfair. Since the publication of my article in 1920, improved methods have been developed. At that time I intimated that electric heaters delivering a known quantity of energy into the discharge duct could be employed as a calibrating device. I had tried them in a rather amateurish way. Since then we have perfected our electrical air heaters and we have also perfected resistance thermometers for measuring the inlet air, the outlet air, and the temperature of the air after it has passed the electric heater. It is now a comparatively simple matter to measure the actual losses of a machine having an enclosed ventilating system, such as turbine alternators, under any condition of load.

We have satisfied ourselves that the question of convection, at least on high-speed machinery, introduces no appreciable error, even though we have not been able to establish an exact emissivity constant. This may possibly vary from 0.0125 watts per sq. in. per deg. cent. rise of the frame surface to 0.007 watts per sq. in. per deg. cent. rise; but when it is realized that even with the higher figure the convection loss amounts to less than two per cent of the total loss on an alternator as small as 3750 kv-a. and the total loss in turn is only 4.2 per cent of the rating (on 3000 kw.), the total loss due to convection will be only about 0.08 per cent of the rating.

It has been my pleasure, during the last year, to build and test a turbine alternator rated three-phase, 480 volts, 7518 amperes, 0.8 power factor. Check tests at full load, 0.8 power factor, were made on the customer's premises a few weeks ago. The factory test consisted of a zero-field (no excitation), open-circuit heat run at normal voltage and a short-circuit heat run at normal current, the calorific method being used to estimate the losses. The aggregate of these losses, assuming the same losses under operating condition as during short-circuit test, was 279 kw. On the customer's premises a check was made under contract conditions, except that the phases were slightly unbalanced; the average armature current was slightly over the rating and the armature voltage slightly less. The normal rating of 5000 kw. was maintained accurately, the field current held constant and the power factor, within one per cent of the 0.8 guaranteed.

What was the result? The generator was equipped with an air cooler. We installed flow meters to measure the quantity of cooling water, thermometer wells, and calibrated mercury thermometers reading to within 0.1 deg. fahr. We also installed numerous thermometers for measuring the temperature of the (inlet and outlet) air. Assuming that the factory measurement of quantity of ventilating air was still correct value, total losses by temperature gain of the ventilating air were 266 kw., while for the temperature gain of the cooling water, the value indicated was 270 kw., a check within 1.5 per cent. An average between the 270 kw. and the 266 kw. (between the air and the water method) gave 268 kw., which was 11 kw. less than the aggregate shown by the factory measurement.

1. A. I. E. E. JOURNAL, May 1926, p. 422.
2. *G. E. Review*, Feb. 1920, Page 161.

B. L. Barns: What I have to offer has reference to the general subject of the determination of losses in alternators.

We have built in Canada some very large vertical shaft alternators which are installed in the Queenston Power House of the Hydro-Electric Power Commission. In making the acceptance tests it was not possible to determine the load losses by any of the methods described in the A. I. E. E. rules, and for the efficiency results an assumption was made regarding the value of these losses. Naturally in view of the size of these generators we were curious to know just what was the true value of these losses. In reviewing the work that had been done it was noticed that in 1913 Mr. H. M. Hobart had suggested what he called the calorimeter method. Later, in 1920, Mr. Dawson described the method which he, himself, has mentioned. Mr. Dawson's method involved heating the air that passes through the machine and under the conditions existing at the Queenston Power House it was quite difficult to take care of this feature. Furthermore it was very difficult to obtain an accurate measurement of the air passing through the generator.

Mr. Hobart's suggestion and Mr. Dawson's experiments offered a clue as to a method that might be used. An accurate determination had been made of the windage and friction and the open-circuit core loss on which we had consistent checks. It was reasoned that since the value of the core loss was known, it would be possible to determine by test the temperature rise of the air passing through the generator due to the core loss; then, having determined this constant, the losses under any other condition of load could be determined by measuring the temperature rise of the air. Thus, if it were found that the temperature rise of the air at full load was twice or three times the rise due to core loss alone it would be reasonable to conclude that the total loss was two or three times the core loss. Accordingly, a series of tests of this nature have been carried out on two of the generators. The tests consisted of measuring the temperature rise of the air under four conditions of load; windage and friction, open-circuit core loss, short-circuit core loss, and full rated load. It was necessary to separate the windage and friction from the open-circuit losses because the losses in the thrust and guide bearings were not taken up by the cooling air but were carried away by the cooling water and circulating oil. The difference in the temperature rise of the cooling air under conditions of open-circuit, normal-voltage core loss and windage and friction represents, therefore, the temperature rise for a known loss which is the core loss and the field copper loss. These results permit the establishment of a constant representing the kilowatts loss per degree rise of the cooling air. Having obtained the value of this constant, other runs at full load or on short circuit may be made and the temperature rise of the air measured and the value of the total losses determined.

This method of test of course involves the measurement by suitable test of the windage and friction and open-circuit core loss so that a known loss may be used for determining the temperature-rise constant. These losses may be determined by running the alternator as a synchronous motor and measuring the input, or by a retardation test. Tests by these two methods were made on one of the Queenston generators and remarkably consistent results were obtained. Our first trial of this method was made in June 1924, but, due to some unforeseen conditions, we were not well satisfied with the results and they were later repeated with quite satisfactory results which were described by the speaker in a paper which was read before the Toronto Section of the A. I. E. E., in February 1925. This method of test is briefly described by Mr. Roth in his paper[3] on the 60,000-kv-a. turbo alternators for Genevilliers.

3. *Three-phase, 66,000-Kv-a., Turbo generators for Gennevilliers*, by E. Roth, A. I. E. E. JOURNAL, September 1925, page 927.

This method of test has certain limitations and obviously it cannot be used on all types of machines. No doubt it could be used with success in the case of most turbo alternators and enclosed alternators, synchronous motors, and condensers. The generator setting at the Queenston Power House is particularly well adapted to this method of test in that it is enclosed in a chamber having walls of hollow tile so that the radiation and convection are reduced to so small an amount that the error would be of a very small order. (A description of these generators and their setting is published in volume XLI, pp. 472-499, of the A. I. E. E. TRANSACTIONS). In carrying out a test of this kind it is essential that the true mean temperature of the air entering and leaving the machine should be obtained and several methods of doing this have been proposed. We have used a large number of thermometers with 0.1-deg. graduations together with an ordinary copper wire resistance grid, and the average readings of the thermometers have checked closely with the grid. I wish to call attention to one necessary precaution in making this test; each run should be continued long enough to obtain a constant temperature of the coils and iron of the machine and at the same time the temperature of the cooling air should be constant because a rising or falling temperature of the cooling air will introduce a considerable error even though a constant temperature rise of the air passing through the machine may be observed for considerable time. These precautions apply to the methods described by Mr. Dawson as well as to the method which I have described.

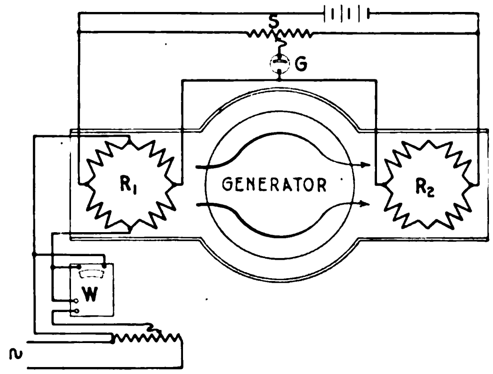
P. A. Borden: In most of the methods which have been used for the determination of losses by measurement of temperature rise in the cooling air, it would appear that there exists the necessity of either determining the quantity of air supplied to the machine, or of maintaining that quantity at a very steady rate of flow. In the testing of large units, exact measurement of the air flow is usually very difficult, while the maintenance of a uniform rate is seldom practicable.

While the following method is not offered as a panacea for all the troubles attending such a measurement, it would seem that the fact of its not being inherently dependent in its results upon volume or rate of air flow or upon temperature of the air supply would tend to remove many of the objections to the thermal system of loss determination.

Basically, the method, like a number of others, consists of introducing into the inlet and outlet air passages resistance grids having the same temperature coefficient, connected as two arms of a Wheatstone bridge. The bridge is first balanced in what we choose to call the "zero" position. After a steady condition of losses is established, the unbalance of the bridge due to the temperature gradient in the air column is corrected; but the restoring of the balance is not accomplished by manipulation of the circuit of the bridge, but by "artificially" raising the temperature of the cooler grid to meet that of the other. Measurement is then made of the power necessary to be introduced into the cool arm of the bridge to equalize the balance; and this value, expressed in watts, should bear a constant proportionality to the heat energy communicated to the air by the losses in the machine.

The elementary parts of the system are shown in the accompanying sketch, where R_1 and R_2 represent the resistance grids in the air inlet and outlet, respectively. These grids, as units, form two arms of a bridge circuit and are balanced on the galvanometer G by means of the slidewire S. The grid in the incoming air passage is itself made up in the form of a balanced Wheatstone bridge, so that the auxiliary heating current may be passed though it without disturbing the balance of the main bridge circuit. This current is derived from an auxiliary source (preferably alternating), and supplied to equipotential points of the grid R. It will be seen that with this arrangement neither the voltage drop due to the auxiliary current nor the resistance of the auxiliary circuit has any direct effect upon the balance of the main bridge. The other grid, while not necessarily a duplicate, is preferably of a similar construction and of approximately equal resistance. Upon the establishment of a temperature difference between the two grids, with a consequent unbalancing of the bridge, current from the auxiliary source is fed into R_1 and adjusted until the balance is restored. A reading on the wattmeter W of the amount of power thus supplied to the grid then gives a measure of the heat dissipated by the machine under test and communicated to the outgoing air. Calibration of the set-up is accomplished by making one or more determinations with a known value of losses dissipated by the machine, thus establishing the relationship between the measured value of the auxiliary watts and the quantity under investigation.

The controlling factor in the acceptability of this method of test would appear to lie in the constancy of ratio between the values of the auxiliary watts and the watts dissipated as losses in the machine; and there has not as yet (Feb. 1926) been an opportunity to study the soundness of the system on an actual power house installation[4]. Laboratory tests have been independently made, however, by the writer and by Mr. Baker of the Ontario Power Company, using set-ups of dissimilar design and following different courses of procedure, but both with a view to establishing the constancy of the ratio under varying conditions, principally of air flow and watts loss.



BALANCE METHOD FOR DETERMINING LOSSES IN TOTALLY ENCLOSED MACHINES

While at the present time a compilation of the results of these tests is rather premature, it has been possible to arrive at conclusions which would appear to justify further investigation under actual service conditions; and it will be of great interest to learn of others following out a similar application of the principle described.

W. J. Foster: It is interesting to note that the author points out what many of us have been conscious of all along; that our method of determining the total losses of machines is approximate.

I should like to revert to the first attempt made to estimate load losses and speak of the two men whom I think had more to do with the exact formula than any others. I refer to Mr. Lamme and Dr. Steinmetz. They both regarded the determination of losses under short circuit as giving excessive values for load losses due to the very abnormal conditions the worst possible distortion of the flux existing. Consequently, they made an estimate of one-third of the short-circuit load losses as the load losses.

It soon became evident to all designers that that was not sufficient. On the occasion referred to by two or three of the speakers, when so many papers were prepared, determinations had been made by input and output method on a number of machines, and it was found that on the machines selected, the addition of the entire short-circuit losses to the other segregated losses gave efficiencies that agreed very closely with the over-all efficiency. That is how it happened to be agreed upon.

4. Since presentation of the above discussion this method has been tried out in a large hydroelectric station with very promising results.

Mr. Roth speaks of the method, I think, as applying to turbo generators. We are all aware that there is a difference in the type of generator. Turbo generators have almost invariably distributed field windings; that is, the field windings are in several slots, with practically uniform air-gap, and with the end windings secured by binding bands usually containing magnetic material. These bands are at almost the same radius, standing out in the line of the air-gap. Thus the determination of short-circuit losses undoubtedly involves larger losses at the heads of the rotor than exist under normal operating conditions.

In like manner the operation of that type of machine which has only a few poles on short-circuit results in losses at the heads of the stator that probably do not exist under ordinary operating conditions, especially at the 80 per cent power factor condition.

C. J. Fechheimer: Mr. Roth applies his method to a comparatively small, slow-speed machine, in which the "load losses" are almost negligible; that is, $k\ r$ is only 9.4 per cent greater than r. Has he applied his method to machines in which the load losses are high, and if so, how close did it check with other tests?

It is questionable whether the method is applicable to the general case in which the power factor does not approach zero. Usually the cross-magnetization of the armature greatly distorts the flux, with the result that the magnetic inductions in the teeth, and to some extent in the core, are far from uniform. The iron losses may be considerably augmented thereby. It is believed that this statement is especially applicable to the machines described in a recent paper by Mr. Roth[3]. For those machines the armature ampere-turns are higher than are needed to excite the machine for no-load normal voltage.

Mr. Roth assumes the equation of the iron-loss curve to be a quadratic parabola (Fig. 2 in the paper). Inasmuch as when saturation is approached, that loss increases faster than the square of the voltage, so that a simple exponential form of equation can no longer be applied, he uses his method at 2000 volts instead of the normal 3000, in the machine he tested. How does Mr. Roth propose to extend his method so as to make it applicable at the normal voltage of the machine? If he assumes that the value of k is the same at normal voltage as at the reduced voltage, and if he allows for the incremental iron losses due to saturation by extending the tests as plotted in Fig. 2 to normal voltage plus the internal impedance drop added vectorially, it is questionable whether the method is correct. A large number of tests would have to be made to confirm the accuracy of the method.

In 1920 a method of separating the iron loss from the mechanical losses was suggested.[5] That did not require the assumption that the iron loss is proportional to the square of the voltage. The method has frequently been used at the Westinghouse Company, and Mr. Roth may find it useful. The machine is run idle as a synchronous motor with minimum excitation, just as as Mr. Roth does for Fig. 2. The calculations are, however, different.

A considerable part of the discussion has centered upon the thermal method of measuring losses. Many of us have attempted to measure losses that way, but it is rather difficult to obtain accurate results. The check that should be used is to run the machine without mechanically-connected load or driving machine, and measure the input with calibrated wattmeters. Then, if one is assured that the testing equipment is accurate, the load conditions may be fixed. It is expected that the results of tests along that line will be reported in an early paper by one of the Westinghouse engineers.

E. H. Freiburghouse: Mr. Roth points out, just as others have done, that there is considerable difficulty involved in measuring power input to a synchronous motor running light at low-power factor. It is more difficult to measure the power input to a stator of an alternator with the rotor removed. As stated by Mr. Roth, the input to the alternator running as a synchronous motor can be measured quite accurately by determining the rate of flow and temperature rise of the air which cools it. In other words, it is quite possible to measure the entire losses of the alternator at low power factor. The method which he proposes, however, for determining the constants k and p depends upon the assumption that the electric losses of the alternator as a synchronous motor are the same when it is over-excited as when under-excited. I do not believe this assumption is justified since it is well known that the stray losses in the end structure of the stator are very much less when it is over-excited than when it is under-excited. These losses as defined by Mr. Roth are electrical, since they are known to be generated by the induction of the stator winding.

This is the principal criticism which I have to make of the method which he has proposed. It is rather ingenious and obtains results which seem to agree quite closely with the tests which he made upon the three different alternators. He found that in all cases the losses as determined by his method checked within 4.3 per cent with the losses as determined by the Rules of the A. I. E. E. and the French Rule.

Mr. Fechheimer called attention to the function of the voltage which appears in the equation on the sixth page. Of course that has been assumed as a square function; that is, as the square of the voltage. He assumed that and used that part of the no-load loss curve in which the relationship of loss to voltage was a square curve.

Mr. Fechheimer also called attention to the distorted form of Fig. 7 in relation to the loss. That is an insignificant influence because it really is the condition which the author states exists at the minimum input current, which is, of course, an extremely small current as compared with the rated current of that generator.

There is one other point; that is with reference to the cross magnetization. I think he takes account of that in the terminal voltage as a function of power factor. That is, one can determine the voltage which causes the loss by combining the fluxes for terminal voltage and that of the reactance voltage.

5. "*A Method for Separating No-Load Losses in Electrical Machinery,*" by Carl J. Fechheimer. A. I. E. E. TRANSACTIONS, 1920, p. 291.

Discussion at Madison

THE QUALITY RATING OF HIGH-TENSION CABLE WITH IMPREGNATED PAPER INSULATION[1]

(ROPER AND HALPERIN)

MADISON, WISCONSIN, MAY 7, 1926

W. S. Clark: One very important feature in the paper of Messrs. Roper and Halperin is the correlation of tests and service, and nobody could do that except an operating man.

Now as to the rating of cable, I think it is most important to get into it a figure based on the so-called accelerated life test, as we have not yet found in Schenectady any test which would give us as correct a measure of the value of the cable as that. I should suggest that the tests on the cold and hot samples might have their ratings reduced to ten each, and the value of the added accelerated life test be put in at twenty, possibly reducing some of the observation tests because, of course, those are very undesirable on account of the personal element.

I should like to second Mr. Atkinson's suggestion that instead of testing to destruction by increasing the pressure 10 per cent every 30 sec. or every minute, the increase be at the rate of 15 per cent and at 5-min. intervals. I believe this would give more reliable data. The volts per mil, quoted in Mr. Farmer's paper, for instance, represent probably less than the one-minute strength of the cable.

Referring to Fig. 11 of Mr. Roper's paper, the slope of the curve in the type of cable on which it is based would be modified by temperature. It has been our experience with semi-solid

1. A. I. E. E. JOURNAL, June, 1926, p. 505.

compounds and on single conductors that the average life of a very large number of samples with insulation 0.28 in. thick, tested at 44 kv., or about 156 volts per mil, with a 2/0 conductor, would run around 40 hr. On the same samples, tested at 85 deg. the average life was in the nature of 1000 hr., the reason being that voids were not present in the second case in the same degree as in the first. You cannot prevent some voids in cable due to the process of manufacture unless you go back to the old Siemens' process and apply the lead cold, because the lead goes onto the cable at a temperature around 200 deg. cent. and it is evident that this must warm up the cable as a whole, so that when it cools to room temperature there is some shrinkage and some voids are created. It is for this reason, I believe, that in the past cables which were operated at average voltage stresses of less than 50 volts per mil have not given as much trouble as cables operated above 50 volts per mil average stress. This is due to the fact that at atmospheric pressure you get ionization effects around 50 volts per mil.

To illustrate how the curve in Fig. 11 may be varied with different types of impregnating compound, I have checked up and found that there the voltage ordinarily varies inversely as the seventh root of the time. We have this check on tests running up to 2800 hours and the results agree quite well with the formula.

On oil-filled cables of the Pirelli type, however, we have found that the exponent, instead of being seven, should be something in the neighborhood of nineteen, indicating a very much flatter curve.

There is one piece of information involving very long and expensive testing with reference to the effect of surges on cable on which I have data and I am giving a brief summary of results below:

Two samples of single-conductor 2/0 cable with insulation 0.28 in. thick; 10 ft. under the lead.

Sample No. 1 was continuously subjected to 13.2 kv. at 60 cycles at room temperature. Once a day a 50-kv., 10,000-cycle surge of approximately 300 microseconds was applied. Total number of surges applied up to the termination of the test, 357.

Sample No. 2 was subjected to an impulse voltage of approximately 300 microseconds duration from the lightning generator (the sphere-gap being set for 75 kv.) once a day. This sample was, of course, also under continuous stress of 13.2 kv. Total number of applications, 333.

Total length of time involved in the test on each sample—9933 hr.

The initial power factor at 28 kv., at room temperature, was 0.5 per cent. The final power factors were as follows:

At 5 kv.—0.6 per cent

At 15 kv.—0.5 per cent

At 28 kv.—0.6 per cent (an extremely small increase in the power factor.)

The above tests were on sample No. 1.

Sample No. 2 at the end of the test at 5 kv. showed 0.45 per cent; at 15 kv., 0.5 per cent, and at 28 kv., 0.6 per cent.

After the completion of the tests, samples were put under continuous stress at 48 kv. a-c. and they stood in excess of 36 hr.

R. W. Atkinson: Mr. Roper and his aids are to be commended for the large measure of accomplishment they have made toward the solution of the complex problem. They have shown that cable having the insulation of their 13-kv. system will not be free from operating difficulties unless it can meet certain test standards and that when it does meet these standards continued satisfactory operation seems assured, and, indeed, so far as their considerable experience goes, is assured by a large margin.

I endorse most of Mr. Roper's conclusions but wish to discuss two of them. The fourth one, stating that the ratio of puncture voltage obtained on cold bent samples to the puncture voltage obtained on the straight sample appears to be an excellent test of workmanship, contains a qualification which I wish to emphasize. Mr. Roper uses the words "that this ratio *appears* to be an excellent test of workmanship." Undoubtedly, in many cases it is a test of workmanship. In general, American cables made at this time show approximately the same dielectric strength on the two tests, that is, this ratio is in the neighborhood of unity and without doubt the increase in the ratio from former times has resulted in no small measure from improvement in general excellence of workmanship. However, I do not believe that there is a fundamental relationship between the ratio and the quality of workmanship such that this condition will always remain true and I believe that the individual tests themselves and other tests and actual direct determinations of the quality of workmanship will be found to be much more important than any chance ratio which may seem to exist between these two tests. If proper weight is given to these other things, then the ratio between the two tests can be omitted from consideration.

I agree with Conclusion 9, that quality rating tables can be used with reasonable accuracy to determine relative merits of different lots of cable, but if this comparison is to be more than a very rough approximation, some additional types of measurements must be made in order to find better means than are now available to cover the subject of uniformity.

There cannot be any doubt of the value of the so called life tests, and the suggestion of these authors to change the eight-hour test in the Edison specification on reels to be used afterward to destruction tests on shorter lengths marks a distinct advance. For many years, we have been carrying on life tests in our laboratories, making these tests at relatively lower voltages and carrying them for many hundreds or thousands of hours. It is interesting to note that very much the same sort of data is obtained in the relatively shorter period, and of course tests for the shorter period have the very practical advantage that far more data can be obtained with a given space and equipment. I agree with these authors in placing this test as doubtlessly the most important single test. It is interesting therefore to note curves in Figs. 12 and 13, from which the authors conclude that this test gives substantially the same result as the rating table and that both are in general agreement with operating experience. The data given, however, do not justify this as a *general* conclusion.

Actually, the life test depends so largely upon the same things upon which the operating experience may be expected to depend that ordinarily there will be a very close relationship between them. It is easy however, to cite cases where this will not be true. The cable might be made with a compound of such characteristics that it would not well withstand a cold bending test or handling while cold; then be installed in extremely cold weather and give a very bad service record in spite perhaps of being able to pass an extremely severe life test.

If, when a group of cables is rated in the order of relative merit, (as determined by the best information available) any characteristic is found to fall in the same order as the rating of the cables, on first thought this may be assumed to indicate that this characteristic has fundamental importance in regard to the rating, or that it varies directly with some other very important property. I have already shown that even such an important test as the life test may vary in a way different from the serviceableness of the cable. It is evident, then, that relatively minor properties may vary, in some cases, as the relative value of the cable, and in other cases, in an entirely contrary direction. To establish the importance of any particular test or item in the rating table, the individual item must be studied and its importance studied separately.

It follows, therefore, that we should be able to take a complete group of mechanical characteristics and get the same comparison as for a correlated and complete group of electrical characteristics. If these results do not coincide, there is no doubt that one or the other is not complete or is not properly evaluated. Each individual item that is given weight should be studied

analytically and the weight determined in that way. Evaluation of these different properties by mere comparison with operating experience, without the initial analytical comparison, is likely to be misleading.

These authors have followed the analytical method to some extent; for instance, in the case of the cold bending test. They have pointed out installation conditions and have shown the relatively excessive number of failures which once occurred in the manholes. They have ascribed the large reduction in such failures to the use of cable better able to withstand the bending test. I should ask, at this point, if the better results may not be partly a result of closer supervision of installation and greater assurance that cables are not subjected to conditions from which they can be protected or for which they were not designed. The general analytical treatment given the bending test justifies that it be considered of important weight.

I have already mentioned that there is no justification for the use in rating table of the ratio between breakdown of the bent and unbent samples. Substantially the same arithmetical result can be obtained by changing the weights and some changes in the limits. It may be asked, if there is no final arithmetical change in the rating due to making the change here proposed, what is the use of making it? In the first place, logic demands it; secondly, there is a very important practical reason. If the test on the bent sample is three times as important as the other, it warrants a great deal more relative attention. If it is three times as important, there should be three times as many tests made of this kind as of the other. Half of the present number of samples now intended for the straight test should be added to those tested after bending.

Uniformity of insulation resistance is given considerable weight in the rating table because it is assumed to be an index of the uniformity of the cable. It is, however, a measure of uniformity of only one property—insulation resistance. If insulation resistance measurements can be used to indicate uniformity in properties important in themselves, those advocating it as important for that purpose should suggest what properties it indicates and should use the insulation resistence measurements to aid in picking out non-uniformities in the important property.

There is, however, another aspect of the matter. Conditions in Chicago are known to be peculiar in one respect that has undoubtedly greatly influenced the whole handling of the cable problem. Street conditions have dictated a limitation of diameter to three inches and power requirements have been for very large capacities at high voltages. No doubt the standard necessarily set for 33-kv. cable had a bearing on a choice in Chicago of insulation thickness less than for usual American practise. Mr. Roper's experience has demonstrated that the problem of suitable specifications for cables with such insulation thickness is vastly more complex than where thicker insulation is used.

I want to express too my pleasure in hearing Mr. Roper mention two things which I have been preaching for quite a number of years. One is that low dielectric loss can be overemphasized, and the other is that the cable manufacturers should not be limited to a particular kind of compound. Mr. Roper spoke of resin and its value. Some years ago the cable manufacturers had considerable difficulty in preventing operating people from insisting on putting into specifications the stipulation that a compound should be a mineral-base compound.

D. M. Simons: In general I agree with most of the conclusions of the authors, but I feel that real consideration should be given to the matter of whether or not some of the specific recommendations for tests are of general application or of general necessity. When the authors speak in general of a 13,000-volt cable, they have in mind a three-conductor, 500,000-cir. mil sector cable, insulated with 9/64-in. paper on the conductor, and 5/64-in. belt insulation. The mental picture of a 13,000-volt cable in the mind of a manufacturer is very different. He will have in mind various sizes of conductor with conductor insulation thicknesses varying from 9/64 in. up to the more usual thicknesses of 12/64 to 16/64 in., and of various belt thicknesses. The manufacturer therefore has a tendency to wonder if the tests and data are of sufficient generality, large as they may be in extent, to justify general conclusions?

I should like to mention one other point. The authors are known to advocate very severe tests and also extremely thin insulation. I believe, however, that most companies go rather slowly in reducing thicknesses. It is of course possible to go to thinner insulation than the average used in the country for a given voltage, but, apparently, in order to do so, the severity and number of tests must be greatly increased so that at least part of the small saving in cable cost, due to thinner insulation, may be lost due to the increased cost of testing to find out if the cable is adequate. The authors state that *some* of the large operating companies have made reduction in the thicknesses of insulation. I do not find that this is by any means the general tendency; in fact out of a list of some fifty of the larger central stations I was able to note only three or four such cases in the entire country.

Percy Dunsheath: For twelve months I have known Mr. Roper has been working on this point of rating and I have not agreed with him. I have always felt that if you have a dozen different factors you can't add them together; any one of them, no matter how good the others are, may cause the cable to fail. For instance, if you have the papers on the cable very well registered, that counts for nothing if there is no compound in the cable. I have always criticized this method of Mr. Roper's on that score, but now I see this curve and I think I am converted. The curve does demonstrate pretty definitely that the testing of a cable by Mr. Roper's method comes very near the truth.

R. J. Wiseman: Mr. Roper's quality rating is most valuable to manufacturers. By using the weighted values, each of us can rate our own cables. Some of us may not agree entirely with the various weights of the separate factors, but as a whole the result should be a guide. As we get to know the various influencing factors which will cause a cable to fail in service, we can assign more weight to them. Is tearing in bending tests equal to half the weight of thoroughness in impregnation? I don't believe so. Today practically all manufacturers butt the tapes or use a slightly open wrap. There is not much difference between a tear and an open wrap. To be sure, too many openings at one point are undesirable. Registration of tapes is more serious than tears.

We still must consider that the dielectric strength of a cable is a big factor. I am glad to see Mr. Roper give most weight to items No. 9 and 10, dealing with voltage on the hot sample and cold bent sample. I believe that practically all manufacturers are getting nearly the same breakdown voltage for hot and cold samples. Therefore, it is possible to reduce the weight value of the ratio of the two and add a new factor, the long-time voltage test on a 75-ft. length. Some of its weight can be taken from item No. 11 and some from item No. 8. I think the weight of item No. 8 is too high. It is definitely known that power factor varies with voltage. Therefore, full weight should be for an actual change in power factor, say 0.5 per cent.

Uniformity of impregnation is the great need today. As the authors state in their paper, cable showing uniform tests, gives the best service. Insulation resistance is one of the best ways to determine uniformity but sometimes even this will not show up a defective reel of cable. If used in conjunction with the a-c. specific inductive capacity, however, it is a good guide to the uniformity of the cable. I am glad the authors recognize that it is the variation in insulation resistance and not the actual value that is important. It appears that there may be a relationship between insulation resistance and dielectric loss, but in each case it must be for each individual manufacturer.

There are some who do not believe the ionization test is of value. Here again, it is the individual manufacture as shown in Fig. 6 of the paper. Each one of us has his own curve, depending on the type of materials he uses and his own manufacturing methods. Let the user obtain the curve for each manufacturer and then compare results with this curve.

The new test for stability of compound needs to be perfected before we can use it as an accepted one. The idea is good but until we are able to prepare samples without entrapping air, we shall have to postpone using the test as a criterion for good compound.

The section of the paper dealing with the relationship between voltage and time of application is most valuable. Although others have referred to it and based their ideas upon short sample tests, the amount of data collected here give weight to the curves obtained. I think it would have been interesting if the authors plotted as ordinates, the logarithm of the maximum stress at the conductor instead of the ratio of breakdown voltage to rated voltage. Although some may question the accuracy of the formulas for calculating maximum stresses at the conductor for multiple-conductor cables, the work done by Atkinson and Simons has cleared up pretty well the discrepancies in the exact formulas. As it is now, a new set of curves must be drawn for each voltage. It is the maximum stress that the material can stand which is important. Low-voltage cables are being made today the maximum stress of which at breakdown is as high as for super-tension cables. Therefore, to expect a 33-kv. cable to withstand say seven times rated voltage for the same length of time as a 5-kv. or 13-kv. cable is asking too much.

There is a problem in connection with high-voltage testing which needs to be solved. We all know that we get different results if we apply a constant voltage until failure, noting the time. If we build up to this same voltage in steps, holding at each step, say one, five or ten minutes, and finally noting the time at the last voltage, the total time will be less, and it should be. On the way up to the last voltage the dielectric is being stressed; therefore, it is going through the fatigue pertaining to the breakdown phenomenon. The ultimate effect is the same failure. I believe the dielectric has been subject to just the same total amount of strain as in the first case. Although it did not stand up as long at the final voltage, it may be equally as good; in fact, it may be better. I have tried to evaluate the step test and the single voltage test but so far I have not been successful.

We must not misinterpret the formation of hot spots in a cable while subject to high voltages. If only one or two occur, it is an indication of possible weak spots but where there are many and uniformly distributed over the sample, I believe it is an indication of a uniformly manufactured cable, and although it may not stand as high a voltage ultimately as one with less hot spots, it may be a preferable cable. The whole length is failing at the same time and not here and there.

H. G. Burd: Many cable failures are charged too readily to defective cable. I should like to see considerable more study of operating conditions. A 25 per cent improvement of cable quality (as shown by recent tests) should be paralleled by a corresponding improvement in treatment of cable during and after installation. Quite radically different operating results in different cities on the same quality of cable present most convincing argument that many failures have a very close relation to operating problems and that even the best of cable as now made wouldn't overcome some operating handicaps.

F. A. Farmer: Some of us have been spending much time during the past two years trying to arrive at some method of taking all of the more or less intangible things which go to make up "quality" and combine them in such a way as to get a quantitative figure which we can call "quality." But even after we have done this, the proposed method must be tested finally by comparison with actual performance, and that is what Mr. Roper has attempted to do. I think he is going to get a satisfactory answer before very long. That, to my mind, will be one of the most important contributions that has been made in many years to our discussion of this subject.

E. S. Lee: If you study the tables in the paper carefully you will find many interesting things. Take, for example, in Table I, the cable as represented by manufacturer *D*. This cable has the lowest rating for tearing in the bending tests and it has the lowest rating for dielectric power loss at 80 deg. cent. It has a relatively low rating on workmanship, insulation and fillers, and it has a relatively low rating on the ionization test. In spite of these deficiencies, the relatively high value of the puncture voltage on straight, and particularly on cold bent samples, earned this cable the highest total quality rating. Nor does this honor seem to be misplaced, for from Fig. 12 we see that samples from cable *D* outlived all others by several fold. Evidently tearing in bending tests, dielectric power loss, workmanship on insulation and fillers, and ionization test values, may have very little weight when the insulation has high dielectric strength.

Those interested will certainly eagerly await the results of this cable in actual operation. In other words, if we had had these figures from some cable that we were trying to rate, wouldn't the tendency have been for some to say, "Well, it has low tearing; it has relatively high dielectric power loss; it has a low rating in the ionization test. Even though it has high dielectric strength, will not these other factors possibly react to give a lower endurance of the cable?" Evidently in this case they have not, but perhaps in some other case they might.

Equally interesting is the fact that cables *A* and *B* rate practically equal in all respects, the total rating being 81.9 and 80.3; yet from Fig. 12 we learn that the life test of cable *B* was 45 hr. as opposed to a life of 115 hr. for the sample of cable *A*, or an increase in life of 156 per cent for the same quality rating. Perhaps this may be attributed to non-uniformity of insulation, though both cables are rated practically perfect as regards uniformity of insulation.

Now on the other hand, cable *C*, which rates inferior to cable *B* in practically every respect, having a total quality rating of only 46 as opposed to 80 for cable *B*, has a life of 35 hr. compared with life of only 45 hr. for cable *B*, or an increase in life for cable *B* of only 29 per cent for a quality rating 72 per cent greater.

I bring these to your attention because I should like to have explained to me how one can use a quality rating of this kind with these irregularities. I recognize that we have wide variations in all of this work, and to me, it seems that the wide variations are still present in this particular quality rating table.

I make an appeal, as has been done by several others, for the inclusion in this quality rating of two other tests, (1) the short-time breakdown test, with five-minute steps rather than one-minute steps, and (2) an electrical endurance test. Increasing the time length of steps in the short-time breakdown test will not increase the difficulties of the test but it will bring into account more prominently the effect of electrical endurance which I know both Mr. Farmer and Mr. Roper advocate. An electrical endurance test where some voltage such as Mr. Roper suggested as 3.6 times normal or some other value times normal for different ratings of cable, (because it will probably have to be different for different ratings of cable) are applied continuously, giving results as in Fig. 12, will serve to take into account all the factors in the quality rating which we can otherwise accomplish only imperfectly.

In Table II, cables *P* and *Q*, with total quality ratings much below those for cables *N* and *O*, have longer life, as shown by Fig. 13. A possible explanation is the fact that cables *P* and *Q* have low dielectric power losses, while cables *N* and *O* have high dielectric power losses. Apparently this factor obtains more prominence in 35-kv. cables than in 13-kv. cables, and is an added argument for including breakdown and electrical endurance tests in the quality ratings as suggested above.

I do not present these points to disparage the idea of quality ratings; I advocate them, and I hope that we may be able to perfect them so that they will be of greater use; but there are still uncertainties in these particular quality ratings, and I hope that they may either be explained so that we won't have to worry about them or that we can improve them so that they can be made of greater use to us.

W. A. Del Mar: I should like to mention something in relation to the point brought up by Mr. Wallace Clark; namely, that some of his associates, some years ago, showed that a determining critical stress in a cable is a stress of about 50 volts per mil or 18-kv. per centimeter, in which a very thin film of air ionizes at atmospheric pressure.

It is interesting to classify cables in accordance with the average stress at which they operate. I believe the average stress is of more significance than the maximum stress in this connection, and I therefore divided the cables into three groups.

The diameter of a cable must not exceed from 3 to 3½ in. but conductor sizes have been going up from the A. W. G. sizes to 500,000 cir. mils and larger and in the last few years working voltages have been rising rapidly. The net result has been a great decrease in the insulation thickness per volt; or in other words, a great increase in the electric stress. Confining our discussion to triplex cables, this increase may be seen from Table I:

TABLE I*

13-Kv. Cable

Insulation Thickness			Average Stress	
64ths on each cond.	Mils between cond.	Cm. between cond.	Volts per mil	Kv./Cm.
16				
14	437	1.111	29.7	11.7
12	375	0.953	34.6	13.6
11	244	0.874	37.8	14.9
10	312	0.794	41.6	16.4
9	281	0.714	46.3	18.2
(a)*				
8	250	0.635	52.0	20.4
7	219	0.556	59.4	23.4

27-Kv. Cable

Insulation Thickness			Average Stress	
64ths on each cond.	Mils between cond.	Cm. between cond.	Volts per mil	Kv./Cm.
23	719	1.825	37.5	14.8
22	688	1.746	39.2	15.5
20	625	1.588	43.2	17.0
19	594	1.508	45.5	17.9
18	563	1.429	48.0	18.9
(a)*				
16	500	1.270	54.0	21.2
15	469	1.191	57.7	22.6
14	438	1.111	61.6	24.3

35-Kv. Cable

Insulation Thickness			Average Stress	
64ths on each cond.	Mils between cond.	Cm. between cond.	Volts per mil	Kv./Cm.
30	938	2.38	37.3	14.7
23	719	1.83	48.7	19.1
22	687	1.75	50.9	20.0
21	656	1.67	63.4	21.0
20	625	1.59	56.0	22.0
19	594	1.51	59.0	23.2
(a)*				
18	563	1.43	62.1	24.5

*The lines (a) represent 1926 insulation minima.

Considering cables on a basis of approximate equality of stress, we have the groups shown in Table II.

TABLE II

	Group I		Group II		Group III	
	About 38 V./Mil or 15 Kv./Cm.		About 48 V./Mil or 19 Kv./Cm.		About 58 V./Mil or 23 Kv./Cm.	
Rated Kv.	64ths each cond.	Mils between cond.	64ths each cond.	Mils between cond.	64ths each cond.	Mils between cond.
13	11	344	9	281	7	219
27	23	719	18	563	15	469
35	30	938	23	719	19	594

The cables in Group I have, as a rule, given practically no trouble in operation; those in Group II have given some trouble, but those in Group III have very generally been failures both in this country and abroad.

The reason is not far to seek if we remember the classic paper presented to the A. I. E. E. in 1919 by G. B. Shanklin and J. J. Matson[2]. These authors showed that at a stress of about 19 kv. per cm., (48 volts per mil), ionization of thin films of entrapped air occurs, and it has since been shown that such ionization is destructive due to its promotion of internal surface discharges and chemical deterioration of the compound. Hence it is not surprising to find Group I, without ionization, giving perfect service, while Group II, on the verge of ionization, is in the balance, and Group III, with decided ionization, is almost invariably in trouble[3].

Mr. Roper's paper brings into prominence the significance of the time–breakdown voltage characteristic of a cable as a measure of its probable life in service. In this respect the paper deals practically exclusively with Group II and attacks the problem with rare insight and rationality. Mr. Roper shows that in order that a Group II cable may operate continuously, (*i. e.*, at a stress of 48 volts per mil or 19.0 kv. per cm.), it must have a time–voltage characteristic at least equal to that represented by the stresses shown in Table III.

TABLE III

Minutes	Factor = times the rated voltage	Average Stress	
		Volts/Mil	Kv./Cm.
5	7	323	128
16	6	278	110
65	5	231	91
360	4	186	73
1000	3½	162	64

He has shown also that certain manufacturers have solved the problem of making Group II cables which are entirely satisfactory and he knows exactly how to obtain these cables and exclude those which are of poor or uncertain quality. This is a big forward step which marks an epoch in the cable industry. It should be noted that as thick insulation is weaker for unit thickness than thin insulation, the higher voltage cables having heavier insulation will be somewhat more severely tested than those for the lower voltages.

Mr. Roper now takes a step which, in the light of events, may or may not prove to be justifiable, for he does not furnish his justification. I refer to the extension of his conclusions to cover

2. *Ionization of Occluded Gases in High-Tension Insulation*, TRANS. A. I. E. E., 1919, p. 489.

3. The Shanklin and Matson paper deals with maximum stresses, but experience has since shown that the average stress is more significant in respect to ionization and breakdown. (See also the paper by P. L. Hoover, *The Mechanism of Breakdown of Dielectrics*, JOURNAL, A. I. E. E., September, 1926, p. 824.

all cables, including those in Group III. It should be noted that his time–voltage curves and tables are not expressed in terms of stresses but of factors of so many times the rated working voltage. When applied to cables in any one of my groups, this is equivalent to specifying stresses but if applied to another group, the factors do not correspond to the stresses, but to either lower ones in Group I or higher ones in Group III.

The question arises, which is the correct procedure, to use certain stresses or factors based on the working voltage? Let us see the voltages obtained by these two systems, as shown on Table IV, considering for brevity, only the 5- and 1000-min. tests.

TABLE IV

Group I

Rated Kv.	64ths each cond.	Kilovolts Min.	by Stress	by Factor
13	11	5	111	91
	11	1000	55.5	45.5
27	23	5	232	189
		1000	116	94.5
35	30	5	304	245
		1000	132	122.5

Group II

Rated Kv.	64ths each cond.	Kilovolts Min.	by Stress	by Factor
13	9	5	91	91
		1000	45.5	45.5
27	18	5	182	189
		1000	95.5	94.5
35	23	5	232	245
		1000	116	122.5

Group III

Rated Kv.	64ths each cond.	Kilovolts Min.	by Stress	by Factor
13	7	5	71	91
		1000	35.5	45.5
27	15	5	152	189
		1000	76	94.5
35	19	5	192	245
		1000	96	122.5

A study of Table IV, shows that if uniform quality of insulation is used in the three groups, so that the cables will stand the voltages calculated from the stresses in Table III, the test voltages for Group I will be far above those calculated by Mr. Roper's factors, whereas those for Group III will be equally below. Conversely, if the cables are to stand tests based on Mr. Roper's factors, the insulation of Group I may be of inferior quality to that of Group II, whereas the insulation of Group III must be of superior quality to that of Group II.

Group I cables, however, are used in order to obtain a greater safety factor, and it would be unfair for a manufacturer to give an inferior quality, as this would result in Group I cable users, who are paying for heavier insulation, being given no greater security than users of Group II. The obviously correct procedure for Group I cable users, is to rate their cables as of Group II in their specifications.

Experience tells us that 35-kv. Group III cables which pass the test voltages calculated on the stress basis, are not necessarily good cables. Cables impregnated with what would now be considered highly unstable oils, will pass both the 5-min. and the 1000-min. tests. These cables would not have passed the tests based on the working voltage factors. Unfortunately the 5-min. test calculated by the factors cannot be tried for the 35-kv. cables, as no known type of terminal will consistently permit 245 kv. to be maintained for five minutes.

Whether the tests calculated from Mr. Roper's factors will insure the permanence of Group III cables, in my opinion, is yet a matter of conjecture. If this opinion is correct, prudence would suggest that Group II design be adhered to in our general practise until Mr. Roper can do for Group III what he has so ably done for Group II.

Present indications point both to the necessity of departure from the present design of triplex cables, if Group III stresses are to become practicable, and to the exercise of special care in operation to insure the maintenance of saturation and suitable internal pressure, so that the original quality which is insured by factory tests, will not be destroyed by chemical deterioration and temperature variations in operation.

Departure from the present standard design of triplex cables will be necessary for Group III cables, because the crude, twisted, paper fillers constitute nuclei of ionization and consequent surface discharges which must eventually lead to failure. It is somewhat early to prophesy the designs of the future, but necessity will doubtless lead to their early perfection.

F. A. Brownell: These authors' idea of a quality rating seems to be the best that has been advanced for the rating of cables.

The engineers of our company were very much impressed with this idea and arrangements have been made with our inspection department to gather the necessary data while inspecting cable so that this method can be followed.

At the bottom of the fourth page there is a clause which implies that all the cable rated at 13 kv. in Table I, is made up with manila paper. I should like to ask the authors if this is a fact, or if any of the cable in this list is made up with wood-pulp paper?

When we stop to realize that the cable tested at the factory and the cable after it has been in operation should have different characteristics, it does not seem so strange that we are unable to devise factory tests that will eliminate failures after the cable has been installed. We have set up a recording expansion meter on our cables at different times and have found that the cable is constantly in motion either expanding or contracting and, due to the different coefficients of expansion of lead, oil, paper and copper, these several parts are moving at different rates.

S. J. Rosch: Mr. Roper's company is probably the only one that has attempted to shed a little light upon what transpires after a cable has been installed; but after all, the results obtained are peculiar mainly to this particular system, because for any given voltage service, their thickness of insulation is lighter than others and therefore the factors of safety in operation are not comparable; and yet it is the work of the Commonwealth Edison Co. that has supplied the proper impetus necessary for further progress in the cable field.

The statement that a cable in the factory is not the same after it has been installed is very true, since the different methods of pulling cables into a duct are bound to change the physical structure of the cable more or less and consequently change some of the electrical characteristics as well.

I believe in placing greater reliance in the testing of cables than of samples, because the results obtained on a sample may not be indicative of a weak portion which may actually exist in the full length from which it is taken. This was very clearly borne out in Mr. Lee's paper in 1925 in which he pointed out that eight sections of cable made under identical conditions gave entirely different results. These are facts which cannot be denied, and in my opinion the only solution is a continuation of the 15-min. voltage test on all reels of cable for operation at voltages above 15 kv.

The quality rating table is a very desirable criterion of cable quality; nevertheless the points just brought out by Mr. Lee are very pertinent. For example, cable *D* had practically the poorest rating on all counts save one and yet the weight attached to this particular phase caused it to have the highest rating of all. It seems that the method of evaluation must be in error when poor workmanship on insulation and filler, excessive tearing on bending test samples, and high dielectric loss can be outweighed by high dielectric strength tests on samples of cable. If this method of evaluation is correct, then we ought to recognize this fact by changing our standards on those counts which are apparently unnecessary. This may change the entire method of manufacturing cables in this country.

But has cable *D* had an opportunity to demonstrate its superior operating characteristics in the duct system? Will the tears produced in the bending test repeat themselves with tears produced while pulling in the cables into the ducts, and will these tears impair the life of cable *D*? Not until these questions have been answered, shall we know whether the present method of quality rating of cables is the correct one.

J. L. R. Hayden (by letter): The curve in Fig. 1 herewith showing disruptive voltage vs. time of application for breakdown appears to be representative of all solid insulations, and various experiments indicate that some such relation may also hold for gases and liquids. As to the relative values of voltage, time and curve slope, these may vary over a wide range, depending upon type of insulation under consideration. The time element over which this characteristic has been generally determined is from a few seconds to an hour.

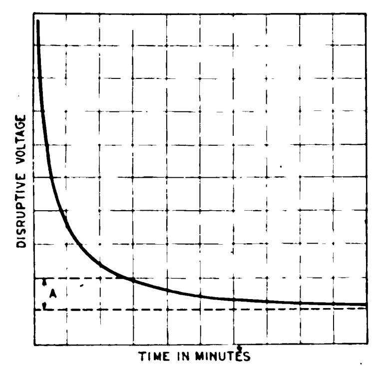


FIG. 1

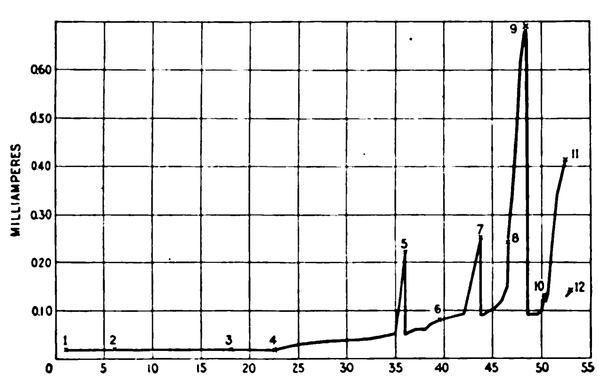


FIG. 2—CURRENT—TIME CURVES, CONTINUOUS VOLTAGE 10.9 KV.—12 ELECTRODES—TOTAL CURRENT

The accompanying Fig. 2 showing current through the insulation plotted against time at constant voltage illustrates a characteristic which has been frequently obtained on solid insulations of rather low specific resistance. Obviously, such a characteristic is obtained only when the voltage applied is in the range marked *A*, in Fig. 1. Such leakage currents are of the order of a few milliamperes at the highest, and it is observed that the current begins to increase rapidly (run away) at very low values of current. Because of these low current values and the

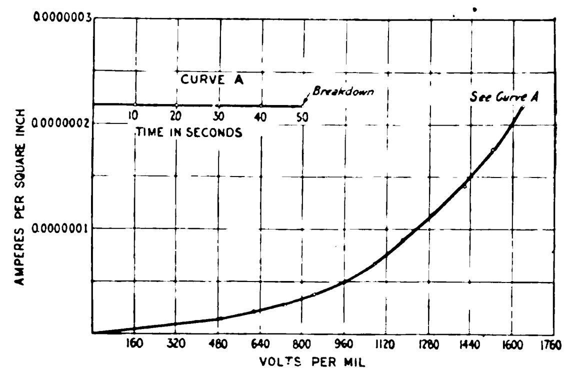


FIG. 3—VOLT-AMPERE DETERIORATION CHARACTERISTIC OF BLACK VARNISHED CAMBRIC (0.012 IN. THICK) AT 25 DEG. CENT.

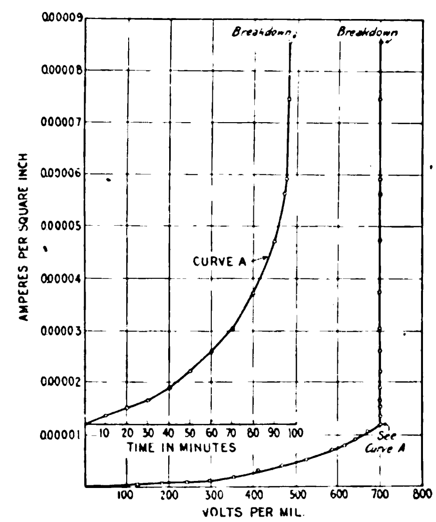


FIG. 4—VOLT-AMPERE DETERIORATION CHARACTERISTIC OF BLACK VARNISHED CAMBRIC (0.048 IN. THICK) AT 100 DEG. CENT.

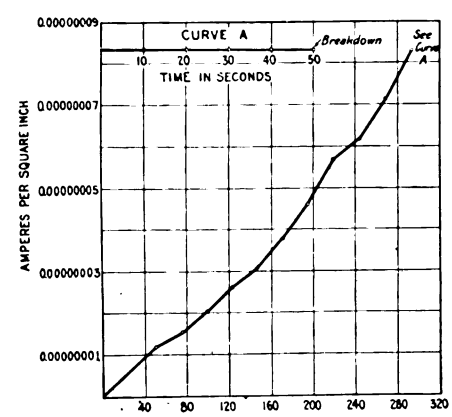


FIG. 5—VOLT-AMPERE DETERIORATION CHARACTERISTIC OF PETROLATUM IMPREGNATED PAPER CABLE INSULATION (0.115 IN. THICK) AT 100 DEG. CENT.

rapidity with which the current runs away previous to failure, it is often found difficult to obtain this characteristic, especially on insulations of high specific resistance. For example, the magnetic oscillograph, when applied to the determination of this

current before failure, will not usually indicate it, because the current is increasing at an enormous rate when it gets within the range of sensitivity of the oscillograph.

The question of whether or not all failures are preceded by a rise in current is, of course, an unanswered one. Examination of Fig. 2 will reveal that disruption of the insulation occurred under several electrodes without a detectable rise in current preceding the failure. This may mean that no gradual rise of current took place, or that the values of current were too low to be indicated. Also, comparing Figs. 3 and 4 herewith, taken on varnished cambric, it is noted that, in one instance, a decided increase in current was measured before failure, while in the other the breakdown seemed to be instantaneous. In similar tests on impregnated paper cable insulation no slow current rises previous to disruption of the insulation were noted at 25 deg. nor 100 deg. cent. The results obtained are shown on the curves in Figs. 5 and 6, of this discussion.

Attempts to substantiate the pyroelectric theory of failure by limiting this run-away current with a series resistance have usually been unsuccessful, because the current at the critical spot is a small proportion of the total leakage through the sample[4]. We succeeded in overcoming this difficulty in an electrode of small area, as the Nernst filament, and in another way with a large number of electrodes in parallel. Dr. Wagner's[5]

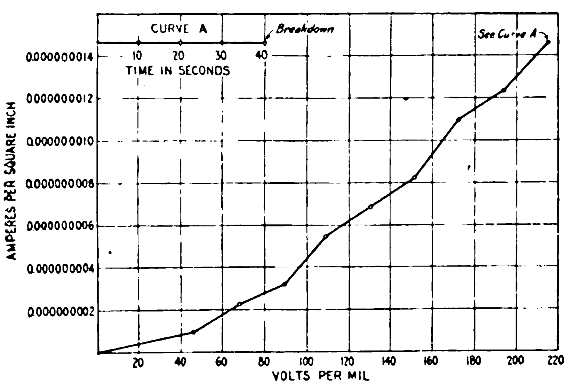


FIG. 6—VOLT-AMPERE DETERIORATION CHARACTERISTIC OF PETROLATUM IMPREGNATED PAPER CABLE INSULATION (0.130 IN. THICK) AT 25 DEG. CENT.

demonstrations of the same characteristic involved the use of the wooden block electrode.

While various experimenters have obtained results which seem to indicate that the mechanism of failure may be something other than a heat phenomenon, it is important that due recognition be given to the difficulties which had to be overcome by Messrs. Hayden, Steinmetz and Wagner in their efforts to demonstrate its nature. Nor is it to be presumed that all insulation failures have this physical nature.

Very few data are available on insulation failures caused by high voltage transients of very short time duration, or upon the chemical or physical changes which may accompany long time applications of low voltages.

It appears that the cathode-ray oscillograph, because of its great speed of operation, may be of considerable value in obtaining information on the run-away currents and the mechanism of failure with high voltages of short time duration.

D. W. Roper: I wish to compliment Mr. Lee upon the very careful study he has given the paper; otherwise, he would not have discovered the weak point in the quality rating table, the weak points being that we have not quite discovered how to make a quality rating and an accelerated life test that would be equally fair to cables of low and of high dielectric loss. There must be some change apparently both in the quality rating tables and in the accelerated life test, that is, the voltage at which the test is made in order to do that. We have not yet quite discovered how it should be done. That accounts for some of the variations to which Mr. Lee called attention.

Mr. Brownell inquired for some information regarding the cables which contained wood pulp paper and manila paper. The information was purposely omitted. The object of the paper is to get better cable by cooperation with the manufacturers and not to boost or discredit any manufacturer.

Several of the speakers have mentioned the plan of incorporating the results of accelerated life test in the quality rating tables. To me it doesn't seem desirable to do that but it seems preferable to use the accelerated life test as a parallel method of quality rating rather than to attempt incorporating the results of the accelerated life test in the quality rating table. Apparently we shall do better if we carry along the two methods of quality rating independently and see that we get results which are in accord rather than to put the one result in the other table.

Mr. Del Mar referred to the subject of high-voltage cables and stated that for the very high-voltage cables we must either use a different quality of insulation or a different design. I think he is quite correct in that point. In my opinion, for each quality of insulation there is a maximum operating voltage for which that quality should be used. If we wish to go to higher operating voltages, we cannot do so by merely increasing the thickness of the insulation, but we must improve the quality.

One of the speakers mentioned the point that in making the test on the full reels, we may cause incipient troubles in the cables which will later develop in service. Our tests indicate that with the full-reel test we are now requiring, high-voltage test of each reel at the factory, and with the proposed requirements which are given in the paper, the full-reel test as now being made will take about 2 per cent of the life of the cable if the cable is exactly on the line of the suggested requirements, while it will actually take only about 1 per cent of the life of the average quality that we are getting. We are getting above the suggested requirement. I think the manufacturing companies are willing to sacrifice 1 per cent of the life in order to assure themselves that the cable is of proper quality. Mr. Rosch, I believe, mentioned the fact, however, that we should test the cable itself rather than samples, and in the paper is mentioned a proposed test or a desired test should be made of each reel, if we could devise the test, so that we could from the test determine the minimum quality of the insulation of each section of cable as accepted by the purchaser at the factory.

Mr. Rosch commented upon cable *D* and mentioned its long life in spite of some deficiencies in workmanship as recorded in the early portion of Table I. It may not be proper to talk about the results of tests on the poorer grades of cable, but certainly no one can object to our giving a few details about the best cable.

This cable *D*, on the accelerated life test, showed a number of hot spots and we were somewhat curious to discover the causes of those hot spots. We opened up a number of them and what did we find? We found broken fillers, wandering fillers, missing fillers, and all of those other points that are given in the early part of Table I. My reaction is quite different from Mr. Rosch's on the point. To me it indicates that when this manufacturer *D* has been able to eliminate those defects in workmanship, which he undoubtedly will do, then what a remarkably high quality of cable he will secure!

Herman Halperin: The data presented by Mr. Clark regarding the slope of the voltage-time curves in Fig. 11 agree with our data in that the voltage varied inversely with about the seventh root of the time to failure for cables impregnated with a grease or a heavy oil and tested at room temperature. When an oil is used for the impregnating compound, the slope of the

4. Insulation Failure—A Pyroelectric Effect: Hayden and Steinmetz, *Electrical World*, October 21, 1922.

5. *Physical Nature of Electric Breakdown of Solid Insulations*: Dr. K. W. Wagner, A. I. E. E. TRANS., 1922, p. 288.

curve is different, according to Mr. Clark, and it becomes necessary to change the Curve $S\ R$.

Regarding conclusion No. 9, Mr. Atkinson's point that the rating tables can be used only as "a very rough approximation" until better tests are available for covering the subject of uniformity. This does not agree with our experience, since the rating tables have been more consistent with our operating records than Mr. Atkinson's statement indicates as possible. An attempt has been made to cover the subject of uniformity in accordance with the best practise of today; and as has been indicated in conclusions Nos. 5 and 6, uniformity is very essential to obtaining the best cable.

Cable specifications allow cable to be installed with a minimum radius equal to six times the diameter of the cable, and it is the practise of this company to make this radius in installation eight to twelve times the diameter of the cable.

We agree with Mr. Atkinson that the accelerated life test alone cannot be used as an indication of the quality of cable, but it has been our experience that the rating table and life test together give a fairly accurate prediction of the quality.

In regard to the point by Messrs. Atkinson and Simons, that with thicker insulations the specifications need not be so stringent, it might be mentioned that considerable trouble has been experienced in this country with the so called thick insulations. The Commonwealth Edison Company, which has reduced the thicknesses of insulation considerably during the past seven years, has found that the quality of the newer cable with thinner insulation is such that for a given voltage cable, the breakdown voltages obtained on samples have increased from 60 per cent to 120 per cent. Another way of stating the improvement in quality is that on 5000-volt, four-conductor cable, with 5/64-in. insulation around each conductor and 3/64-in. belt insulation, the voltage tests are higher now than were considered sufficient a few years ago for 10-kv. cable.

If we were to continue using thick insulations in this country there would be little progress towards obtaining satisfactory extra high-tension cable, such as 35-kv., three-conductor, and 75-kv. and higher, single-conductor cable. The important thing for high-tension cable is to have high quality insulation. Then there will be considerably less liability of local spots of poor quality which contain germs of failures to take effect almost regardless of the thickness. With good insulation, it is an economic waste to have the extra great thicknesses that have been and still are used by some companies.

With reference to Mr. Simons point that manufacturers have to deal with a large number of sizes while our paper in arriving at certain test requirements presented data mainly for one size, our procedure is a common one in electrical practise. The knowledge of the variation of the requirements due to different sizes of conductor is entirely too indefinite now to arrive at any scale of test values which might be arranged according to the size of the conductor. From a practical standpoint the test on 500,000-cir. mil cable seems to be quite representative of the various sizes of commonly used conductors for transmission cables; that is, sizes from No. 0 to 750,000 cir. mils.

In regard to Mr. Dunsheath's statement that one type of defect in the cable may be so bad as to cause the cable to fail, it should be pointed out that the rating tables are for cable that has passed the specifications and has been shipped. Therefore, the cable would not be very likely to have a bad defect, such as a large number of registered tapes mentioned by him, as the specified tests at the factory would very probably cause such cable to be rejected. Furthermore, it has been our experience that when the cable of a certain manufacturer has more registered tapes than allowed by the specifications, this deficiency is found in several lengths and is revealed by poor results in several tests. In such a case, the poor quality of the cable would be indicated on the items concerning workmanship of the insulation, increase of power factor with voltage and puncture-voltage tests.

Dr. Wiseman's point that the tearing in the bending tests is given as much as one-half of the weight for thoroughness of impregnation, (for 13-kv. cable), appears to be in error. In Item 8, eight points are given for the increase in power-factor test (ionization), which test is generally considered the best electrical test known for thoroughness of impregnation. This weight of eight points and the weight of eight points for the visual test for thoroughness of impregnation make a total of 16 points, which is four times the points for tearing.

His point that the power factor always varies with voltage is not borne out for us by commercial tests made on several makes of high-tension cable.

Dr. Wiseman's statement that the stability test for compound cannot be used until samples can be prepared with no air present does not seem to be warranted by Mr. Farmer's test; but be that as it may, a stability test for compound in high-tension cable is necessary, and no doubt a test satisfactory to all parties concerned will be evolved shortly.

Dr. Wiseman and Mr. Del Mar have referred to dielectric stresses in judging cables. One of them prefers to use maximum dielectric stress in discussing the stress in the cable, while the other prefers average stress, thus indicating the indefiniteness of judging the stress in the cable. From the standpoint of operation, what one wishes to know is the factor of assurance for the cable for a given service. For example, how many times the normal operating voltage will a sample of the cable stand for eight hours? The operators see no reason why extra high-tension cable should be purchased with a considerably lower factor of assurance than is obtained for cable of the moderate voltages, such as 15 kv. As has been pointed out, the quality of the insulation for 35-kv. and 66-kv. cable and even higher voltages should be such that it will give a proper factor of assurance. Two of the discussors have stated that potheads are not available for testing 35-kv. cable at seven times its rated voltage for 5 min. If this is true, then the test can be made at a lower voltage for which potheads are available; for instance, at six times the rated voltage for 16 min., as was suggested in the paper.

The curve *SR* indicates the minimum test requirements for satisfactory cable, and if a purchaser adds extra insulation for 13-kv. cable, (such as indicated in Group I of Table II in Mr. Del Mar's discussion), then the test requirements should be increased above the line *SR* in order to get the extra factor of assurance that is desired.

Mr. Del Mar's statement that cables in Group III of Table II "have been very generally failures abroad" is not warranted by our information concerning 35-kv. cables which have 19/64-in. insulation or less on each conductor. There are many cases, in England, France, and elsewhere, of these cables having been in successful operation from a few years up to ten.

It is agreed, with Dr. Wiseman, that the evaluation of a step test to an equivalent test at one voltage is not easy, but it appears possible to approximate the step test. In order to do this for any make of cable, it is necessary to know the nature of its voltage–time curve. After this curve is determined then the step test can be drawn in on the curve sheet on log-log paper by the following method:

Corresponding to the first step, draw a horizontal line at the ordinate of the length representing the duration of this step. At the end of this line, draw another line parallel to the voltage–time curve and as high as the voltage of the next step. From the end of this diagonal line, draw a third line representing, in length, the duration of the second step. This process is continued until the last step is drawn and the result is the equivalent test given for the voltage of the last step. The abscissa for the resulting point at the end of the last line represents the equivalent time. If this test is to be evaluated for a test at another voltage, then it can be done by drawing a line through this last point parallel to the voltage–time curve, and reading the values from this new voltage–time curve for this particular test.

As to Dr. Wiseman's discussion of the general distribution of hot spots, in the high-voltage tests mentioned in the paper, the cable usually had a few pronounced local hot spots which were from about 5 to 74 deg. cent. above the temperature of the adjacent cable sheath.

Mr. Burd's statement that different operating results have been obtained with cable of the same quality when installed in different operating systems presupposes that the insulation thicknesses were the same for given voltage cables installed in these different cable systems. From general information this does not appear to be correct. No doubt, the treatment given the cable during installation and operation will have some effect on the number of failures of the cable. It has been the aim of the company with which we are associated to install and operate the cable in accordance with the best practise. This kind of practise appears to be followed by most companies, especially the relatively few large operating companies, which are the ones that use most of the underground cable. In our experience of the cable failures, it has been frequently found that if the insulation, for instance, had been thoroughly impregnated, the failure would not have occurred.

In regard to Fig. 12, Mr. Lee has pointed out that the points for cables A, B, and C did not come as close to the curve as they might. The durations of the accelerated life tests on these three makes of cable were in consistent relative order as compared with the ratings in the table. The ratings are based on the large number of various tests covering all of the 50,000 ft. or more of the cable for each manufacturer, while the accelerated life test results are based on tests on a few samples. It has been usually found in dielectric-strength tests that there will be fairly large variations in the results and obtaining a life of 115 hr. for cable A, which was rated at 81.9, and only obtaining a life of 45 hr. for cable B, which was rated at 80.3, would not usually be considered a great discrepancy for such long tests. The voltage–time curve for these tests indicates a difference in voltage rating of only about 12 per cent.

Regarding the effect of dielectric loss on the life of the cable, the 35-kv. cables with high power factors of the dielectric will have shorter lives than would cables with low power factors, but with the same qualities in other respects. On the 13-kv. cables the makes that had the highest dielectric loss were the ones that had the longest lives, indicating high qualities in other respects.

Several discussors have made unfavorable comments about taking the variation of insulation resistance as an indication of uniformity. To begin with, this item has been given a maximum weight of only six points. The experience has been that the makers who have the greatest variation of insulation resistance also have other troubles. Manufacturers B and C in Table I, and manufacturer Q in Table II, had the highest variations, respectively, in the two tables, and these manufacturers are the ones who had the most trouble at the factory and the lowest quality insulation in other respects.

Mr. Hayden's information regarding the mechanism of failure of insulation is interesting, and it is agreed that more such information based on testing is needed.

PAPERS ON RURAL ELECTRIFICATION

(Neff[1] and Post[2])

Madison, Wisconsin, May 6, 1926

Eugene Holcomb: I notice the difference in the rate schedules in these two papers. The rates shown by Mr. Post seem undoubtedly too low for average rural territory.

It has been our experience that copper-weld lines are more satisfactory than aluminum lines and I believe that with proper sizes selected for the work to be performed, this will be found generally true.

The elastic limit as mentioned in the paper as 1860 lb. might also be checked. The sum of the strands in aluminum cable gives an elastic limit of 1593 lb., whereas this is stated in the table as 1860 lb.

The clearances given in the paper are mentioned as 18 ft. I believe 18 ft. in the code is for a 150-ft. span and for a 300-ft. span it is 19.3 ft. However, the clearances mentioned in the paper may be sufficient.

Mr. Neff has given a vivid illustration of the magnitude of rural electrification. Notwithstanding that only a very small dent in the total has thus far been made, the 33,000 mi. of lines mentioned in the inter-mountain section of the country would reach once entirely around the earth and one-third of the way on the second lap. Suppose we consider the possibilities of completely serving one township which is six miles square. A line on each one-mile road would total 72 mi. of line, counting the border lines as being half in the adjoining townships. A cost of $1200 per mile gives a total investment of $86,400 for lines. With an average of three customers per mile there would be 216 customers per township. Using the rates given in the paper and assuming the lowest monthly service charge at the stated average consumption, the monthly bill for each customer would be $10.60 and the total annual revenue would be $27,475 which, with good operating practise, would yield an adequate return on the investment and provide for replacements and other fixed charges.

Of the many forms of rate schedules proposed for rural service, the most practicable seem to be those which are based upon a demand or service charge plus a low energy charge. The simplest measure of demand seems to be the installed transformer capacity. This is tangible and easily understood and sufficiently accurate for the purpose. The energy charge should be made low to encourage the liberal use of equipment. The amount of the demand charge is determined by capacity or investment costs. Where the customer makes the investment in the lines and turns them over to the utility to maintain and operate, then the service charge should be reduced by the amount of interest on such investment. If the investment is $400, the demand or service charge should be reduced $2.66 per month from the amounts stated in Mr. Neff's paper and for a transformer capacity of not over 1½ kw., the amount of service charge becomes $2.84. In respect to the costs to the customer, it matters little who makes the investment. The matter of permitting the consumption of a few kilowatt hours to be included with the minimum charge is a question of costs and if we are to have the large monthly consumptions desired, the difference would be very slight and by that time undoubtedly most of the rates now in effect will be materially modified.

To electrify all the 6,500,000 farms in America will require some $6,500,000,000 of capital and years of time and probably some remote parts never will be served. As stated in the paper, however, progress is being made and as equipment is developed and experience gained from the experimental lines, the work will proceed more rapidly. Above all things in order to avoid costly mistakes, this work should be thoroughly mapped out and handled by men who are devoted to rural service.

Unquestionably our industry will be able presently to show how electricity can be utilized by the farmer so that it will be profitable to him and not only that, but will help do things for him and the people in the farm home that will make life there very much more attractive and satisfactory.

C. B. Hayden: There are a few points which I shall mention as important from the standpoint of the Railroad Commission in particular. The question of rural electrification is unquestionably important and the activity of the utility organization is cooperating with the farm bureaus and college experimental departments in developing a workable plan to bring

1. A. I. E. E. Journal, August, 1926, p. 733.
2. A. I. E. E. Journal, May, 1926, p. 415.

about a complete consideration of the problems involved is highly commendable. The response of the utilities has been quite unanimous and I do not believe that it can be said that, in their enthusiasm to provide this service, their interests have been completely submerged. And this is as it should be because in some instances in the past the rural policy, at least in the early years following the construction, would not provide returns sufficient to carry the investment and operating expenses.

I believe that the general policy shown by these papers, in that it tends to provide rural service for the larger consumer at very low service rates, is decidedly good. In this connection, however, we must not lose sight of the impression to be created in the mind of the average urban consumer when he realizes that, under the average community rate, he cannot purchase energy as advantageously.

I realize fully that in order to make the service of value to the farmer, aside, perhaps, for the use of lighting and small power appliances, he must be able to purchase in quantity at low rates, and I think that in a few years the energy will be so used by the average farmer. For a number of years, however, and until the experimental lines and special installations have proved that the farmer can actually make money by the use of large quantities of energy on the farm, we must remember to provide for the smaller user on terms that will not be prohibitive to him. In this connection, I should like to say that where the farmer wants the energy it has not been difficult for him to see that it is necessary to pay the cost of securing it. This applies to the average well-to-do farmer and does not apply to the smaller farmer who is operating on 15 to 20 acres where he does not figure on making very much money, but on making a living and that is all. There the use of power in large quantities, except for special uses, is out of the question.

I should like to make this point; that the average farmer must be given full consideration during this development period, and also it must be borne in mind that the rates must not favor the farmer as compared to the urban consumer for the same quantity consumption.

E. W. Lehmann: I should like to outline briefly what I think is the purpose of this rural electrification program. From the standpoint of the farmer, I believe it is first to provide service so that he can improve his efficiency in production; second, to improve the economy or lower the cost of production; third, if possible to increase or improve the quality of produce; fourth, to make the job easier and more pleasant, and fifth, to improve home life. From the standpoint of the public service company, however, I believe that the problem is to extend service to the farmer and to build up a load which will pay for the service rendered. The real job will be to sell the idea of the value of electricity and in that way sell more kilowatt hours.

It is difficult, I think, to estimate the part that electricity will play in agricultural production in the future. A look into the past, however, seeing what machinery and equipment have done and analyzing our present problems will give a fair basis for an estimate.

There is no question but that machinery and equipment have played a larger part during the past 75 years in increasing the productive capacity of the individual farmer than any other factor. While about 90 per cent of our population were farming 75 years ago, only 26 per cent are doing the job at the present time.

In regard to the development of the dairy industry, which is so important in Wisconsin, in a statement before an agricultural policy committee in Illinois a few years ago, Dr. M. W. Hepburn, an authority on dairying, said, "In a general way we may say that four factors have been largely responsible for the development of dairy production. They are:

"1. The introduction and utilization of the silo.

"2. The centrifugal cream separator.

"3. The discovery of the simple test for fat in milk,—the Babcock test, discovered at the University of Wisconsin.

"4. Better and more rapid transportation, together with the development of refrigeration."

All recognize these factors as being mechanical and their effectiveness is dependent on the application of power. Even the filling of the silo is a problem and there are other problems of the same kind.

In the whole field of crop production, equipment and machinery have played a large part; the production of wheat per person employed increased eighteen times from 1850 to the beginning of the twentieth century. With the advent of the gas tractor and the combine harvester-thresher, the efficiency per individual has been still further increased. A local farmer in Illinois who purchased a combine harvester-thresher rather recently told me that he harvested his grain at about one-third the former labor cost.

In discussing horticultural production, Dr. J. C. Blair, head of the Department of Horticulture in the University of Illinois, stated, "Without the protection afforded by spraying, insect and fungus attack will no doubt make apple-growing in Illinois an impossibility." This would apply also to other states. In certain sections of the country the application of electricity to the spray problem is being investigated with special attention to the stationary spray outfits. We should not overlook the fact that electrically driven equipment now plays an important part in the processing and manufacture of all sorts of fruits and garden produce. In addition to processing and canning, fruits are graded with electrically-driven graders and in that way made ready for market. In fact, in every phase of agriculture, mechanical equipment has played and still is playing an important part.

In considering the farmer's immediate problem we must recognize the fact that he is interested most in increasing his net income. There are three ways in which this may be done: First, by getting a better price for his produce; second, by lowering the cost of production; third, by producing more per worker. I believe the application of electricity will help in all of these methods.

In considering the application of electricity to the farm, remember that there is more than the mere matter of equipment and power involved in the farmer's problems. It is safe to say that four types of problems will be met in a rural electrification program; namely, (1) economic, (2) agricultural, (3) educational, (4) engineering.

I do not want to deprecate the part machinery has played in what I shall now say. From an economical standpoint, there are three equally important factors in agricultural production—land, labor and capital, or equipment. In addition to this, we, of course, have the item of managerial ability; in other words, the farmer himself. I believe he is as important a factor as any of the other three. Every manufacturer recognizes that there must be a proper balance between the three economic factors mentioned for economic and efficient production.

Where there is an abundance of good land, the tendency is toward the bonanza type of farming, rightfully called "agricultural exploitation." The recent rapid agricultural development in the Argentine has been due to this type of farming. The primary need there was machinery. That was formerly true in the Middle West. We cannot put too much emphasis now on the value of the soil; in fact, the life of our nation depends upon it. Much of our soil is already becoming depleted of its fertility. For efficient, economic production, our land must be well-drained, protected from erosion and must be used in accordance with the best farming practises to maintain a high state of fertility. The first step in economizing on land is a more intensive type of farming and that is a thing farmers will do when there isn't a chance for expansion.

In countries where really intensive agriculture is practised, labor is cheap and a low standard of living is the rule. We do not want this situation in America. Under our condition, we must

economize on labor as well as on land. With the apparently high wages paid in the industries competing with the farm, labor on the farm must not be wasted by the use of poor and inadequate equipment. Farm operations and organization must be more carefully studied so that the distribution of labor will tend toward more efficiency and greater economy in production.

Whether the farmer receives a living wage from his produce will depend on his ability as a manager as well as a worker. The average of forty cents an hour for the farmer as his wage is really a misnomer because he does not receive a wage until his expenses are paid and his products are sold. So the farmer is not receiving forty cents an hour as might be inferred from the remarks of the previous speaker.

We must also remember that the problems of the individual farmer will not be solved by greater production in the aggregate, but greater production per man and at lower cost. It is true that labor is one of the big items of farm production cost and we can well economize on this point. The farmer has many ways to economize on labor. His whole system of farming should be planned with this idea in mind. In agriculture, the rotation of crops, methods of handling, all affect the item of labor. One of the methods of harvesting submitted by our Farm Management Department is to use hogs. Another is to use sheep,—in other words, no equipment at all,—practically eliminating the entire item of labor and producing a finished product without the use of equipment as far as the harvesting of the crop is concerned.

It remains true however, in production that ordinarily when we economize on labor we must spend more for equipment. We recognize that the farmer's equipment must be adequate for the particular problems on the farm. I am emphasizing this because I believe the average engineer, or the man who goes out on rural electrification development work, must have a true appreciation and a true understanding of the farmer's problems, for unless he does have this true understanding he is likely to make mistakes concerning the application and the substituting of power in farming operations.

As I said before, the farmer's equipment must be adequate. But what was adequate twenty years ago might not be now. At the present time the cost of equipment on the farm is quite an item. If we study any problem in agriculture in the aggregate however, it will assume large proportions. For example the valuation of farm buildings in Illinois is around $750,000,000. On the basis of depreciation, interest on investment and upkeep at 10 per cent, the farm buildings in Illinois are costing each year $75,000,000. The cost of electrification from the standpoint of the farmer, getting his wiring done, lines connected and equipment installed might represent a little more than his building cost for a two-year period. Fifty dollars a year, if set aside on each farm, would electrify all of our farms in less than twenty years. This amount is about one-third of what it cost per year to own a low-priced car.

However, we cannot expect all our farms to be electrified. I think it is a wrong idea to believe that every section is going to be influenced the same way. The man who farms the poor land and has a small income cannot have the same type of equipment and the same buildings as the man who farms the most fertile lands.

There are situations where there is so much labor in a particular farm family that even if it costs only a few cents to operate a motor, it will be next to impossible to have it adopted.

From an agricultural standpoint, the individual farmer and the individual farm must be considered. There are a number of factors that would affect the amount and kind of equipment that can be economically used on a farm; but I will not discuss this phase of the subject. The present tendency is toward larger and fewer farms, better equipped. As you may know, there are fewer and larger farms now than ten years ago. On the larger farms the tendency is to displace labor with equipment, and this will continue as long as equipment costs less than labor. When one farmer drops out and sells his land to his neighbor, that neighbor expands and uses different methods.

There are agricultural as well as economic problems involved. In attempting to electrify farms the principle should be recognized that while the type of farming may be changed successfully by a few individuals on applying electricity, this practise cannot be generally followed. In other words, because electricity plays a large part in poultry and dairy farming, we cannot expect every farmer who has his farm electrified to buy cows and chickens and build new barns and poultry houses. We must electrify grain farms and cotton farms as well as dairy farms.

Then there is the big problem of education. The fourth factor in production which I mentioned, managerial ability, will be greatly influenced by education. The trained farmer is interested in the largest possible net income, but with all factors of production considered. His labor income should not be produced at the expense of his land.

One particular point that I wish to mention is the question of seeing that the buildings are properly wired and that they have the proper number of outlets. If the wiring is left to the farmer and he hires a contractor, it is likely that a lot of needed outlets will be left out. My suggestion would be to have the rural service man make a definite plan and get this plan approved by the farmer when he is interested and knows just what he expects to install and then have the plan carried out by a reliable contractor. I believe every man from the utility company who comes in contact with the farmer should be a salesman, not necessarily a salesman of merchandise but one who can sell the idea of electric service. Regarding rates, I believe that we should have a rate that will encourage the use of electricity, and to do that you don't want to put into the rate schedule something that is going to penalize the farmer who is going to use this service. We should have a simple rate that is easily understood.

The question of financing the line has been discussed. The possibility of having the company finance the line and eliminate all refunds and special records, and the possibility of eliminating misunderstanding and suspicion on the part of the farmer as to whether he is getting back all that he should are matters that should be considered.

Mr. Post's schedule of rates may be adequate, but I really doubt it. I wonder if it is taking care of the situation. It seems to me that any rate schedule that makes it necessary to charge a man when he installs additional outlets, penalizes him and makes it harder to build up a load. I don't believe that the farmer wants to have, as would be indicated by this particular paper, one rate when service is started and a different rate later. I think the farmer should be sold on the basis of what it is going to cost him. Farmers are not looking for charity or any special privileges. To avoid misunderstandings and dissatisfaction, the rate should be simple and easily understood; this is quite important.

It does not necessarily hold true that rural electric service is going to cost the farmer either more or less than the urban customer; it might be more or it might be less. A farmer might be classed as a manufacturer, and there would be no question so far as the people in town criticizing are concerned because of the fact that he was getting a lower rate. The farmer expects to pay for what he gets whether used in his home or in his production work.

F. W. Duffee: I wish to speak of the matter of rate, because I believe that the matter of rate is one of the most important things to be taken up and settled first, as we believe that the rate can either kill or make the proposition.

There are just a few things we might mention as having been discovered about electric service and rates. The first is that the farmers all want electric service and they want it very much. They want light probably more than anything else, and very frequently that is about all they think of until they

find out through education and experience the things they can do with electricity.

The next thing they want is a low monthly bill, $1, $2 or $3 would suit them finely, but less than that would suit them still better. When you start talking about $5 or $6 as a minimum monthly bill it hurts and it hurts bad for a while until they are shown that they can actually get out of it $5, $6, $7 or $8 worth of value. That is a point we have to educate them up to, because probably the minimum monthly bill is going to be somewhere around $5 or $6.

Then, of course, we must show them the advantage of using equipment; and the rate should be such as to encourage the use of equipment, because there is no question, in any one's mind I believe, that a low rate per kw-hr. can only be secured by a large consumption and the rate should be such as to favor that to a very great extent. A great deal of effort should be directed toward educating the people to the fact that a large current consumption will bring a low rate. Some of the rates in effect now in Wisconsin are such that, with a consumption of around 200 kw-hr. per month, the rate per kw-hr. is actually less than in some of the fairly good-sized cities.

As to our line at Ripon which has been built and upon which we have been working, it might be interesting to say in connection with the point that Mr. Neff brought out regarding the amount of power which each worker uses, that on some of these farms we have from 10 to 12 h. p. of connected load around the farmstead at the present time. That includes all motors and all household equipment. I don't believe that we are beginning as yet to get the maximum results from that connected load by any manner of means. I believe we can do a great deal toward increasing the use of that equipment, thereby decreasing the amount of work which the man and woman have to do around the barn and around the farmstead, and as you reduce the time that he must spend around his barn, you can thereby increase the amount of time he can spend in his field. That is a way to make more money; it is an indirect way, but a very real way just the same.

Regarding the matter of rate, I have one very interesting example. Up near Ripon a farmer had built for himself a line. He was a rather well-to-do farmer. This line cost him about $1500. He was the only one on it. It was built when the prices were high, but nevertheless it was quite long, I think a mile. He had installed and connected an electric range, refrigerator, motor-operated milking machine, a water pump and a large number of household appliances. His total consumption had been running less than 100 kw-hr. for all of that equipment. When asked why he didn't operate it after he had spent all of his money for this line and equipment, he said it would break him to operate it because the rate was constructed in such a way that it was prohibitive to use any large quantity of current. He has gone onto a different rate recently and I haven't heard what his consumption is at the present time.

As to the particular projects, some things which we consider of the greatest importance, I shall just mention:

1. Grain elevating and handling.
2. Grinding feed.
3. Grinding bones for chickens.
4. General utility motor.
5. Hoisting hay.
6. Individual cooking units.

Some of the above applications are fairly successful now, but it seems as if there was room for development in order to obtain the maximum benefits. That will be discussed later.

The following equipment is mechanically satisfactory if one can afford the initial expense of the equipment or the high cost of operation:

1. Electric ranges.
2. Electric refrigerators.
3. Electric ironers.
4. Water heaters for household use.

Electric ranges, surprising as it may seem, have been found rather economical in certain conditions where there is no natural fuel on the farm. We found, in one case, that they could operate an electric range for just about what they would pay for coal. It has been shown by monthly readings that they must *learn* to use a range and they must use certain types of utensils with it to get the best results. For example, one farmer bought his wife a pressure cooker. The current consumption dropped off about 20 or 25 per cent immediately afterward.

The handling of grain by elevators is a thing that can be done very readily by electric power and is something that is not done generally at the present time. At threshing time it usually takes anywhere from two to four extra hands to handle the grain. That can be cut down very readily to about one hand and a small motor and little equipment.

We have found that a small feed mill operated by a 3-h. p. to 5-h. p. motor can be equipped with an overhead self-feed hopper and a bin underneath for ground feed or an elevator to take it away. Two such mills are in operation and another could be operated with self-feed, except that it makes a good job for an 11-year old boy.

During the six-months' grinding season, these mills have averaged, monthly, from 12 to 35 kw-hr., grinding from 150 to 300 lb. daily. On the average these mills increase the monthly bill of each farmer 63 cents, grinding about 3.45 tons.

The local mills charge about $2.00 to $2.50 per ton. Even after adding interest, depreciation and repair on the motor and mill, the actual cash saving will almost pay the total monthly bill for electricity during the six months of use, to say nothing of the time saved in bagging up the grain and hauling it to town and back.

In connection with this it is important to note that two of the mills are not troubleproof. In one case, a mill clogged and a belt was burned in two. The third mill is priced so high as to put it out of the reach of the average farmer. We firmly believe, however, that developments will soon be made overcoming these objections. All of the mills will produce a satisfactory product when grinding small grains, and one of them will handle corn on the cob with a little special feeding mechanism.

Hoisting hay is a comparatively short job in the year, but a good job, providing we can operate a hoist satisfactorily with a motor. From a mechanical standpoint there is a tremendous overload at the beginning of the operation in breaking the bunch of hay away from the load, and you need either some kind of gear mechanism for quickly changing from a low speed to a higher speed or a large motor to handle the load at that time.

The ordinary household appliances are, of course, just as satisfactory on the farm as anywhere else, and some more so. The washing machine, for example, is worth more to the farmer's wife than to the city man's wife, I believe, for the reason that she has a great deal of hard work and many chores to do.

Incubation and brooding is a matter to which we have given considerable attention. Last year electric incubators did not work as well as the oil incubators, probably partly due to the fact that the operators were unfamiliar with the electric incubators. This year results show that they now compare favorably. In the meantime we have done some work in trying to perfect some of the electric controls because it has seemed that they were not sufficiently sensitive.

The problem of operating a milking machine is one to which electricity adapts itself most admirably. Electrical milkers are being used more all the time.

In this connection it is interesting to note that just recently the tariff has been raised on butter from eight to twelve cents, to permit farmers in this country to compete with the Danish farmer and the New Zealand farmer. The New Zealand farmer does not put butter on the market at a low price altogether because of the climatic conditions. It is true they have pasture practically all the year round, but at the same time they do use all the latest and best labor-saving equipment. I should like to

repeat a remark that was made to me recently by an engineer. He said he thought there wasn't a milking machine on the American market that was the equal of the average milking machine sold in New Zealand.

Another job that has proved very successful is water heating for the dairy. That has been a difficult problem. The electric water heater solved it very, very successfully and at a moderate cost, the average being 57 kw-hr. per month in one case. By turning on the switch when you start milking, the water will be hot by the time you get around to washing your utensils.

Water pumping is another job which can be very successfully handled by electricity. There are a few features about that which we have found are not taken care of in the ordinary system. The current will occasionally be disconnected and the stock absolutely must be watered. We must have some kind of standby power to be able to pump water while the current is off or else we must have storage. Most of the automatic systems are so arranged with the electric motor built into the system that it is impossible to operate them by hand or in any other way. This means you either have to have a big storage system, another well, or two pumps in one well so that you can operate one by hand or by some other means when the current is off. This is a rather important problem.

E. A. Stewart: The papers by Mr. Post and Mr. Neff are evidences of the fact that rural electrification is soon to be put on a sound scientific basis. The methods used in the past, whereby each public utility company blindly and arbitrarily developed some haphazard method of carrying out rural extensions, are now being superseded by orderly methods. The results secured by experimental work, such as we are doing at Red Wing, Minnesota, and in nearly a score of other states, will be of no avail to our farmers unless the electric utilities adopt some such plans as are proposed in these two papers. The steps taken by these two companies in adopting a uniform method of developing rural service in each of their territories is a wonderful step in the right direction. This movement should be enlarged so as to continue throughout the state and even across the state boundaries. I mean that these companies and other companies operating in this state should get together and agree upon certain fundamental factors so that the rural service will be put on a uniform basis throughout the state and eventually throughout all contiguous, comparable territory.

You will note that the methods of financing rural extensions and the fundamental methods of rate making as proposed by these two executives are radically different. One proposes that the company finance the major cost of the line, the other proposes the farmers finance the major part of the costs. Some companies propose to finance the entire cost of high line, transformers, and secondaries, while others propose to have the farmers finance the entire cost. Urban utility business is now financed largely on the same basis throughout all contiguous territory. It is essential that farm extensions be treated in a similar way.

On account of the difference in rate structures proposed by these two companies, at the fringes of their territories where the two services meet there will be a misunderstanding of these rates by the farmers and dissatisfaction produced. One proposes a rate based on a fixed or service charge, which we are inclined to call a delivery charge, and a low energy rate. The other proposes a rate using a minimum charge based upon energy consumption and type of installation. The former proposal is like the rate that was put into effect at Red Wing, Minn., in 1923, after a rate study extending over four years had been made. So far as I know, this was the first place in the U. S. A. to use this type of rate for farm service. This type of rate is being used now by companies in at least eight different states. Our Red Wing rate, based on three customers per mile of line with all 3-kv-a. transformer installations, is a delivery charge of $6.90 per month per customer, and the first 30 kw-hr. at 5 cents per kw-hr., and all excess at 3 cents per kw-hr. It may be necessary to modify this rate for consumptions beyond 500 kw-hr. per month, and for water-heating loads. There are about ten different types of rates in use throughout this middle-west territory. These rates must be unified and coordinated to allay distrust and to make some of them more equitable and applicable.

A movement has been started in Minnesota to unify methods of operating rural extensions. A committee is working on coordination of methods in making rural extensions, particularly as regards financing, rate structure, organization, line construction and utilization in rural service. We believe that it is essential for all states to agree on some comprehensive, workable plan that will unify methods of farm electric service.

The rate structure proposed by Mr. Post has some features which may be disadvantageous and complicate the explanations that must be given to the farmer. It makes no difference to a power company whether a man has ten rooms or three rooms, if his maximum demand at time of system demand is the same in both cases. Is not the installed transformer capacity necessary to carry the load a more probable indicator of demand? The active-room basis may apply to farm service as it has been, but not as it should be, and, may I predict, as it will be. Minimum-bill type of rates have influenced thousands of farmers to keep energy consumptions down to minimum-bill size by the psychological effect. High energy charges on the minimum amounts is bad propaganda and customers forget the cheap energy on the excess rate.

Methods of financing the farm lines are important. If the farmer is to make his electric service earn money and if he is to be a satisfied customer with such high basic costs as are necessary for farm service, he must utilize electricity for many uses. To use electricity in many operations requires adequate wiring and considerable equipment. Wiring and equipment will cost from $500 to $1500. The farmer needs his money and credit to carry out this program. It is obvious that the power company should carry the investment in the high line, and even services to the farm house, as is done in urban service.

In reference to disparity of average kilowatt-hour charges on farms and in adjacent towns and cities, I cannot see how they can be the same and be equitable. Are costs for taxes, foodstuffs, fuels, and transportation the same? Obviously they cannot be. The average kilowatt-hour rate on the Red Wing farms is now below six cents per kw-hr. Some farmers have as high as nine cents, and why should they be the same or the same as in urban service.

I want to commend the suggestion that the rural salesman sell service. Also I want to say "more power to you," when you suggest that farm service must be as reliable as city service. One hundred and eighty-five acetylene lighting plants were recently installed in a district having rural service. Many electric installations were removed. The farmers were right. The electric service was execrable. Electric incubators can be bought for a song in this territory. By its type of service this company has blasted the possibilities of electric service to hundreds of farmers.

I wish to commend Mr. Neff's suggestions on the formation of a department of rural service; also his suggestion as to the desirability of a proper type of rate. The manner of converting present customers over to the new rate structure must be carefully worked out. Some plan will be proposed for Minnesota very shortly. It may involve refunds to purchase equipment.

I am glad to hear the suggestion in regard to a rural service man. The farmer should have service. Many companies that are now selling farm equipment are already putting in service departments. Two large nation-wide organizations have started such service as suggested by Mr. Neff during the past year. The electric utility companies must adopt some such plan.

I wish to close this paper with a plea for unified action, not only within the state, but in adjoining states on rural service programs.

K. A. Pauly: I was particularly impressed with the convincing demonstration by Mr. Neff—that the farmer could never hope to be prosperous so long as his production is so largely dependent upon manual labor. This is a fact which all of us, who are connected with the electrical industry, fully appreciate, but I am afraid that too few workers realize the part which machinery plays in the prosperity of the wage earner.

Mr. Neff confirms the statement which I have frequently made myself and have heard others make, to the effect that it is not an unhealthy sign to see farmers' sons leaving the farm and going to the city. This merely indicates that improved methods in agriculture have made it possible for the ever increasing needs of the cities to be met without a corresponding increase in farm labor, a distinctly healthy, rather than unhealthy, symptom.

Without electric power, it would have been impossible to place at the disposal of the industrial worker the power which he now directs and which is the secret of his prosperity and I believe that the opportunities for the application of electric power in agriculture are just as great as they were in the industrial field. The tremendous advances in industries have been due largely to new methods made possible by electric power. So we must look for modifications in agricultural methods for our greatest gains, which methods will be, as was the case with the industries, built up around the convenience and flexibility of electric service. Just as the developments in the industries have been gradual and the outgrowth of experience with electric power, so, I believe, they will be in agriculture and the new ways of doing things will come step by step.

While I heartily advocate a thorough study of all the problems involved to avoid unnecessary and expensive errors, I am not optimistic to the degree of believing that we shall ever approach the ideal without putting into practise improved methods as they appear, and confidently expecting in the future to make still further improvements. Experience thus gained may be of material assistance in hastening the further development or may even point the way to entirely different lines of study which otherwise would not have been suggested. Advance in the industries has not been haphazard. On the contrary, much study and experimentation has been at the bottom of most of the essential advances.

A. H. Ford: In connection with the question of financing farm lines I wonder how many public utility men have considered that the farmer turns his capital very much slower than does the public utility? As the result of this, the public utility should finance the farm lines rather than leave it to the farmer; because it is too hard for the farmer to get the necessary capital.

Practically all the discussion concerning electric service on the farm has been based on the premises that the farm is a factory and everyone has been waiting for the time to come when the farm factory can use electric service to advantage. It will now be demonstrated that this is not necessary. The farm is a home as well as a factory. If the interest and taxes on the farm home and on a city home of the same grade are computed, each at the common rate, it will be found that the difference amounts to about $100 per year. The fixed charges on a farm line will be less than this amount per customer. A farm with electric service can have the town advantages of water supply, electric light, refrigeration and electric cooking at a cost not greater than the same services would cost in town. It seems unnecessary therefore to wait until economical methods are developed for the use of electric service on the farm. Electric service can be sold to him at once for use in his home and at a price which he can afford to pay rather than move to town in order to get the use of the town utilities.

A couple of speakers have mentioned selling kilowatt-hours. I wish that we could forget that expression. We are not selling kilowatt-hours but electric power service. However, those who are engaged in the electric power business have thought in terms of kilowatt-hours so long that they seem unable to get away from it. We are selling electric power service which involves a demand cost as well as an energy cost and if we talk about selling kilowatt-hours we are apt to forget the demand cost and the corresponding charge which should be made. We are also prone to talk kilowatt-hours to our customers who know nothing of the term. What the customer wants is service and he is not interested in kilowatt-hours. The sooner we stop talking kilowatt-hours and talk service, the better off we will be.

G. G. Post: Mr. Holcomb questions the elastic limit of the aluminum conductor mentioned in my paper. Since the meeting, the elastic limit of 1860 lb. given in the paper was checked with data furnished by the Aluminum Company of America and was found to be correct.

Mr. Holcomb made the statement that there was little difference as to who makes the investment in the line, whether it is the farmer or the utility. Of course in the long run the farmer pays for all that he gets. There is this to be borne in mind, however; where the farmer finances a portion of the line cost, he pays his money at the beginning; where the utility finances the extension work, the utility reminds the farmer every month forever thereafter that he has paid something toward the cost of the line. People who contribute toward the cost of extensions have the faculty, you know, of forgetting in time that they have paid, and it seems to me that in the long run the man who pays the smallest monthly bill is the one who is going to be permanently satisfied.

Two of the discussors stated that the rates to the small consumer under the two plans given are about the same. Consider the case of the farmer who uses perhaps 20 kw-hr. in a month. Under one rate he would pay $2.00 and under the other he would pay $6.60.

Mr. Lehman apparently is under a misapprehension concerning some of the provisions of the rate outlined in my paper. He spoke of the effect of changing the number of outlets from time to time. The number of outlets does not affect the rates. The amount that the farmer pays depends upon the active rooms which he has in all of his buildings and upon the h. p. of connected motor load in excess of 3 h. p.

There also seems to be a misapprehension concerning the meaning of the statement "a rate schedule designed to pay full returns on investment from the very start, by using burdensome minimum charges or high rates per kw-kr., will produce the opposite result." It is not the intention to change the rate in order to increase the return; the rate remains the same. What is meant is that a line which may not be productive of adequate return in the beginning will give an adequate return later when the use of the service on the line has grown sufficiently.

I think there was also some question as to the active-room basis taking care of motors. It is true it does not take care of the motors. Motors are taken care of in another way by adding fifty cents to the minimum charge for each h. p. connected above three.

COOPERATION BETWEEN THE COLLEGES AND THE INDUSTRIES IN RESEARCH

(Wickenden, Potter, Bailey[1], Bennett)

Madison, Wisconsin, May, 7, 1926

E. B. Paine: The Engineering Experiment Station of the University of Illinois was established December 8, 1903. The object of this experiment station was stated to be the encouragement of training in engineering and the study of problems of special importance to professional engineers and to engineering industries.

The control of the Engineering Experiment Station is vested in the executive staff, composed of the director, the heads of the nine departments in the College of Engineering, and the pro-

1. A. I. E. E. Journal, August, 1926, p. 742.

fessor of Industrial Chemistry. The research work of the Station is conducted by a corps consisting of 32 full-time investigators, 14 research graduate assistants who devote one-half of their time to research and the other half to graduate study, and 50 members of the teaching staff of the college, who devote part of their time to research investigations. For the year 1925-26, approximately $95,000 has been appropriated for this work from state funds and over $60,000 has been contributed from outside sources for carrying on cooperative investigations.

The present list of research investigations includes 88 titles distributed among the engineering departments as follows:—Ceramic Engineering 10; Civil Engineering11; Electrical Engineering 8; Mechanical Engineering 14; Mining Engineering 4; Theoretical and Applied Mechanics 13; Physics 8; Railway Engineering 6; Industrial Chemistry 14. Some of these investigations are carried on in part by funds from the state and in part by funds from industrial organizations. Work is now in progress on 25 cooperative investigations.

The Engineering Experiment Station, supported chiefly by public funds, cannot be employed in the exploitation of inventions or processes or in the conduct of scientific work, the results of which are to be held from the public. Cooperative research is undertaken only in those instances where the chief purpose is to establish fundamental principles and physical laws which have a wide practical application.

The standard agreement for a cooperative investigation at the University of Illinois provides that the University contribute the use of its facilities. It will also assume the general administration of the investigation and publish in bulletins or circulars of the Engineering Experiment Station the results of the investigation. The cooperating agency furnishes the funds which are necessary to pay the salaries of special investigators, to purchase materials and special apparatus needed for the work, and other necessary expenses of the investigation. The university retains the ownership of all data secured. The research program is outlined by an advisory committee representing the cooperative agency and the executive staff of the Engineering Experiment Station.

The Engineering Experiment Station will not undertake commercial tests except under unusual circumstances. In no case will it undertake such a test if the results are to be used for advertising purposes.

Whenever discoveries and inventions result from research investigations, whether conducted with funds from the state or with funds furnished by a cooperating agency, the member of the University staff who made the discovery may be required to obtain a patent at university expense and assign the patent to the University.

John Mills: Professor Bennett's well ordered paper is both diagnostic and specific of a functional disorder in our educational system. Financial considerations and a natural impatience to get to work will probably always act to limit the number of students who can pursue continuously more than the usual four years of an engineering course. Financial progress and increased scales of personal expenses will also act to prevent any large number of practising engineers from returning to resident graduate study. Since, in general, the student will neither remain nor return, the university must go to him; and Professor Bennett's suggested method seems worthy of wide trial and very definite support.

It presupposes on the part of the practising engineers an interest in further study which is found as a rule only in those engaged in investigative work as distinct from work in commercial relations with the public or in the industrial management of routine operations. It is immediately evident that it is not for those who brag that they have never had occasion in their engineering careers to consult the theoretical books or to use the calculus tables of their student days.

Of the three types of seminar which are proposed, the first two deserve the emphasis in the judgment of the present writer who believes that a combination of the two would be most satisfactory. In such a combination the consideration of recent advances would accompany and serve to motivate reviews and extensions of theoretical considerations.

This is the type of post-graduate study in industry with which the writer is most familiar. Within Bell Telephone Laboratories there was evolved a scheme for such study which for some years has been organized by George B. Thomas, its Personnel Director. There the group of engineers and scientists is large enough to carry on such work as a self-contained group without assistance from educational institutions. Courses of graduate grade of difficulty, highly analytical in character, but illustrated by current problems and recent developments, are offered to the members of its technical staff. These are given by other members of the staff who are experts in the particular subjects. Each year there are several hundred registrations for these courses. Both instruction and attendance and study are on the time of the individual and are entirely optional. The preparation of the text material, however, is carried out as part of the regular company duties as are all the other matters with the exception of instruction and attendance. Incidentally there are neither tuition fees nor special payments to instructors, for the immediate rewards of instruction are non-financial although ultimately there may be financial return.

Some of the text material has attracted interest in academic circles and one of the texts, namely on telephonic transmission was published some time ago. Another on the subject of sound is at present on the press, and the text material of certain other courses, in mimeograph form, is being revised for publication. Such a cooperative scheme of advances in education, however, is probably unique and will always be limited to large groups, homogeneous in training and interests. To provide for similar groups representing members of different corporations some scheme like Professor Bennett's must ultimately be adopted. That advanced education of the character described is valuable both to the individual and to industry has been proved in the eight years' experience with the so-called "Out-of-Hour Courses" in Bell Telephone Laboratories. That it should be available more widely and could be accomplished under the proposed plans appears to the writer of these remarks to be so self-evident that Professor Bennett's program should meet with immediate acceptance and trial in several localities.

S. H. Mortensen: Speaking as a practising engineer, I feel that seminars conducted along the lines suggested in Professor Bennett's paper would be of great value to the experienced engineer as well as to the young graduates.

Practising engineers frequently encounter problems the successful solution of which could be quickly facilitated by means of a discussion with university professors and research workers as well as with engineers active in the same or allied fields.

Certain of these problems would be suitable for investigation in a research department of the universities and others for factory or field tests. Cooperation in this work between the universities and the industries would lead to improved measures and a broader interpretation of the results obtained.

In arranging a program for practising engineers it might be well to bear in mind that they are called away frequently on business trips. For this reason it would be desirable if each meeting would take care of one subject in such a manner that it would be more or less independent of the preceding and the following meetings, thereby making continuity of attendance less imperative.

There is little doubt in my mind that the proposed seminars will benefit universities and industries alike. The university research department and teaching staff will be in touch with the problems of the day and the practising engineers will gain added experience and broadened vision.

J. S. Coldwell: Professor Bennett's paper appeals to me

very much and I believe if any university would plan several such seminars and properly approach practising engineers and industrial concerns, they would be well attended.

Cooperation between the universities and industry would be mutually beneficial. The industrial organization would keep pace with the advance of science and would have available a very high type of research organization. On the other hand, the arrangement would broaden the university professors, keep them in touch with industrial conditions, make their teaching more effective and probably serve as a means for increased remuneration. Of the two I should say that the universities and the professors would profit the most and it is significant to note that the five papers presented were given either by a commissioner of education or by college deans. I get the impression of an effort to sell the research ability of the university to industry.

In the first place, this cooperation can be achieved only when both the university and industry have the same point of view. At present the universities' point of view is generally the advancement of science whereas industry's point of view is profit.

In order to serve industry properly and to be sought for service by industry, it will be necessary for the universities to get the profit point of view and sell their services to the industry as anything else is sold to industry. Any time the university can show industry anything which will lead to a profit in dollars and cents, it will be taken up immediately by industry.

At present it is doubtful that industry can refer immediate and concrete problems to the university for research on account of the need for familiarity with the many commercial, manufacturing, service, and other factors, also the need for quick action and furthermore on account of patent complications and competitive situations.

It is significant that in the ten years I have been with the Cutler Hammer Mfg. Company, I have seen only two university professors who visited our department. The universities and the professors should interest themselves in industry, call upon industry with much the same general point of view as a salesman, get acquainted with industrial problems and bring themselves to the attention of industry. If I were a university professor, I should visit various industrial plants, making myself acquainted with their problems and their personnel, at the same time letting them know of my familiarity with certain particular problems which they are working upon and that in a very short time the industry would be naturally turning to me as a source of information on their particular problems.

The university professors would be very welcome at our plant or other plants, and we would be glad to discuss many interesting problems with them, even pointing out the road for many important investigations of a general nature which we know have a commercial demand but which we either cannot afford to work upon or which do not tie in with our particular problems occupying most of our time.

Furthermore, if the universities want to serve industry, and at the same time maintain their organization and personnel, they will have to cut loose from traditional restrictions and make it possible for their professors to sell their services and their patents at such a price that their income would be sufficient to keep them with the university.

Some years ago when I was with a concern in the East, we had an instructor from the Cornell Metallurgical Laboratory working as a draftsman during the summer. While he was there, a rather difficult heat-treating problem came up and in the course of time it occurred to some one that he might be able to help us. The minute we put the problem up to him he gave us a general answer, and after very little checking he gave a specific answer. Immediately all the other heat-treating problems which arose were referred to him, and he continued to take care of their metallurgical problems after he went back to Cornell.

F. E. Turneaure: The question of research in the engineering colleges has been of much interest to me for many years,—in fact, ever since I began teaching at Washington University, St. Louis, where the late Dean J. B. Johnson was operating a materials-testing laboratory. In the early days of college research the subject of probably the most general interest was that of strength of materials. It is a research subject comparatively easy to develop in a college laboratory, and many of the engineering constants and empirical formulas used in civil-engineering design have been determined in the college research laboratory. Later on, many other lines of research have been developed, as have been explained before this meeting, and concerning which most of you are well informed. Along with this development of college research work has come a much closer cooperation between engineers and teachers. I suppose this is because the practitioner is becoming more scientific and the college professor more practical. This is well illustrated in the organization of the research committees of our national engineering societies, made up as they generally are of a combination of engineers and professors. The college professor is relied upon generally to conduct the research, and the practitioner offers practical suggestions relative to his experience. It is interesting to note how harmoniously they now cooperate, and at their meetings it is often difficult to distinguish between the professor and the practitioner. It is a good illustration of the growing scientific basis of engineering practise; and in electrical engineering this condition has, of course, obtained for many years.

Considering the trend of things, it would seem certain that there will be a considerable further extension of cooperative research between engineers and colleges or between industries and colleges. I believe that such cooperation is one of the very best aids in the development of the right kind of engineering instruction. Perhaps the most valuable feature is the effect that it has upon the teachers themselves, and through them, upon the students.

C. F. Harding: President Frank of the University of Wisconsin has emphasized the importance and necessity of making practical the pure research which has been developed during the last ten years. It seems to me the principal object of this discussion is the converse of that proposition, namely, the development of research in the colleges and universities resulting from practical problems. Many of these have been listed in the different institutions of the country.

At Purdue University we have been particularly interested in high-voltage developments. The great educational value of our high-voltage laboratory and the research carried on therein has resulted very largely from what may be considered commercial tests undertaken primarily as tests of a practical engineering nature of particular interest to the public utilities of the State. Like the tests at Illinois, as outlined by Professor Paine no commercial tests are undertaken unless they have some development or research value, but, for example, if competitive high-voltage insulator tests are made, in practically every case a long series of researches has resulted which has been valuable, I believe, to the profession as a whole. The same thing is true of corona tests between wires, started in the first place as a purely commercial investigation and developed in a number of years into a fundamental research in connection with corona losses. A number of other similar cases might be listed as illustrations.

In addition to this, the value of senior and graduate theses and investigations carried on partly as a result of cooperation on the part of utilities and manufacturers has enhanced very greatly the educational work of the institution.

Commenting upon Professor Bennett's excellent suggestion, it seems to me that the conferences which have been held at different technical universities are bordering very closely upon the *B* and *C* types of seminars which he outlined. Most of you are familiar with the conferences for electric meter men that are held at the different educational institutions. Following that

precedent, conferences for superintendents of distribution, particularly in the State of Indiana, and quite recently the innovation of industrial electric heating conferences, one of which was just concluded last month, have in all cases developed a fine cooperation between the university, manufacturers and public utilities of the state and have resulted in continued research and development problems of value.

So it seems to me that the work outlined in these papers is perhaps on a par with the application of pure research to industry as outlined by President Frank.

Edward Bennett: In his discussion, Mr. Coldwell makes one statement which calls for comment; namely, the statement that "if the universities want to serve industry, and at the same time maintain their organization and personnel, they will have to cut loose from traditional restrictions and make it possible for their professors to sell their services and their patents at such a price that their income would be sufficient to keep them with the university."

In other words, university professors, whose primary loyalty should be to the ideals and objectives of the educational world, are to find it feasible to remain in educational work because of the compensation received from industry for services rendered directly to industry!

When the proposal is stated in these terms it should require but slight reflection to see that in the conduct of its own affairs, industry does not subscribe to such a doctrine of divided loyalty. The old statement still holds that "No man can serve two masters: for either he will hate the one, and love the other; or else he will hold to the one and despise the other."

I cannot emphasize too strongly my view that a policy of meeting the situation or the competition pictured in Mr. Coldwell's statement simply by permitting and encouraging educators (engineering, medical, or otherwise) to supplement an inadequate salary by private practise is a short-sighted policy for which society is paying dear. The results obtained under such a program, as contrasted with those obtained under a program displaying educational statesmanship, are well presented in an article entitled, "The Extension of the Full-Time Plan of Teaching to Clinical Medicine" appearing in *Science* for Aug. 11, 1922.

As stated in my paper, it seems to many educators that the essential features of a policy under which a State university and an industrial enterprise can effectively cooperate in industrial research are set forth in the circular of the Engineering Experiment Station of the University of Illinois, entitled "The Functions of the Engineering Experiment Station of the University of Illinois." In his discussion, Professor Paine has outlined this policy.

There is, however, an element of truth in Mr. Coldwell's statement, and it seems to me to lie in his definite recognition of the fact that no engineering college can hope to enter upon the worth-while and greatly desired program of cooperative research with industry so long as it pays inadequate salaries. One of the essential first steps in the advancement of such a program is the adoption of an adequate scale of salaries.

Discussion at Annual Convention

REMOTELY CONTROLLED SUBSTATIONS[1]

(Blackwood)

White Sulphur Springs, W. Va., June 23, 1926

C. M. Gilt: The load and service requirements in the metropolitan districts are such that there has been some hesitancy in the introduction of purely automatic stations. In these territories it is common practise to maintain crews on 24-hr. duty for the promptest possible restoration of service in case of feeder outages. It is therefore important that the repair crews learn of the outage of any particular feeder as quickly as possible after it has occurred.

The purely automatic station does not provide this information without special indicating equipment approaching remote-control in cost and complications. In some cases indicators have been installed to show that a feeder in a particular substation is out and in other cases, the indication has shown in addition, which feeder is open.

The remote-control equipment not only indicates which feeder has gone out for any cause, but makes it possible for the operator to reclose the breaker under directions from the repair crews as soon as they find the trouble or sectionalize the feeder. It also provides some indication of load characteristics and distribution as well as voltage conditions which frequently are of great value in maintaining proper service.

As indicated by this paper, equipment is available for accomplishing the results over comparatively few wires, and in spite of the fact that it appears light and delicate to the man accustomed to powerhouse equipment, it seems to have a remarkably satisfactory record of performance. It is to be hoped that the manufacturers will continue their efforts in developing simpler and more sturdy devices for this very important type of control.

F. B. Johnson: Mr. Blackwood spoke of bus regulation and if I understand him correctly, that refers to bus regulation on the 4000-volt side of the substation. I would like to ask him how large blocks of power are regulated through bus regulation?

Chester Lichtenberg: The remotely-controlled substations which have been described seem to be only an intermediate step in the development of the art. They seem to be merely an extension of the manual operation of substations and, therefore, are only a step towards the ultimate which probably is a completely automatic system.

In many parts of the country, central station companies have adopted the use of automatic substations for the class of service described by Mr. Blackwood. Some of the stations are remotely supervised where this has been deemed necessary.

A consideration of remotely-controlled substations brings with it a very important question. It is the hazard introduced if equipment designed for supervisory purposes is used for remote-control purposes.

Remote-control equipment in common use today has a distinctive feature. It is provided with at least one wire between the controlling point and the outlying station for each device to be controlled. Supervisory equipment, on the contrary, uses only a few wires for controlling a number of devices in an outlying station. It uses these wires in a predetermined fashion and as a result there may be quite an appreciable time lag between the operation called for by a supervisory equipment and the functioning of the devices at the remote end. Besides, this time interval may vary from one to two seconds up to eight or ten seconds. It is therefore difficult to operate a supervisory system as a remote-control system unless the limitations of the supervisory equipment are realized.

G. O. Brown: We have advanced beyond the remote-controlled substations by the use of entirely automatic substations.

In about 1920 the Kansas City Power & Light Company put in two substations entirely automatic and during the next year added only the indicating part of the supervisory control

1. A. I. E. E. Journal, June, 1926, p. 531.

so the load dispatcher would know what was going on in those stations.

Within the last two years we have added two automatic substations of the same type and this fall we shall convert the last two of our manually operated stations into automatic. This will make all substations within Kansas City entirely automatic.

Our experience with this method of operation, using the supervisory-control devices for indication only, has been highly satisfactory. There have been less interruptions, and the time required to restore service has been much less than in the manually controlled stations.

E. K. Huntington: Our experience has been somewhat similar to that mentioned by Mr. Brown, in having two fully automatic, a-c. substations built about three years ago. Later we installed a simple form of remote indication which advises the system operator of trouble in the stations. This indication divides the trouble into three classes: transformers and station equipment; feeder circuits; and street-lighting circuits, so that the proper gangs may be sent out. Inasmuch as we have to rely upon circuits available from the local telephone company, I fear that at times entire control of the station by this means would be rather unsatisfactory. Much better service could be obtained by the use of a direct line, preferably underground, between the substation and system operator's office.

I fully agree with what Mr. Lichtenberg has said in connection with the automatic station having a number of advantages over the station which is entirely remote-controlled with no automatic equipment whatsoever in the station.

R. J. Wensley: The two stations described by Mr. Blackwood presented many new problems in design of the supervisory control equipment. The requirements of the induction-regulator control and of the single-pole breakers on the three-phase, four-wire circuits presented the most difficult problems. In the solution of these and other new problems incident to the remote control of the stations described, it is believed that a reasonably satisfactory solution of a complex problem has been obtained.

The author gives as his conclusion that supervisory control equipment should be made more sturdy. He is misled by the belief popular among engineers used to dealing with heavy power equipment, that size constitutes sturdiness. There are many cases where increase in size or weight of parts actually makes the device less suitable for its duty.

In his discussion[2] of the Lichtenberg paper on the subject of supervisory systems, (presented at the Midwinter Convention, February 1926), F. R. McBerty, President of the North Electric Manufacturing Co. and a telephone engineer of many years standing, gives an excellent brief for the telephone relay as a reliable device. He shows that the design tests on this class of equipment run into many millions of continuously successful operations. In the equipment described by Mr. Blackwood, the telephone-type relays have been improved by the addition of twin contacts. These operate on the halves of a split spring, each half of which is free to move independently. The chance of failure due to simultaneous contact trouble is small. This twin-spring construction has been standard with one manufacturer for about three years.

The upward swing of the sales curve of supervisory control equipment is so pronounced that it is felt that the idea is now well established and that there is a large future for this class of equipment. So many possibilities in the flexible and economical control of power distribution systems are revealed when these problems are examined as potential applications of supervisory control that many large power systems are being studied to determine where this new art may be used to advantage. Another year will undoubtedly show a great increase in number of equipments in service as well as some improvement in general design. This improvement will probably show mostly in simplification rather than in change in design of essential parts.

2. A. I. E. E. Journal, July, 1926, p. 672.

W. C. Blackwood: I shall close by answering the question as to the blocks of power which are bus-regulated. In the Hollis Station we have three 7500-kv-a. transformers and the total station load of 15,000 kv-a. will be bus regulated. The area served by the station is approximately a circle with a radius of from about 2 to 2 ½ miles.

GENERAL THEORY OF THE AUTO-TRANSFORMER[1]

(Upson)

White Sulphur Springs, W. Va., June 25, 1926

J. R. Craighead: In calculations on instrument transformers, more exact work is necessary than on power transformers if the results obtained are to be worthy of the accuracy which can be developed in the transformer itself.

One of the main difficulties that we have found in obtaining exact results by calculation is the separation of the primary self-inductance from the secondary self-inductance. It is very easy to obtain a total self-inductance for a transformer but not easy to separate the two components.

We have used various methods and are now able to separate the two quantities with reasonable accuracy on standard transformers. In certain cases where auto-transformers are concerned, there is considerable difficulty in finding a method which will accurately separate the two components.

I should like to ask if Mr. Upson has any suggestions as to how this fundamental separation of the two inductances can be made for purposes of accurate calculation?

In attempting the separation of secondary reactance in current transformers we have calculated ratio and phase angle from exciting current and losses. Successive assumptions were made of secondary reactance until a value was found which brought the result of calculation into agreement with test results. This value of secondary reactance was then assumed to be characteristic of the structure of the type of transformer under consideration. We also built models in which the secondary was made of cored wire so that the inner wire could be used to obtain measurements from which the secondary resistance was excluded.

If we did that with the auto-transformer, would the resulting complex of primary and secondary voltage render the function an unsatisfactory one from which to calculate?

W. L. Upson: I don't think we should have any greater difficulty with the auto-transformer. In general, I think it would be more symmetrical than the other, or may be made so at any rate.

If you are going to fix up an auto-transformer, you can carry the wires themselves right along together so that they will be perfectly symmetrical with respect to one another and that will give you the minimum leakage reactance, which is what you want. In general, that is true; I don't know whether you want it for your current transformers, but I presume that you do. You get better action from an auto-transformer with the minimum reactance and there is no reason why you shouldn't get your leakage reactances by that method in the auto transformer if you can in the other.

I think we can get the leakage reactances and inductances combined with some fair degree of accuracy. But, to separate them into their two parts and get the correct values for both of them,—the only way I know of doing that, (and it is no good for accurate work) is by some sort of graphical or geometrical study of the system.

I have a feeling, though, that we can make some progress in that kind of determination and that that is about as far as I can go. I don't know how to get at it in any other way.

1. A. I. E. E. Journal, July, 1926, p. 661.

PRODUCTION AND APPLICATION OF LIGHT

(MILLAR)

WHITE SULPHUR SPRINGS, W. VA., JUNE 22, 1926

W. E. Beaty (Cincinnati): The application of individual motor drive to varied machines, and particularly to the machines requiring 5 h. p. and below, has introduced the need for indicating lamps in connection particularly with automatic control of such machines. The gaseous lamp shown may meet that problem, and I should like to ask Mr. Millar what the voltage limitations are on a lamp of that character? I am wondering if the lamp can be used on all circuits up to, say, including 550 volts?

W. N. Goodwin: We are quite familiar with these gaseous lamps for advertising purposes in tubes several feet long employing a few thousand volts. I understand that in those, the the voltage is frequently a function of the distance between the electrodes, so that it should be quite easily possible to adopt them for any voltage from 115 volts up to several thousand.

P. S. Millar: The Committee Report records the achievement of operating these small lamps on a voltage as low as 115. It should be easy to make them operate on 220 or 550 volts.

THE HIGH-SPEED CIRCUIT BREAKER IN RAILWAY FEEDER NETWORKS[1]

(MCNAIRY)

WHITE SULPHUR SPRINGS, W. VA., JUNE 23, 1926

J. J. Linebaugh: Very few engineers other than those actively engaged in railway substation and distribution work appreciate the great advance made during the last few years in the protection of substation apparatus and railway networks, due to the development of the high-speed breaker.

It should be appreciated that the high-speed breaker operates and opens the circuit so quickly that practically all of the phenomena regarding amperes, volts, etc., are actually transients. This opens up possibility of obtaining selectivity and protection which has not been possible in the past.

Another important feature of the high-speed breaker described by Mr. McNairy is the characteristic that it only operates with current in one direction. This feature makes it possible to obtain maximum selectivity in railway networks under short circuits.

It is now possible to tie as many tracks together as desired utilizing all the copper in regular operation to the best advantage and isolate any section if it should become grounded or short-circuited without disturbing other tracks or sections. This is particularly applicable and advantageous on systems of two or more tracks.

The high-speed breaker has practically eliminated short circuits as we originally knew them on substation apparatus and distribution systems; that is, the breaker operates so quickly after short circuit occurs that the current is prevented from reaching dangerous values which would cause serious damage. This is due to the speed with which it attacks the circuit rather than the speed or time of rupturing the circuit which is about the same as with an ordinary breaker.

The advantages of high-speed breaker protection are becoming more evident as their use is extended. Figures now available indicate that they very materially decrease locomotive and substation maintenance.

Chester Lichtenberg: The circuit breakers described have been of the so called magnetic type. In addition, there is the latched-in type of high-speed breaker. Emphasis is laid upon the difference between these two types because in applying them different parameters must be recognized. Those of the latched-in type were the first high-speed circuit breakers developed. The magnetic type followed. Both have been very successful where their inherent characteristics were recognized and applications correctly made.

A prime characteristic of the latched-in type is that it will always trip at a definite current depending upon the setting of its overload feature. It always trips at the same current whether the rate of rise of current is slow or rapid.

The magnetic type described in the paper has a quite different characteristic. It is provided with a so called bucking bar, which gives it a discriminating characteristic; that is, if set for tripping at a definite, steady current, it will trip at a lower current. The difference between the point of tripping and the point of setting will depend upon the rate of rise of the current.

This characteristic can be and sometimes has been incorporated in the latched-in type of high-speed breaker and wherever this discriminating feature is incorporated in the breaker, allowance must be made in its application.

This point is quite important in the application of high-speed breakers because if they are not correctly adjusted or set, they will open when they should not. The discriminating characteristic is a point of very great importance because it extends their application.

1. A. I. E. E. JOURNAL, July, 1926, p. 619.

MERCURY ARC RECTIFIERS

(PRINCE)

WHITE SULPHUR SPRINGS, W. VA., JUNE 25, 1926

A. Odermatt: While it is true that there are still some phenomena in connection with the mercury arc rectifier which we don't quite understand, it is also true that we know enough about the process taking place inside the rectifier to design perfectly reliable converters of both the glass-bulb and the iron-clad types.

Statistics covering about 800 rectifiers in service, with a total output of over 400,000 kw. supplied by the European Brown Boveri Company, show that the percentage of failures with rectifiers is smaller than with most of the other classes of electrical machinery such as synchronous converters, generators and motors. This refers to big rectifiers in iron casings but probably also holds good for the glass-bulb type. With the latter, of course, the risk of breakage should be taken into account, but on the other hand, it is easy to have available spare tubes for replacement.

I mention this in order to emphasize that the mercury arc rectifier, after having gone through a period of development of over twenty years, is today a thoroughly reliable apparatus, and its many advantages at higher d-c. voltages especially give the static mercury vapor converter a marked superiority over the rotating type.

The Brown Boveri Company is still using the condensing chamber, which has given excellent results in preventing the mercury from being extracted by the air pump. This rather long chamber of comparatively small diameter acts indeed as a kind of safety device in that direction, the piping through which the air and gases are exhausted being connected to the top of the condensing chamber.

It has been mentioned previously that the operating engineers in Chicago do not feel very enthusiastic about the results obtained with the rectifiers there. So far as the Brown Boveri rectifiers installed by the Commonwealth Edison Co. are concerned, I should like to make the following statement:

Two rectifier substations were installed there in the summer of 1925, both of which have given excellent results until the spring of 1926, when there was some trouble with one of them. The other one has given entire satisfaction all the time. The trouble which occurred was due to an external cause and had nothing to do with the proper working of the rectifier. It was water entering the working chamber, as a result of corrosion at the welding seam, that caused the breakdown; and not only rectifiers,

but most electrical apparatus would stop working satisfactorily under such conditions.

Although it is easy to prevent the repetition of a breakdown of that kind, it is most unfortunate that this should have happened in one of the few plants installed in this country, because it is likely to put the reliability of the rectifier in a wrong light. I can give assurance, however, that rectifiers installed in great numbers—I mentioned the number of 800 before—have given such excellent results that the percentage of failures is actually smaller than with other electrical equipment. The 800 rectifiers of which I am speaking are spread over the five continents of the world and the fact that over 50 of them are operating very satisfactorily, as far away as Australia and Japan, is the best evidence of the great reliability of this apparatus.

C. P. Osborne: About twenty-three years ago, the company with which I am associated was the first to try out the mercury arc rectifiers for street lighting. These sets were installed by the General Electric Company and some of them are still in operation.

The operating engineer today is greatly interested in mercury arc rectifiers not only for street lighting but for low-voltage distribution. Operating companies will no doubt install more d-c. distribution in the future than in the past, if it can be done with the mercury arc rectifier.

Our company is confronted at this time with a program which necessitates moving motor-generators which feed our d-c., three-wire Edison system from one location to another. At present the system is fed by motor-generator sets and it would be much more convenient if mercury arc rectifiers could be used and not have rotating apparatus in the new building.

I feel that the 1400-volt mercury arc rectifier will be a success and that the manufacturers' further developments and research will succeed in building lower voltage sets at a reasonable cost so they can be considered instead of converters and motor-generator sets for d-c. systems.

We visited in Chicago a substation where the mercury arc rectifier was furnishing energy for railway operation, and we did not find a great deal of enthusiasm among the men from the results they were getting from the mercury arc rectifier. The sets had just been started, however, and no doubt there will be changes which will be found necessary in order to get the desired results.

We operating men are responsible to the public for good service and in trying out new equipment we feel the manufacturers should be sure of its good operation before it is placed in service for the public. We are anxious to give the public good service in the cheapest way, but we must consider that the service comes first.

J. A. Cook: A small power application of mercury arc rectifier tubes is important to electric utility companies in street-lighting work. Glass tubes for this service have an average life of several thousand hours. Individual tubes may last double normal life or may fail after a few hours' operation. Such failure is attended by darkness on those city streets where lamps are located which depend upon this tube for their supply of current. It follows that failures of tubes should be anticipated so far as possible. C. M. Green, at West Lynn, advances the theory that failure can in some instances be anticipated. He uses a 1-to-1 ratio current transformer designed to operate at open circuit without excessive heating. The secondary of this transformer is connected through suitable resistance to the vibrator of an oscillograph. This gives a view of the ripples superimposed on the direct current. When certain tubes are about to fail there will be noted a pronounced peak which occurs on an otherwise flat portion of the wave. I should like to ask Mr. Prince if he can tell us of a test of this kind and whether tubes can be successfully treated to restore their full usefulness after the indication of approaching failure has been observed. I should also like to ask him if there is on the market an inexpensive oscillograph for visual use which would permit an operator to detect this condition in advance of failure.

I have tried the oscilloscope and find that it is not adequate for routine use by a station operator. The mirror is not driven synchronously, but is turned with the thumb. A wave without a peak can be made to show a peak. I have also tried an oscillograph of the spring-galvanometer type. Depending upon the tension of the spring, a large number of wave forms can be observed due to mechanical resonance of the vibrator system. I should repeat that a device which would indicate approaching failure of rectifier tubes on street-lighting work will be most valuable to public utility companies.

W. A. Hillebrand: I should like to ask if the use of the mercury arc rectifier is accompanied by any danger from radio interference, particularly in railway service? Is there any danger that arcing between trolley wire and collector will be more likely to set up troublesome oscillations when the circuit is supplied through a rectifier than when the source of supply is a rotating machine?

D. C. Prince: There are two general ways in which series street-lighting rectifiers fail. In one, the rectifiers actually break down at the peak of the voltage wave, due either to poor vacuum or to high temperature in the tank. If the failure be due to too high temperature it can, of course, be guarded against by keeping track of the temperature and reducing it by additional cooling water if it passes the safe value. The other type of failure is due to too perfect a vacuum. As the tube operates, the vacuum becomes more and more perfect until there is nothing to remove charges which accumulate on the glass arms. These charges prevent the current from shifting from one anode to another until a high voltage has been built up, and then the transfer occurs with a considerable shock which may break down some part of the tube or connected apparatus. This kind of breakdown in its incipient state appears as a distortion of the wave, such as is shown in Steinmetz' "Transient Electric Phenomenon Oscillations," first edition, Fig. 77. This condition can be detected by any sort of oscillograph. When this condition becomes apparent, the tube may be taken out of service and it is customary in some utility properties to impair the vacuum slightly by heating the tube in oil, water, or a small oven, after which the tube can usually be returned to service if the heating has not been overdone.

The question of radio interference has been raised a great many times. As far as we know, a rectifier in good order does not produce any radio interference. However, interference may be caused by the fading condition which produces oscillations, such as shown in Dr. Steinmetz's oscillogram, or by loose contacts. When complaints of radio interference have been made in the past, I believe they have always originated in one or the other of these ways.

Regarding the use of rectifiers on locomotives, I believe that the Westinghouse Company operated a motor car by means of a rectifier over the New Canaan branch of the New Haven railroad. There are naturally difficulties due to vibration, but I do not believe any of them is insurmountable.

As to the voltage limit of mercury arc rectifiers, I believe Mr. Odermatt will corroborate me in saying that his company has in operation a 4000-volt, d-c. railroad system supplied by mercury arc rectifiers. We have experimentally operated at 10,000 volts and there is no apparent theoretical limit, provided the proper temperatures can be maintained.

At present the floor space required by a 600-volt mercury arc rectifier is greater than that required by rotating equipment of the same voltage. At 1500 volts and higher, I believe that the advantage is in favor of the rectifier. It is probable that as rectifiers become more standardized it will be possible to reduce considerably the area which they require.

MULTIPLEX WINDINGS FOR D-C. MACHINES

(Nelson)

White Sulphur Springs, W. Va., June 23, 1926

H. B. Dwight: Part of the work done by Mr. Nelson in preparing his paper was a detailed study of all editions of Professor Arnold's books as well as a study of the few other books which have referred to multiplex windings on cross-connected d-c. armatures.

While Arnold's recommendations were valuable, they were not, by any means, complete. They consisted mainly of isolated examples. A clear description of the types of windings recommended and the types which should be avoided was not given. Some of the earlier editions of Arnold's books contained arrangements of multiplex windings with armature cross connections which were unworkable or inadvisable, and which were not included in the later editions. Probably they were recognized by Professor Arnold as being inadvisable. Other types of windings, which Mr. Nelson's paper states appear favorable and should be tried out by the industry on practical machines, were not described in Arnold's books.

J. L. Burnham: The impression I get from reading this paper is that the entire emphasis is given to the necessity of equalizing at points 360 electrical degrees apart and devising windings that will give interconnecting points exactly 360 degrees apart in the different windings employed. The necessary condition for obtaining windings that can be so equalized involves the use of an odd number of armature slots per pair of poles, thereby giving armature circuits having unequal numbers of conductors in parallel between adjacent sets of brushes of opposite polarity. This point is mentioned in the first paragraph of the third page and passed over casually as possibly of no importance. I believe that this is a very vital objection to these arrangements of multiplex windings. The intimate connection through the brushes of these adjacent circuits having unequal voltages varying in a cyclical manner to produce a continuous exchange of current through the brushes, is harmful to commutation, causing excessive local currents in the brush contact surfaces. I have observed performance of such machines in which the brushes were severely burned in sharply defined zones, causing very rapid wear of brushes and roughening and pitting of the commutator bars.

The arrangements of windings described in this paper are not new. It seems strange that such arrangements of windings have not been used commercially if they have the merits claimed. It is probable that they have been tried and found inferior to the more usual types of simple windings.

The frog-leg winding, to which reference is made at the end of the paper, has been discussed considerably of late. With this arrangement, which requires four layers of windings in the armature slots, the objections mentioned above have been diminished, but it is my feeling that well equalized. simple windings, giving equal circuits between adjacent sets of brushes, are to be preferred. The conductors of such windings may be split to reduce eddy-current losses to any degree equivalent to that obtained in the frog-leg winding. When commutation limits are reached with the simple coil, it is possible to split the individual coils to reduce the reactance voltage, giving the equivalent for which investigators have been striving in devising the multiplex windings without the objectionable features that preclude good performance in the type of windings described in this paper and the objectionable structural features of the four-layer frog-leg winding.

H. B. Dwight: The fact that duplex wave windings are successfully used at the present time by designers of machines in the United States and Canada, is one of the strongest reasons for giving a thorough practical try-out to other multiplex windings, which are in some ways very similar to the approved duplex wave windings.

Duplex wave windings consist of two wave windings side by side but cross-connected and built according to the rules described in the paper by Mr. Nelson. Duplex wave windings, as well as simplex wave windings, have a cyclic variation in the number of conductors per path. This does not seem to increase the sparking at the brushes. On the contrary, duplex wave windings have been proved by test to have less sparking than the corresponding simplex windings of the same voltage and amperage rating but with fewer and wider commutator bars. The improvement in commutation that goes with more, and narrower, commutator bars, is due, probably, as stated by Mr. Nelson, to the substantial decrease in amperes per bar and the resulting decrease in the number of amperes that are reversed when a brush leaves a commutator bar. An example of this is commonly observed by designers; namely, when they change a two-circuit, wave-wound, four-pole armature so as to give the same voltage and amperage with a multiple winding. The latter requires twice as many commutator bars and the improvement in commutation is most marked.

One criterion of the commutation characteristics of a winding is the width of the commutator bar, other things being equal. If the narrow bars are obtained by using a duplex wave winding, which is as irregular as any winding described in Mr. Nelson's paper, it has been shown by test that the improvement in commutation is obtained. Nothing has been shown to prove that the improvement will not be obtained by using other multiplex windings, such as the duplex lap winding, in order to have narrow commutator bars. Consequently, such windings should be given a trial.

Some failures with multiplex windings 25 or 30 years ago were due clearly to the lack of cross-connections. The inequality in length of paths was probably not a contributing factor. It is not peculiar that these failures put all kinds of multiplex windings into disrepute, for the action of armature cross-connections was not well known at that time, when they were just beginning to be used with simplex lap windings.

The improvements due to the frog-leg winding are probably that it gives thorough cross-connection and reduces the amperes per commutator bar. It cannot be said that it does away with inequality in length of paths, for it is made up of usual simplex and multiplex windings. Reference 7 specifies that the number of bars divided by the number of pairs of poles should be an integer, but not necessarily an even number. Thus, in Part II of Reference 7 there are 52½ slots per pole in the 1000-kw. generator, and so the number of coil sides between two adjacent brushes continually varies between 52 and 53.

A. A. Nims: The cross-connections in multiple or multiplex armature windings should connect points which are at equal potential for all positions of the armature. To make sure of this a general method of examination is preferable to one based upon a definite position of the armature.

Such a general method is indicated by the fact that the several coil e. m. f's. are essentially alternating and therefore may be represented by vectors. Though these coil e. m. f's. are likely not to be sinusoidal, they are identical in wave-shape and amplitude, disregarding any minor effect of different positions of the various conductors in a slot. Therefore, some convention may readily be devised[1] whereby the coil e. m. f's. may be represented by vectors of equal length, but in proper phase.

To apply this scheme to some of the windings illustrated in the paper, it will be found more convenient to use coil-side voltage vectors rather than coil voltage, as thereby the potentials of the rear noses of the coils, to which cross-connections are attached, become apparent.

Fig. 1A shown herewith then represents vectorially the conductor voltages of the winding of Case I, Fig 1 of the paper. For clearness, the several vectors are radiated from a nine-sided polygon instead of from a point, since there are nine slots per

1. *Electrical World*, September 28, 1912, p. 660.

pair of poles. The vectors labeled with the slot number followed by the letter *b* represent the voltages of the bottom coil-sides or conductors, assumed to be shown at the left side of each slot in the original paper, while *t* suffixed to the slot number designates the voltages of the top coil sides assumed to be shown at the right of the slots.

In Fig. 2B herewith these coil-side voltage vectors are combined in the order shown in Fig. 1 of the original paper; the outer

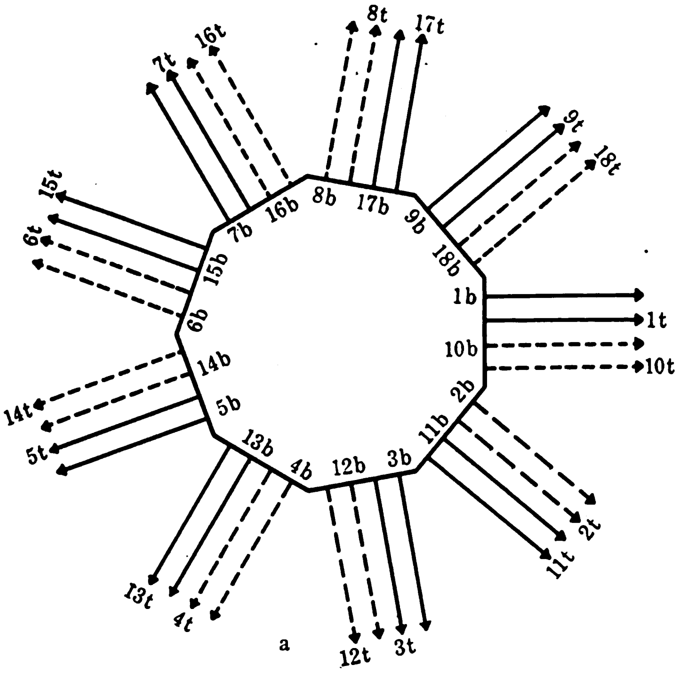


Fig. 1a—Coil-Side Voltage Vectors Separate. Dotted Lines Refer to One Winding; Solid Lines to Other

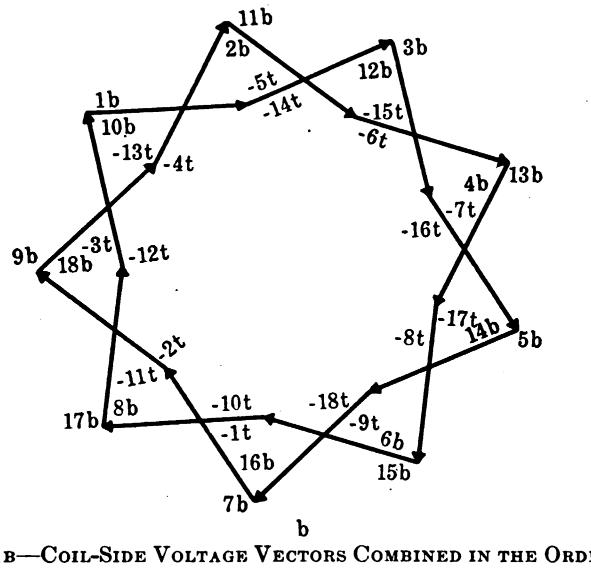


Fig. 1b—Coil-Side Voltage Vectors Combined in the Order Shown in Winding of Fig. 1, Original Paper

The vector diagrams for both windings coincide; thus all lines appear solid.

points of the star correspond to commutator bars, and the inner points to the rear noses of the armature coils. It is then evident that for every commutator bar or rear nose in one of the windings there is a commutator bar or rear nose respectively at the same potential in the other winding. This is in agreement with the statement in the paper that equipotential connections may all be located at the rear end of the armature.

Cross-connections are often used between the equipotential points of a simplex lap winding. These points are under alternate poles as in the case of the duplex winding. But it is to be noted that in the winding proposed as typical, duplexing the winding has not increased the number of points having any given potential. There is only one point in each winding having

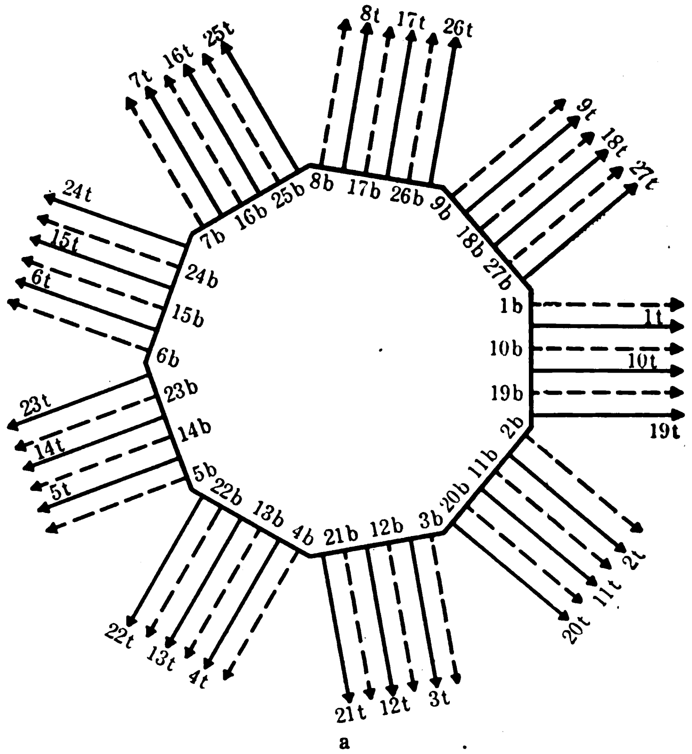


Fig. 2a—Coil-Side Voltage Vectors Separate. Dotted Lines Refer to Coil-Sides at Bottom of Slots

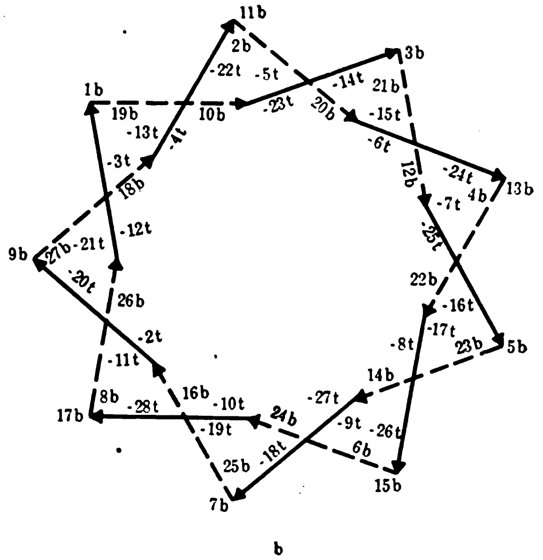


Fig. 2b—Coil-Side Voltage Vectors Combined in the Order Shown in Winding of Fig. 2, Original Paper

any given potential, and the cross-connections still unite only two points.

Fig. 2, a and b, are corresponding diagrams for Case II of the original paper, showing that there are three commutator bars or rear noses having a given potential. The cross-connections now tie three points together, as in simplex lap winding for

six poles. Since there are only two windings, these three points must be in one winding, or two in one winding and one in the other. With single re-entrancy as in this case, the distinction between the two windings practically disappears, and since the equipotential points divide the winding into three equal parts, the symmetry appears to be complete.

In the earlier treatises on armature windings, practically the only consideration imposed on multiplex windings, either lap or wave, seemed to be the selection of a proper number of commutator bars, armature coils or coil sides to permit re-entrancy. Later study brought out the importance of symmetry between circuits, and in 1916 there was added to the usual winding formulas the condition that the ratio of poles to armature circuits must be integral[2].

This condition limits windings to the usual simplex lap and wave windings, the duplex wave winding in four-pole machines, the triplex in six-pole machines, the duplex and quadruplex in eight-pole machines, the duplex, triplex and sextuplex in twelve-pole machines, and so on, always keeping to a degree of multiplicity which is an exact factor of the number of bipolar elements of the machine.

Multipolar machines may be regarded as an aggregation of bipolar elements. If each of these elements be regarded as a unit in arranging the series-parallel grouping, the numerical reason for the condition that the ratio of poles to armature circuits must be integral is apparent from Fig. 3, which shows the possible combinations of different numbers of units up to 16 poles, except for 14 poles, which has the same combinations as 10 poles.

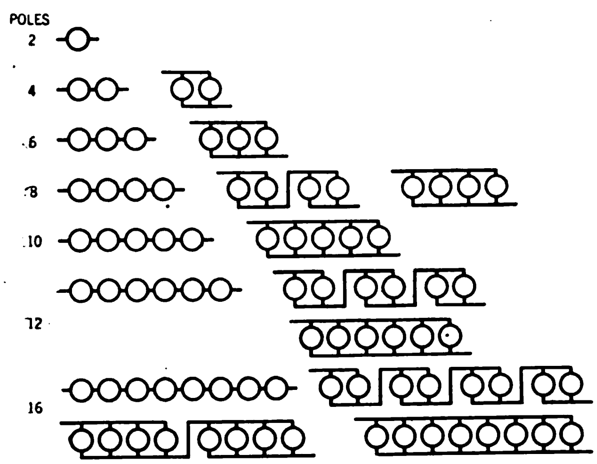


FIG. 3—MULTIPOLAR ARMATURE WINDINGS; COMBINATIONS OF BIPOLAR ELEMENTS

It is now suggested that some of these parallel combinations may be duplexed or even triplexed, thereby making the number of circuits greater than the number of poles. This, of course, violates the condition of an integral ratio of poles to paths. Such a procedure appears to give symmetrical windings that can be cross-connected conveniently, and records of satisfactory performance are cited. Evidently some modification of the condition just mentioned is indicated.

Experience with four-circuit, six-pole windings has been such as to warrant staying pretty close to the rule that the ratio of poles to paths must be integral when the paths are fewer than the poles. But if more paths than poles are desired, the indications are that the ratio of paths to poles should be integral.

C. C. Nelson: At the present time we are not in possession of any complete and conclusive evidence to show that multiplex windings will not work. The knowledge we have on such windings is of a fragmentary nature and consists mostly of what we have gained from the observation of a few isolated cases. In regard to Mr. Burnham's discussion, I grant that there may be a cyclical change in the number of conductors per path but there has not been any direct work done in connection with this to show that it is a vital objection. We do have the cross-connected duplex wave winding, however, which now operates well but which was not satisfactory before cross-connections were applied, indicating that the cross-connections have made it a useful type of winding, commercially, whereas formerly it was objectionable. As pointed out by Professor Dwight, this winding is as irregular as any of those described, and yet it has given a satisfactory improvement in commutation when the cross-connections were suitably applied.

To my knowledge, the duplex wave winding with cross-connections is the only multiplex winding which has gained a great deal of commercial importance before the introduction of the recent frog-leg winding. For this reason the other types described in the paper should be tried, with a view to possibly increasing the number of types of windings which are to be considered useful. If designers are to be satisfied with only simple windings we cannot hope to progress very far in the armature-winding art.

Professor Nims' general method of pointing out the equipotential points may be preferable to one based upon a definite position of the armature. The conclusions reached by the two schemes are in agreement, indicating that the general method may be of some value.

On the first doubly re-entrant wave windings used without cross-connections there was considerable unbalancing between the two parts of the winding and hence cross-connections joining the two parts of the winding were put on to equalize and balance the circuits. Before cross-connections were used the results secured with the singly re-entrant winding may have caused it to gain some favor due to the fact that the singly re-entrant winding is continuous and not separated like the doubly re-entrant type and hence would probably not unbalance so much as the doubly re-entrant type.

Professor Nims states that the number of equipotential points with the duplex lap winding is not greater than the number of equipotential points secured with the simplex lap winding. This is true but the fact that unbalancing between the separate parts of a multiplex winding was experienced when these parts were not interconnected indicates that multiplex windings should be designed so that the cross-connections join the separate parts and cause as good equilization between the circuits as possible. It is probable that a greater number of cross-connections would be necessary on multiplex windings than on simplex windings.

Professor Nims further states that the ratio of poles to armature circuits must be integral and cites the case of the four-circuit, six-pole winding as being a violation of this rule. I infer from his statement that he believes experience has shown this to be an unfavorable type of winding. The four-circuit, six-pole winding of regular design cannot be cross-connected and hence there are no means whereby the circuits can be kept balanced. This is evident from the following explanation.

To produce points of equipotential it is necessary for one conductor to occupy a position under one pole while another conductor occupies a similar position under another pole of similar polarity, assuming, of course, that the flux in the poles is equal and similarly distributed. As the conductors are in slots, it is necessary that the slots occupy similar positions. If n_x denotes the number of slots per x poles, where x is necessarily an even number if similarly situated slots are to be obtained, then the total number of slots is given by

$$N = n_x \frac{p}{x}, \text{ where } p = \text{ the total number of poles.}$$

In the above p/x must be a whole number so that the total number of slots can be a whole number, remembering of course that n_x must be a whole number. Also p/x must be greater than one

2. S. P. Smith, *London Electrician*, June, 1926.

if similarly situated slots are desired, or in other words x is not to be taken equal to or greater than the number of poles, p. Then for duplex wave windings the commutator pitch is given by

$$Y = \frac{n_x \dfrac{p}{x} B_s \pm 2}{\dfrac{p}{2}} = \frac{\text{number of bars} \pm 2}{\text{pairs of poles}}$$

$$= \frac{2\,n_x B_s}{x} \pm \frac{4}{p}, \text{ where } B_s = \text{the bars per slot,}$$

and because $p = 2\,P$ where P = the pairs of poles the above equation becomes

$$Y = 2\left(\frac{n_x B_s}{x} \pm \frac{1}{P}\right).$$

The commutator pitch, Y, must be a whole number. The product, $n_x B_s$, must be a whole number because each individually must be a whole number. Therefore Y can be only a whole number when $x = P$ and as x must be even, P, the pairs of poles, must be even. Furthermore the similarly situated slots are x poles apart and as $x = P$, where P = numerically half the number of poles, the similarly situated slots are necessarily diametrically opposite. The above explanation is general and holds for all duplex wave windings.

If the nature of the four-circuit, six-pole winding was such that cross-connections could be conveniently applied so as to balance the circuits it then probably would be a favorable type of multiplex winding.

REPORT OF STANDARDS COMMITTEE

(Osborne)

White Sulphur Springs, W. Va., June 22, 1926

H. M. Hobart: It seems to me that we are only just beginning a much larger activity in standardization. Now that the Standards are being brought out in a large number of different pamphlets, it seems to me that we are just at the beginning of an era when hundreds of people can be doing the standardizing work.

Those people should be doing the work who are specialists in particular subjects. It seems to me that the most natural way to bring this about is for each Technical Committee to take on automatically those Standards relating to the subjects coming under the purview of that technical committee. Each committee would probably have two or three Standards that would be its special property, and it would be its special responsibility to keep those up to date.

Some progress has been made in that direction. In the Electrical Machinery Committee we have a subcommittee on Standards, of which Mr. J. C. Parker is Chairman, and during the past year this committee has done a good deal of very vigorous work in connection with the further revision of standards.

There is one Standard entitled Synchronous Alternators which has been adopted for less than a year but since that time very many suggestions have come from very many people. Ambiguities have been pointed out; the attention of the committee has been called to incorrect statements; the need for revision in various limits has been urged. Take, for instance, in the company where I work, there used to be just a few people interested in standardization. Now that we have Standards in separate pamphlets, the designing and commercial departments are interested and they have made at least a dozen suggestions since the revision suggesting that that Standards Committee, when opportunity presents itself, should have certain changes made.

That ought to be going on all over the country in all of the manufacturing companies. They could either come straight to the Standards Committee with those suggestions or send them to the particular Technical Committee that would deal with the subjects in which they are interested.

I want to suggest that now it isn't necessary for a few of us to be working hard on standards, but it is arranged so nicely and naturally that the subject falls into the hands of hundreds of members of the Institute in respective committees, if the committees see fit to turn their attention in that direction.

VIBRATION RECORDER[1]

(Mershon)

White Sulphur Springs, W. Va., June 25, 1926

W. F. Davidson: Some time ago, I had occasion to consider the possibility of carrying on measurements of about the type described by Mr. Mershon and looked into the possibility of several methods, but we seemed to run into difficulties because the vibrations that we wanted to record were in the order of 200 cycles. Modulating a 500-cycle wave with 200 cycles does not give a very satisfactory wave to work on. On the other hand, using frequencies higher than 500 cycles is likely to lead to some circuit difficulties, especially if an oscillograph is to be used. I have wondered whether it might be possible to use frequencies in the order of several thousand cycles and then, through a valve arrangement similar to a radio detector circuit, unscramble the composite current so that the wave can pass through the oscillograph and reproduce truly the original modulating action. It seems to me that there is a possible development of considerable value in this direction.

J. W. Legg: Mr. Mershon's paper proves that the study of vibrations in turbines, and in machinery in general, must be very important or such recording apparatus would not have been developed by several large companies in approximately the same period of time.

Mr. Mershon has perfected one method of recording minute vibrations with the oscillograph. The apparatus described is nicely arranged and has many of the undesirable features of that method eliminated. However, this particular method, of transforming mechanical vibrations into changes in current through an oscillograph vibrator, had so many drawbacks that the writer abandoned this method years ago and chose to push through a design which required no high-frequency alternator for excitation and which gave a true wave record and not a modulated record.

The final design consisted of an inductor-alternator modification which generated a voltage and set up a current in the oscillograph vibrator which was always proportional to the actual vibrations being studied. The calibration was constant over the range of vibrations studied. This apparatus was much more sensitive than that described by Mr. Mershon, and operated over a much greater range. Furthermore it required no 500-cycle motor-generator set nor any other electrical excitation or amplification. A cobalt-steel permanent magnet was the only excitation, and the complete apparatus was no larger than a medium-sized fan motor.

This vibration converter fitted into a cavity in the end of the shaft of a steam turbine or other rotating apparatus. Torsional vibrations of even less than 0.01 deg. and longitudinal vibrations of even less than 0.00001 in., at frequencies even above 2000 cycles, have been recorded. On the same film, within a small fraction of a second, more than a dozen different frequencies have been recorded ranging from 60 cycles to 2200 cycles per second. Such records could never be made by modulating a 500-cycle wave, or even a 5000-cycle wave.

In order to achieve these results, the usual principle of the alternator was modified so that the rotor would tend to seek the position where a slight relative movement between rotor and stator would give the *maximum* voltage generated in the wind-

1. A. I. E. E. Journal, September, 1926, p. 820.

ing, instead of minimum voltage. Also the flux distribution was uniform, each side of this stable position. Both rotor and stator of this special inductor alternator rotated at the same speed as the machine being studied, but one member (usually the outside member) was rigidly fixed to the shaft of the machine being studied, while the other member (usually the inside member, consisting of permanent magnet, pole tips and shaft) was free to rotate at a strictly uniform angular velocity even though the other member vibrated torsionally or longitudinally while it rotated at the same speed.

The special cobalt-steel magnet was magnetized, in place, with 300,000 ampere-turns, and the magnetizing coil (of copper) was allowed to remain on the magnet to have an additional fly-wheel effect.

One end of the permanent magnet had a multiplicity of north poles, each under two teeth of the stator. The stator teeth had a series winding in which was induced the torsional vibration currents. The other end of the permanent magnet had a ring-shaped south pole inside a toroidal winding on the outside member. This winding had radial punchings on each side so that longitudinal vibrations induced currents in this winding proportional to the amplitude of vibration of the machine being studied. The inductive drop in each winding was kept large compared with the ohmic-resistance drop, over the range of frequency to be studied, and hence a calibration *constant* could be used in place of a complicated calibration curve.

The extreme sensitivity, efficiency and compactness of this apparatus made it possible to install several of these vibration converters in different positions in the shafts of the turbines of an ocean liner. Tests were made under actual operating conditions of the vessel during a severe storm, without in any way interfering with its reliability in carrying the usual quota of first-class passengers and freight. The portable oscillograph was located in a first-class cabin at the end of a 250-ft., 12-conductor cable.

In spite of the simplicity of this device, it recorded more minute vibrations in the turbine blades themselves, by reaction through the turbine shaft to the vibration converter, than could be recorded by the apparatus described by Mr. Mershon even though the latter were attached to the blades themselves.

The outstanding advantages of the inductor-alternator vibration-converter scheme over that of the varying inductance, bridge and 500-cycle motor-generator set, may be summarized as follows:

1. Extremely compact (about the size of a fan motor).
2. Fits in a cavity in the end of the shaft of the machine being studied.
3. Requires no wires stretching up into the heart of the apparatus being studied.
4. Will operate on a standard steam turbine running in normal service and yet record the vibration of turbine blades which may be at a dull red temperature in highly super-heated steam.
5. Has actually recorded turbine vibrations of 0.00001 in. at frequencies up to 2200 cycles per second. This is not the limit of possibilities.
6. Has a calibration constant and not the complications of a calibration curve, over the operating range of frequencies.
7. When once determined, this calibration constant did not vary perceptibly even when the converters remained on turbines operating over 12,000 mi. of ocean.
8. Oscillograms are comparatively easy to read even though many different frequencies of vibration are present in a record made in 0.1 sec.
9. Both longitudinal and torsional components of vibration may be recorded simultaneously with but one converter and two oscillograph elements.

A. V. Mershon: In regard to the possibility of measuring mechanical vibrations around 200 cycles per sec., I might speak of Fig. 7 as having a natural mechanical frequency of 120 cycles per sec. What is called approximately 500 cycles in my article is actually around 700 cycles for Fig. 7. We did not try in any case to hold the 500-cycle generator at 500 cycles and I feel sure that the same circuit can be used to measure a 200-cycle mechanical frequency with very good results, and in that case, in order to obtain proper shading, it would be necessary to boost up the frequency of the 500-cycle generator to around 1000 or 2000 cycles. This frequency I do not believe would be harmful to the working of the oscillograph. In this case, as the frequency is boosted up the losses which occur around the coil would decrease the sensitivity, but not seriously.

The main difference between the vibration converter described by Mr. Legg and the vibration recorder presented in the present paper lies in the results obtained on the oscillograms. The deflections obtained on the oscillograms using the vibration converter are a function of the frequency. The oscillogram deflections obtained by the vibration recorder are true representations of the magnitude of the mechanical vibrations regardless of frequency.

The vibration converter is designed and built to do one class of investigational work and is more analytical than quantitative. The vibration recorder is designed to investigate a different kind of mechanical motion and the results obtained are more quantitative. Each circuit has its own class of investigational work to perform and should be able to perform one class of work better than the other.

The vibration converter cannot be applied at the point where the vibration occurs on turbine blades because a piece of apparatus as heavy as a fan motor is too large. The vibration converter evidently will not work well without the magnetizing coil attached to add weight so that the rotor will have a fly-wheel effect. A heavy vibration converter the size of a fan motor could not be mounted on the turbine blades on account of the mechanical strength required to hold it in place, furthermore if such a scheme of mounting could be used it would damp out the vibration and destroy its natural period. There are many cases in which the weight of a fan motor would change the natural period of a vibrating mass and render the application of a vibration converter impracticable.

The vibration recorder requires a small test coil only 1 in. in diameter by ¾ in. thick which is not attached to the vibrating part. This small coil can be mounted at the periphery of a rotating wheel adjacent to the blade that is vibrating and measure the vibrations without changing the natural period, and it will not damp the vibrating blade. A calibration curve is determined very easily, simply by varying the air-gap a fixed amount and observing the oscillographic deflections.

The vibration recorder has an additional advantage of being able to measure pressure variations. Pressure variations as slow as one per minute can be measured as easily as 200 per sec.

ENGLAND HAS ALL-ELECTRIC VILLAGE

An all-electric village has grown up in Eltham, England. When the housing scheme of the Woolwich Borough Council was first proposed it was the intention to provide electricity for lighting only and gas for cooking. The plan was apparently dealt a heavy blow when it was found that gas would not be available in that locality. Subsequent investigation however, indicated that the advantages of complete electric service could be had without sacrificing economy so that today a thriving community of 600 houses uses electricity entirely for lighting, cooking, heating and the performance of household chores.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

New York Regional Meeting

NOVEMBER 11 AND 12, 1926

A program of very timely interest will be presented at the Regional Meeting to be held in New York City, November 11 and 12, under the direction of District No. 3 of the American Institute of Electrical Engineers. There will be three instructive technical sessions and other attractive features. The Engineering Societies Building, 33 West 39th Street, will be headquarters for the meeting.

Technical Papers

The technical papers will include the general subjects of a-c. distribution networks, illumination and communication.

Demonstration of the Induction Lamp. A striking demonstration of the electrodeless induction lamp will be made on Friday morning, November 12, in connection with the paper on this subject by T. E. Foulke.

Lecture Thursday Evening

On Thursday evening a lecture of great general interest will be given by a well-known and able speaker.

Buffet Luncheons

An excellent opportunity for pleasant informal association of those at the meeting is offered by the buffet luncheons which will be served at a reasonable charge after the morning session on each day. These luncheons will be served on the fifth floor of the Engineering Societies Building so that it will be convenient for all to attend.

Inspection Trips

A number of interesting trips of inspection are planned among which are those to the Lighting Institute of the Edison Lamp Works, picture transmission and machine switching at a plant of the American Telephone and Telegraph Company, shops and signal system of the Interborough Rapid Transit Company, the Electrical Testing Laboratories, the New York-New Jersey Vehicular Tunnel and the Hudson Avenue Plant of the Brooklyn Edison Company. Further details of these trips may be obtained at the meeting.

Register in Advance

All who will attend this meeting are urged to notify Institute Headquarters as soon as possible. Also please indicate whether or not you will take lunch with the other members in the Engineering Societies Building. All should visit the registration desk at the meeting as early as possible to receive badges, to register for trips, etc. This desk will open at 9:00 o'clock each morning and the sessions will begin promptly at 10:00 a. m.

The committee in charge of the New York Regional Meeting is as follows: G. L. Knight, Vice-President, District No. 3; H. A. Kidder, General Chairman; O. B. Blackwell, H. V. Bozell, W. A. Del Mar, H. E. Farrer, E. B. Meyer and G. H. Stickney.

PROGRAM

Thursday Morning

9:00 a. m. Registration.

10:00 a. m. Distribution Session (Auditorium).

Recent Progress in Distribution Practise, J. F. Fairman and R. C. Rifenburg, Brooklyn Edison Company.

Design and Application of A-C. Network Units, G. G. Grissinger, Westinghouse Electric & Mfg. Co.

Evolution of the Automatic Network Relay, J. S. Parsons, Westinghouse Electric & Mfg. Co.

Operating Requirements of the Automatic Network Relay, W. R. Bullard, Electric Bond and Share Company.

A-C. Network Relay Characteristics, D. K. Blake, General Electric Company.

Thursday Noon

Buffet Luncheon (Fifth Floor)

Thursday Afternoon

2:00 p. m. Inspection Trips.

Thursday Evening

8:15 p. m. Lecture (Auditorium).

Friday Morning

10:00 A. M. Illumination Session (Auditorium).

(Joint session with N. Y. Section of Illuminating Engineering Society).

Remote Control of Multiple Street-Lighting Systems, W. S. Dempsey, New York Edison Company.

Lighting of Railway Classification Yards, G. T. Johnson, New York, New Haven and Hartford R. R.

Illumination from Atoms.

(a) *Theoretical Considerations*, Saul Dushman, General Electric Company.

(b) *The Induction Lamp, A New Source of Visible and Ultra-Violet Radiation*, T. E. Foulke, Cooper-Hewitt Electric Company.

(Interesting demonstrations of the induction lamp will be made.)

Friday Noon

Buffet Luncheon (Fifth Floor.)

Friday Afternoon

2:00 p. m. Communication Session (Auditorium.)

Frequency Measurements with the Cathode-Ray Oscillograph, F. J. Rasmussen, Bell Telephone Laboratories, Inc.

A Shielded Bridge for Inductive-Impedance Measurements, W. J. Shackelton, Bell Telephone Laboratories, Inc.

Radio Broadcast Coverage of City Areas, Lloyd Espenschied, American Telephone and Telegraph Company.

Award of John Fritz Medal for 1927

The John Fritz Gold Medal for 1927 was awarded Oct. 15, 1926, to Elmer Ambrose Sperry of New York, for the development of the gyro-compass and the application of the gyroscope to the stabilization of ships and aeroplanes.

This annual award was made unanimously by the board of sixteen from the four founder American societies of Civil, Mining & Metallurgical, Mechanical and Electrical engineers, representative of an aggregate membership of 56,000. It is given for notable scientific or industrial achievement, without restriction as to sex or nationality and is a memorial to John Fritz of Bethlehem, Pa., the great leader in the American iron and steel industry.

This is the 23rd award; the first was to Mr. Fritz himself in 1902, in celebration of his eightieth birthday. A few of the subsequent medalists have been Lord Kelvin, George Westinghouse, Alexander Graham Bell, Charles T. Porter, Alfred Noble, James Douglas and Henry M. Howe.

The members of the Board of Award for 1927 were as follows: American Society of Civil Engineers: John R. Freeman, Charles F. Loweth, C. E. Grunsky, Robert Ridgway, American Institute of Mining and Metallurgical Engineers: Charles F. Rand, Arthur S. Dwight, William Kelly, J. V. W. Reynders. The American Society of Mechanical Engineers: Fred J. Miller, Henry B. Sargent, Fred R. Low, W. F. Durand, and the American Institute of Electrical Engineers: Frank B. Jewett, Gano Dunn, Farley Osgood, M. I. Pupin, all past presidents of the Institute.

The official presentation of the medal will take place on the evening of Tuesday, December 7, at 8:30 o'clock in the Engineering Auditorium, 29 West 39th Street, New York as a function of the annual meeting of the American Society of Mechanical Engineers. At this session President William L. Abbott, of the Society, will deliver the annual address and Mr. Charles M. Schwab, President-elect, will be inaugurated. The medal will be presented by Frank B. Jewett, Ph. D., Chairman of the board which made the award. Members of the four Founder Societies and ladies are invited to attend the presentation of the medal and the other ceremonies of the evening.

Elmer Ambrose Sperry, engineer and inventer, was born in Cortland, New York, October 12, 1860. In 1879, when not yet twenty, he had become the inventer of a successful device, perfecting one of the first electric arc lights in America, and secured its practical adoption. The following year he founded the Sperry Electric Company, of Chicago, for the manufacture of arc lamps, dynamos, motors and other electric appliances. In 1883, he erected on Lake Michigan the highest electrical beacon in the world, (about 350 ft.) equipped with 40,000 c-p. arc lights. In 1888 he won the distinction of having been the first to produce electrical mining machinery.

Shortly after his first successes in mining machinery, Mr. Sperry designed electrical street railway cars. He then founded the Sperry Electric Railway Company, of Cleveland, Ohio, to manufacture his cars, and continued with success to 1884, when the patents were purchased by the General Electric Company.

While the earliest pioneers of the American gasoline automobile were still conducting experiments, Mr. Sperry designed a successful electric carriage, which he manufactured for several years. He also drove the first American built automobile in Paris in 1896 and 1897, where afterward, a large number was sold.

The field of electrochemistry is also indebted to Mr. Sperry. An important commercial process for producing caustic soda and bleach is due to his activity. The National Battery Company was organized and operates under Sperry patents. Among other of his achievements may be mentioned an electrolytic process whereby white lead of superior quality is produced at low cost from waste of copper mines.

About thirty years ago Mr. Sperry turned his attention to the gyroscope and soon concluded that this "scientific curiosity" could be put to work. His investigations led him to the belief that it could be used as a true compass, and it was he who made the first successful gyro-compass.

For many years it was obvious that something should be developed for stabilizing ships. Fruitless attempts were made by naval architects and engineers throughout the world, but no practical means were brought forth until as a result of tedious and expensive work Mr. Sperry's gyroscopic ship's stabilizer was evolved. It has been recognized by the foremost naval architects as an innovation revolutionizing ships' hull design, and by insuring a steady gun platform it increased the efficiency of naval gunnery many times.

Mr. Sperry has done much also to increase the efficiency of arc lights. Some eight years ago he made the first public announcement of his high intensity arc searchlight. Notwithstanding the fact that the old type of carbon arc had been accepted as the ultimate. The art was at a standstill. The old type of searchlight, however, was of practically no value for military and naval use with the increased range of gunnery and the advent of the airplane, in one step Mr. Sperry produced a practical light with a brightness 500 per cent greater than the brightest previous artificial light, an advance which may be ranked with Sir Humphrey Davy's discovery in 1807 of the electric arc itself. By using a positive carbon with a mineralized core, or a vapor-producing material, an incandescent gas is generated to give brilliancy as high as 900 c. p. per sq. mm. with a temperature of nearly 6000 deg. cent. Development of this form of arc, together with the electrical and mechanical means for operating it and caring for tremendously high temperatures, produced a searchlight which is standard for the principal armies and navies and used successfully for aircraft and coast line beacons, giving a white finger of light that has been seen upwards of a hundred miles.

This light has revolutionized also the production of motion pictures, and the same light is utilized for projecting pictures on the screens in theatres.

About thirty years ago Mr. Sperry produced his first compound, internal combustion engine, since then adding substantial contributions to its development from time to time. His greatest achievement is his compound diesel engine, lately put into a practical power plant usage with the lowest grade fuel oil but giving high efficiency.

Soon after Wright and Curtiss built their first airplanes, Mr. Sperry became interested in aerodynamics and has brought forth several inventions for the aircraft industry. In 1914 he was awarded first prize by the Aero Club of France for his airplane stabilizer, or automatic pilot, which is also the basis for the aerial torpedo. With its aid, aerial torpedoes have been made to function reliably for distances of over 200 mi. The gyro-compass has also been adapted to aircraft. Mr. Sperry also brought out the drift indicator, (for which in 1918 he was awarded the Collier trophy), and the turn indicator which makes it possible to fly in fogs and other adverse weather. He is an active member of the Naval Consulting Board and chairman of two important committees thereof. The value of his contributions to American and foreign governments during the late war is inestimable.

Mr. Sperry is a charter member of the American Institute of Electrical Engineers and the American Electro-chemical Society, a member of the American Society of Mechanical Engineers, American Chemical Society, Society of Naval Architects and Marine Engineers, Society of Automotive Engineers, and many others. He has been the recipient of the following Awards: Honorable Mention, World Columbia Exposition, 1894, for Mining Machines; First Prize, Aero Club of France, 1914; Franklin Medal, Philadelphia, 1914; Grand Prize for Gyro-Compass and Gyroscopes, San Francisco Exposition, 1915; American Museum of Safety Medal. He was deco-

rated by Czar Nicholas III, of Russia, for navigational equipment, and in 1922 received the Order of the Rising Sun from the Emperor of Japan.

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, October 15, 1926.

There were present: President C. C. Chesney, Pittsfield, Mass.; Past President Farley Osgood, New York; Vice-Presidents W. P. Dobson, Toronto, H. M. Hobart, Schenectady, N. Y., G. L. Knight, Brooklyn, N. Y.; Managers H. P. Charlesworth, New York, E. B. Merriam, Schenectady, H. A. Kidder, New York, I. E. Moultrop, Boston, H. C. Don Carlos, Toronto, F. J. Chesterman, Pittsburgh; National Secretary F. L. Hutchinson, New York. Present by invitation: Dr. William McClellan, Dr. Clayton H. Sharp.

The minutes of the Directors' meeting of August 10, 1926, were approved as previously circulated.

Action of the Executive Committee, under date of September 24, 1926, in approving applications for Student enrolment, admission to membership, and transfer to higher grades of membership, was ratified.

Reports were presented of meetings of the Board of Examiners, held September 20 and October 11, 1926, and upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 166 Students were ordered enrolled; 36 applicants were elected to the grade of Associate; 3 applicants were elected to the grade of Member; 43 applicants were transferred to the grade of Member.

Upon request, the Meetings and Papers Committee was given authority to accept for presentation at the New York Regional Meeting, November 11-12, papers from four non-members.

Upon application from the various Districts concerned, regional meetings were authorized as follows:

Kansas City, Mo., March 17-18, 1927
(South West District)
Bethlehem, Pa., April 14-15, 1927
(Middle Eastern District)
Pittsfield, Mass., May 25-27, 1927
(North Eastern District)

Approval by the Finance Committee for payment of monthly bills amounting to $33,119.73 was ratified.

A budget for the appropriation year beginning October 1, 1926, was adopted as prepared by the Finance Committee.

Upon the recommendation of the National Secretary, an increase of approximately twenty per cent in the advertising rates of the Institute Journal was authorized.

A selection of five members of the Board to serve on the National Nominating Committee, as required by the by-laws, was made as follows: H. P. Charlesworth, G. L. Knight, E. B. Merriam, I. E. Moultrop, E. C. Stone.

Upon application, the Board authorized the organization of a Section of the Institute at Louisville, Kentucky, and Student Branches at the Municipal University of Akron, Akron, Ohio; the College of Engineering of the Newark Technical School, Newark, N. J., and the University of Santa Clara, Santa Clara, Calif.

A revision of Sec. 83 of the By-laws was adopted, changing the date upon which the president of the Institute becomes a member of the John Fritz Medal Board of Award from the third Friday in January to the third Friday in October, to conform with the change in date of the annual meeting of the Board.

Upon the recommendation of the Marine Committee and the Standards Committee, the Marine Rules of the Institute were adopted as Section 45 of the Institute Standards, with the title "Recommended Practise for Electrical Installations on Shipboard."

Consideration was given to the appointment of a Local Honorary Secretary in Australia to fill a vacancy. Mr. H. W. Flashman of Sydney was appointed.

The following representatives were appointed: Mr. Calvert Townley, on the Board of Trustees of the United Engineering Society, to succeed Mr. H. H. Barnes, Jr.; Mr. L. B. Stillwell, on Engineering Foundation Board (reappointment); Mr. H. M. Hobart, on American Engineering Standards Committee (reappointment); Dr. J. Franklin Meyer, Mr. John C. Parker, and Mr. L. T. Robinson, alternates on American Engineering Standards Committee.

The following were appointed as a special committee to make recommendations upon the design and conditions of Award of the Lamme Gold Medal, for the annual award of which the Institute received a bequest from Benjamin G. Lamme: Professor Charles F. Scott (Chairman), Messrs. H. H. Barnes, Jr., E. B. Meyer, L. W. W. Morrow, and N. W. Storer.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Future Section Meetings

Cleveland

Inspection Trip to Avon Power Plant of the Cleveland Electric Illuminating Company. Joint meeting with Association of Iron and Steel Electrical Engineers. November 18.

The Transmission of Pictures over Telephone Lines, by R. D. Parker, American Tel. & Tel. Co. December 16.

Columbus

Standards, by C. E. Skinner, Westinghouse Electric & Mfg. Co. December 3.

Pittsfield

Mr. C. C. Chesney, National President, A. I. E. E., will give an account of his trip to the Pacific Coast. November 2.

Modern Reproduction of Sound, by L. T. Robinson, General Electric Co. November 16.

Why Intelligent People Do not Vote, by W. J. Millard, Field Secretary of the National Municipal League. December 16.

St. Louis

The Public Utility Engineer's Privileges and Responsibilities, by B. H. Peck, Illinois Power & Light Corp. November 17.

Radio-Photography, by Dr. E. F. W. Alexanderson, General Electric Co. December 15.

Seattle

The Geology of the Puget Sound Region, by Dean Henry Landes, University of Washington. November 17.

Diablo Development of the Skagit River Project, by J. D. Ross, Supt. of the Lt. and Pr. Dept., City of Seattle. December 15.

New York Section Meeting

The first meeting of the New York Section of the Institute for the year 1926-27 was held on Friday evening, October 8, 1926, at the Engineering Societies Building, New York. Before an audience of over 700 Dr. Irving Langmuir of the Research Laboratory, General Electric Company, delivered an exceedingly interesting talk on "The Flames of Atomic Hydrogen."

Dr. Langmuir's work, originating some fifteen years ago in a theoretical investigation of the heat loss of tungsten filaments of incandescent lamps in a hydrogen atmosphere, has now been applied in a different field—the development of a new method of welding. In brief, a stream of hydrogen is passed between two electrodes, the heat of the arc breaking up the hydrogen molecules into atoms. These combine again a short distance in front of the arc with the liberation of an enormous amount of heat. Much higher temperatures are obtained than with usual welding methods, and welding can be accomplished without oxidation and without fluxes. The speaker illustrated his talk with a very interesting collection of slides and a motion picture of the actual application of atomic hydrogen in welding. The

great interest manifested in the meeting was evidenced by the fact that when Chairman E. B. Meyer opened the meeting to questions and discussion, the questions occupied a period of over one hour.

2,000,000-Volt, High-Tension, Laboratory at Stanford University

The highest voltage yet obtained by man was demonstrated in the new laboratory of Stanford University, California, on Friday, September 17, before an assemblage of eminent men of science including Cummings C. Chesney, president of the Institue educators, and the press, a ribbon of living flame, more than 20 ft. long, leaped between two points high into the air above six giant transformers, marking the highest voltage yet attained at commercial frequency.—2,100,000 volts.

With this new equipment experiments will be carried on under the direction of Professor Harris J. Ryan, of the electrical engineering department of the University and past president of the A. I. E. E., who with his assistants, will endeavor to determine the necessary facts for engineers toward design of equipment to handle the high voltages which will be needed in the near future when electrical power in the far west (utilizing 60 per cent of the whole nation's water power) will have to be carried over long distances from its sources in the waters of the mountains to cities and valleys hundreds of miles away. The laboratory will also be used by scientists and engineers of the electrical industry, with whom Professor Ryan has cooperated for a number of years in working out practical problems.

The laboratory has been erected by Stanford University and the nation with the aid of a number of the large electrical concerns of the Pacific Coast, as a monument in recognition of Professor Ryan's contributions to electrical science and industry and to insure his continuing his research work which has outgrown the capacity of the high-voltage laboratory building erected by the University in 1913.

The new laboratory is an immense structure, the main building being 173 ft. long, 60 ft. wide, and 65 ft. high, with an interior height of 50 ft. in the clear to the roof trusses, with no supporting columns.

When expedient the building can be made light-proof, not a ray penetrating to its vast interior. For other uses, practically one whole side can be rolled away, utilizing three doors that are the largest every constructed, each 47 ft. high and 40 ft. wide. A single man can move them easily, opening a space 120 ft. long.

The studies and tests which Professor Ryan and his assistants will carry on in the new laboratory are vitally essential to the growth and continued development of the Far West.

Chas. M. Schwab, President Elect of the American Society of Mechanical Engineers

The American Society of Mechanical Engineers announces Charles M. Schwab as its president elect of the Society for the coming year. Mr. Schwab is already well known to the 18,000 members of this national engineering organization, having been elected an Honorary Member in 1918 in recognition of his great part in the upbuilding of the steel industry and his ability as an industrialist, a financier and an organizer of men.

Mr. Schwab will formally assume his new office as A. S. M. E. President at the Annual Meeting of the Society in New York early in December, at which time he will succeed William L. Abbott of Chicago.

Use of Safety Codes

A series of statements have been issued recently by the Bureau of Labor Statistics in the Department of Labor giving a record of industrial accidents and accident prevention. They also summarize in outline form, the use of national safety codes by the various States. Although numerous codes have been issued in various publications, it was shown that they have not been widely adopted. From several States, however, reports were received indicating that similar codes were being enforced or that the standardized codes were being studied from the standpoint of enacting suitable legislation.

The Bureau's statement gives complete references to the safety codes as approved by the American Engineering Standards Committee and the results of a questionnaire which was sent to all States.

University of Pennsylvania Placement Bureau

Following action by its Board of Directors and with the appointment of Professor Clarence Edward Clewell as its first director, the University of Pennsylvania has established a Placement Service, according to announcement made by Doctor Josiah H. Penniman, President and Provost.

The creation of this service marks the first important step taken by the trustees toward fulfillment of the plans for graduate educational service designed to supply cultural and technical information to the University's graduates and to render them such further service as may be possible. It is the expressed opinion of Doctor Penniman that the bureau will be able to perform an important economic service to alumni, the industries, and, incidentally, the various communities throughout the country.

Tests of Welded Rail Joints

The American Electric Railway Association and the American Bureau of Welding (The Bureau is the welding research department of the American Welding Society and the Division of Engineering, National Research Council), united in an authoritative investigation of various types of welded rail joints in commercial use, through a representative Committee which was organized late in 1921. This Committee now has a membership of about sixty individuals including Way Engineers of several of the larger street railway companies, representatives of manufacturers of welded joints and welding equipment, welding experts, scientists and testing experts.

Dr. G. K. Burgess head of the Division of Metallurgy, Bureau of Standards at the time this investigation was organized and now Director of the Bureau of Standards, was elected Chairman. Mr. E. M. T. Ryder, Way Engineer of the Third Avenue Railway System was selected Vice-Chairman and Mr. W. Spraragen, 29 W. 39th St., New York City, Secretary of the Division of Engineering and the American Bureau of Welding, was appointed Executive Secretary. Inasmuch as it was impossible to have this large committee meet more than once or twice a year, the administration of the affairs of the committee were left in the hands of a small representative Executive Committee.

Three progress reports have been made, Report No. 2 containing 72 pages and Report No. 3, 136 pages of proved data.

The committee is now studying and testing the effect of varying the form and dimensions of the side bars and of variations in the method of welding. This work will result, it is believed, in a material increase in the life of the joints under service conditions.

ENGINEERING FOUNDATION

DETROIT HONORS ENGINEERING FOUNDATION

For the purpose of promoting the cause of Engineering Foundation and its service as a joint engineering research organization, the Associated Technical Societies of Detroit gave a dinner at Hotel Statler, in that city, on October 4, with Mr. Ambrose

Swasey, Founder of Engineering Foundation, as guest of honor. Captain Harrington Place, Chairman of the Associated Technical Societies, presided. Mr. Rose, Technical Adviser to Mayor John W. Smith of Detroit, spoke on behalf of the Mayor, who was unable to be present and Vice-Chairman, Elmer A. Sperry, of Engineering Foundation, widely known as an inventor and, for his work on gyroscopic compasses and stabilizers for ships and aircraft, medallist of the John Fritz Award for 1927, was the principal speaker. He told of the history and general benefits of applied science research and described some notable research achievements. Alfred D. Flinn, Director of the Foundation, told of its purposes and policies, also describing a number of projects which the Foundation was aiding and the work which it had accomplished in the years gone by. Mr Swasey closed the speaking of the evening with an expression of appreciation for the value of the service being done by science and engineering for the benefit of mankind, and a plea for the spiritual values of life along with the material advancement.

A New Offer Announced for Muscle Shoals

A group of New York engineers and financiers are prepared to make a new offer for Muscle Shoals, involving stock from $20,000,000 to $80,000,000 depending upon whether or not the third dam is constructed. The plan for development and the offer will be presented to Congress when it convenes in December. The proposal, which will come from the Farmers Federated Fertilizer Company, is understood to involve a 50 year lease of the property with guarantee for using the power generated in making nitrate for fertilizer.

AMERICAN ENGINEERING COUNCIL

ADMINISTRATIVE BOARD MEETS AT CORNELL

Upon invitation from President Dexter S. Kimball, the Administrative Board of American Engineering Council has decided to hold its next meeting at Cornell University, Ithaca, N. Y., November 11 and 12. The regular meeting of the Executive Committee will precede the meeting of the Board.

The program of work for this meeting has not been completed, but will be issued about the middle of October.

PROPOSAL FOR NEW PATENT OFFICE BUILDING

It now seems certain that the Department of Commerce will get a new building. It is the wish of Secretary Hoover that all offices of this department shall be located in the same building and although the Public Buildings Commission and the National Commission of Fine Arts are still giving consideration to the nature of the proposed new building and its location, it is understood that it will probably be located on Pennsylvania Avenue at 14th Street.

American Engineering Council, the National Association of Manufacturers, and the American Patent Attorneys Association are using their influence for a new Patent Office Building out of the $50,000,000 appropriation now available for the District of Columbia, and to have it either in or near the new Commerce Department Building.

Those interested in the Patent Office can help in this effort by writing to the Buildings Commission or the National Commission of Fine Arts, both of which are located in the District of Columbia, urging that the Patent Office be put in a new building in or near the proposed new Department of Commerce Building. Meetings will be held early in November in an effort to reach final decision on this question so that early action is required.

Work in the improvement of Patent Office equipment has been started with the installation of four miles of steel shelves for the filing of copies of patents. This is the beginning of the replacement of approximately 20 miles of wooden shelves on which copies have formerly been filed.

PARTICIPATION IN STREET AND HIGHWAY SAFETY CONFERENCE

Committees of the National Conference on Street and Highway Safety, of which the Council is a member, met with Secretary Hoover on October 15th for the purpose of reviewing their work to date.

It now appears that American Engineering Council will be supplied with finances for extending the work of the Street and Highway Traffic Facilities Committee so that a complete survey may be made to develop the best form of lighting system, traffic control, and other engineering phases of the problem. The Committee on Elimination and Protection of Grade Crossings reported that a large number of crossings had been eliminated at great expense.

Mr. Hoover emphasized to the conference the importance of this work and urged that all branches of it be pushed forward to the fullest extent. He pointed out that while some excellent results had been obtained there were still many places in which there was no apparent improvement.

Those attending the Conference as representatives of American Engineering Council were: Dean A. N. Johnson, W. B. Powell, H. E. Riggs, and L. W. Wallace.

History of Engineering

The Engineering Societies library is the most complete library on engineering subjects in the world. Among other features it has an interesting collection of books on the history of engineering which it is anxious to better, for it finds considerable demand for such books and few subjects are more alluring to the technical man. The library has, however, but a small fund with which to purchase books, and this fund must necessarily be used in the purchase of such new books appear as from time to time on engineering subjects. Quite a number of engineers have inteiested themselves during the course of their professional career in collecting books upon the history of engineering. These books are usually of little interest to the family of the engineer and although they may have cost the owner a relatively large sum of money, they can seldom be disposed of with much advantage to the estate. This condition has suggested to the Library Board a possible method of building up the historical side of engineering within the library. It is requested that those engineers who have collections of books on the history of engineering or related subjects communicate with Mr. Sydney N. Ball, Chairman of the Library Board, or Dr. Harrison W. Craver, Director, Engineering Societies Library, and indicate their willingness to bequeath to the library their books upon the history of any branch of engineering. The library proposes to keep a card catalogue of such bequests. If the owners of books on the history of engineering feel disposed to cooperate with the Library Board in this way the library's historical collection can be strengthened gradually but greatly.

PERSONAL MENTION

Leonard S. Horner has been appointed president of the Niles-Bement-Pond Company, having resigned the vice-presidency of the Acme Wire Company of New Haven to accept this new position, with headquarters in New York.

Thomas J. Maitland has resigned his position as instructor in Electrical Engineering at the University of New Hampshire and has accepted a position with the Long Lines Dept. of the American Telegraph and Telephone Company, New York City.

Irving W. Phillips, formerly with Perry & Whipple, Providence, R. I., has formed new connections with Gray's Electrical Engineering and Construction Company,—also of that city—engaged in the construction of power and light installations and specializing in power plant and large industrial work.

JAMES E. THOMPSON, until recently in the office of the Metropolitan Division Traffic Superintendent, New York, is now on leave of absence and is acting as Instructor in Mathematics at Pratt Institute. Mr. Thompson is pursuing his graduate studies in Physics and Electricity at Columbia College as well.

ELMER L. GOLDSMITH, who, for some time has been associated with Lockwood & Lockwood, Patent and Trade-Mark Attorneys, Indianapolis, Ind., has just been elected a member of the firm, with the Company name of Lockwood, Lockwood, Goldsmith & Galt.

NOEL F. HARRISON, formerly of Winnipeg, Canada, has opened an office of his own in Bri Cualann, County Wicklow, Ireland, where he will carry on general engineering practise in design, supervision, investigation and reports. Mr. Harrison was for some years assistant to the late R. J. Parke, consulting engineer of Toronto, prior to going to Western Canada where he served with the Canadian Northern Railway Company, the Manitoba Power Commission and the Manitoba Power Company.

DR. HERBERT GROVE DORSEY, research engineer in the Submarine Signal Corp., Boston, Mass., has been appointed Senior Electrical Engineer in the U. S. Coast and Geodetic Survey. In the Hydrographic and Topographic Division of the Coastal Survey, he will continue his research work in acoustic methods of depth measurement and radio acoustic methods of position finding, to facilitate and lend accuracy to the making of charts. This work was begun on the *S. S. Lydonia* at Wilmington, N. C.,—later transferred to the Pacific Coast.

GUSTAV F. WITTIG, formerly Assistant Professor of Electrical Engineering at Yale, has resigned that position to become Statistical Editor of the *Electrical World*, New York, N. Y. For the past two years he has been a regular contributor to the Digest of Electrical Literature of the "World." Before going to Yale he had been head of the Department of Physics and Electrical Engineering at the University of Alabama for eight years, having joined the faculty shortly after the organization of the College of Engineering to include the newer engineering departments. He also taught for a time at the University of Maine. Mr. Wittig is a graduate of Rutgers and also holds the degree of E. E. from Columbia. He joined the Institute in 1905.

"Behind the Pyramids"

The National Carbon Company, Inc., Cleveland, Ohio, has prepared a moving picture entitled "Behind the Pyramids" which shows in a very interesting manner the manufacture, application, operation and care of carbon brushes and other carbon products used in the electrical industry. This picture will be shown before technical society meetings, operating department groups, engineering college classes, etc. There are three reels, requiring approximately forty-five minutes for showing. Arrangements for this filmmay be made with the Carbon Sales Division, National Carbon Company, Inc., at Cleveland, Ohio.

Obituary

George Schley Davis, president of the Wireless Specialty Apparatus Company, Boston, Mass., and Associate of the Institute since 1913, died suddenly at Brookline, Mass., October 10, 1926. Mr. Davis was born at North Platte, Nebraska, October 1, 1884. At the completion of his high school education, he undertook his technical education through the United States Naval Training Schools and home study courses. He had seven years in the Navy School and as chief electrician in charge of the wireless telegraph station, Navy Yard, Brooklyn, N. Y. For three and a half years he was with the United Fruit Company as chief operator and assistant superintendent; then superintendent, and at the time of his death he was one of its vice-presidents. He was a director of the Radio Corporation of America and a Fellow of the Institute of Radio Engineers, having been closely identified with the development of radio engineering for many years. He was an intimate friend of Marconi, Edison, General Harbord as well as of other notable scientists and his loss will be felt keenly in this field of service to mankind.

Adolphe Alfred Dion, one of the most prominent electrical engineers of Canada, and a Fellow of the Institute, died October 8, 1926, in the Water Street General Hospital, Ottawa, Canada, following a critical operation. Born and educated in the city of Quebec, Mr. Dion's activity in the electrical field included telegraphy, railway operations and electric light and power work. When he removed to Ottowa, he entered the employ of the Old Dominion Telegraph Company. After occupying various positions there, he was given charge of the electrical work of the Intercolonial Railway, running from Montreal to Halifax: in fact for 35 years he has been identified with electrical enterprises in Ottowa, in addition to engaging in his own consulting work.

In spite of his many activities and responsibilities in public utilities, Mr. Dion found time to participate in association work, and was for four terms president of the Canadian Electrical Association, first in 1900 and 1901 and again in 1912 and 1913. He joined the Institute in 1890 and was transferred to the grade of Fellow in July 1913. He was also a member of the British Institution of Electrical Engineers and of the Canadian Society of Civil Engineers. At the time of his death, he was general manager of the Ottowa Electric Company, the Ottowa Light, Heat and Power Company and the Ottowa Gas Company.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street, New York.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—M. C. Benedict, 940 Ash St., Johnstown, Pa.
2.—R. L. Bertolacci, 2937 So. Normandie Ave., Los Angeles, Calif.
3.—Eric G. Blomquist, 1954 Winona St., Chicago, Ill.
4.—Lincoln Bouillon, 731 21st Avenue N, Seattle, Wash.
5.—William A. R. Brown, c/o Radio Corp. of Am., 33 W. 42nd St. New York.
6.—Andres R. Conde, 505 So. 5th Ave., Maywood, Ill.
7.—John C. Donahue, 1601 No. 8th St., Tacoma, Wash.
8.—I. H. El-Kordi, Royal Consulate of Egypt, 103 Park Ave., New York, N. Y.
9.—John C. Fretz, N. Y. & Queens Elec. Lt. & Pr. Co. Bridge Plaza North, Long Island City, New York.
10.—Wm. F. Gilman, Belgrade Lakes, Me.
11.—Newman D. Gray, 41 Sanford Street, St. Augustine, Fla.
12.—Edward C. Hanson, Box 59, Pinelawn, New York.
13.—A. Hirth, 519 Lincoln Pl., Apt. 20; Brooklyn, N. Y.
14.—M. Kalapesi, Faculty of Tech. Union, Sackville St., Manchester, Eng.
15.—Eric Kjellgren, 145 13th Street, Milwaukee, Wis.
16.—Victor J. Kubanyi, 708 St. Nicholas Ave., New York, N. Y.
17.—Otto U. Lawrence, Avenue A., Bound Brook, New Jersey.
18.—Akos Ludasy, P. O. Box 1841, Chicago, Ill.
19.—L. Lustig, Krizik Elec. Mfg. Co., Karlin-Prague, Czechoslovakia.
20.—Ronald W. S. Marsano, 714 Curtis Avenue, Merchantville, New York.

21.—Eugene Messinger, Otis Elevator Co. Engg. Dept., 26th St. & 11th Ave., 4th Floor, New York, N. Y.
22.—Wilbur Miller, Y. M. C. A., Dallas, Texas.
23.—Stafford Montgomery, Riverside, Ill.
24. Jack Nile, 378 Boyden Avenue, Hilton, New Jersey.
25.—Edward W. Parry, 23 Passaic Avenue, Passaic, New Jersey.
26.—G. K. Pierce, 2619 So. 59th Court, Cicero, Ill.
27.—Irving T. Roberts, 2355 Prairie Avenue, Evanston, Ill.
28.—Orville B. Weeks, 305 Martense St., Brooklyn, New York.
29.—E. J. Schouw, 775 27th St., Milwaukee, Wis.
30.—Wm. E. Seaman, 1253 Leland Avenue, New York, N. Y.
31.—N. V. Stonestreet, Central Y. M. C. A., Baltimore, Md.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (SEPTEMBER 1-30, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AIRCRAFT YEAR BOOK, 1926.

N. Y., Aeronautical Chamber of Commerce of America, 1926. 331 pp., illus., diagrs., 9 x 6 in., cloth. $5.25.

The 1926 Yearbook presents the customary review of the developments of the year in commercial aviation in America and abroad. It gives a concise account of the principal events in this country—commercial, governmental and technical. Chapters are devoted to special uses of aircraft in agriculture, exploration, etc. Legislative needs are discussed. A chronology and revision of the year are given as well as a summary of technical development. Appendixes contain data on commercial and technical associations, government services and appropriations., etc.

AMERICAN MACHINISTS' HANDBOOK.

By Fred H. Colvin and Frank A. Stanley. Fourth edition. N. Y., McGraw-Hill Book Co., 1926. 972 pp., illus., tables, 7 x 4 in., fabrikoid. $4.00.

The new edition of this popular handbook is but little larger than its predecessor, which it closely resembles in appearance. The authors state, however, that it has been thoroughly revised and that much of the earlier material has been replaced by new standards and shop practices, so that the book is again representative of the best current practise.

DIELEKTRISCHES MATERIAL.

By A. Bültemann. Berlin, Julius Springer, 1926. 160 pp., diagrs., 10 x 7 in., paper. 10, 50 r. m.

The manufacture of insulating materials is constantly being undertaken, says Dr. Bültemann, by persons who are insufficiently conversant with the existing information on these important substances. As a result there are placed on the market all kinds of insulating materials, many of which are practically worthless and lead at times to heavy losses.

To disseminate correct information on the subject is the purpose of the present book. It sets forth, in easily understood fashion, the properties of all classes of dielectrics—gases, liquids, plastics and solids. The chemical and physical properties of each are explained and the effect of these on their dielectric properties is discussed. The methods of manufacture are set forth concisely. Methods of testing are given, with German and foreign standard specifications. The book affords a useful concise survey of the subject, with special emphasis on manufacture.

ELEKTROCHEMIE . . . v. 3; ENERGIE.

By Heinrich Danneel. Ber. & Lpz., Walter de Gruyter & Co., 1926. 149 pp., 6 x 4 in., cloth. 1, 50 r. m.

The third volume of Dr. Danneel's treatise on electrochemistry is devoted to the question of energy. In it he discusses the theoretical thermodynamical principles, the total energy, energy and equilibrium, electrode potentials, galvanic cells and the use of E. M. F. measurements in chemistry.

EMPLOYEE REPRESENTATION.

By Ernest Richmond Burton. Balt., Williams & Wilkins, 1926. (Human Relations series). 283 pp., tables, 8 x 6 in., cloth. $3.00.

The author presents a careful investigation of employee representation which has occupied his time during the past seven years. His purpose has been to ascertain the history of the movement, the reasons that have prompted employers to adopt the plan, the extent to which it has achieved the objects sought, and the difficulties that have beset the movement. The book also endeavors to define the place and function of employee representation in the policy of personnel relations and to indicate the desirable direction of its development.

ENGLISH APPLIED IN TECHNICAL WRITING.

By Clyde W. Park. N. Y., F. S. Crofts & Co., 1926. 313 pp., 8 x 6 in., cloth. $2.25.

This book, by the Professor of English in the College of Engineering and Commerce, University of Cincinnati, is intended for use as a textbook in technical schools. The aim of the author is to assist the student to acquire a clear personal style and the ability to express his ideas correctly in practical writing. Throughout the book, instruction in English is linked with the written work done by the students in their technical courses. The book is not only a good text but will also be useful as a reference book for counsel.

ENLARGED HEAT DROP TABLES: H. P. GAUGE PRESSURES, L. P. ABSOLUTE PRESSURES.

By Herbert Moss, from the formulae and enlarged steam tables of H. L. Callendar. Lond., Edward Arnold & Co., 1925. 88 pp., 9 x 6 in., cloth. $3.75. (Gift of Longmans, Green & Co., N. Y.)

In 1917 Mr. Moss published a set of tables, based on Professor Callendar's formulas and tables, showing the adiabatic heat drop of steam with initial pressures up to 400 lbs. per sq. in. and vacua from 27.0 to 29. 1 in. The present book supplements the original set. It gives new tables of the adiabatic heat drop of 1 lb. of steam, in British thermal units, for initially dry saturated or supersaturated steam of pressures from 400 to 2000 lbs. per sq. in. gauge and vacua from 27.0 to 29.5 in. of mercury. It also extends the original tables to vacua from 29.2 to 29.5 inches.

Enlarged Mollier or H-Φ Diagram For Saturated and Superheated Steam.

Plotted by H. L. Callendar from his enlarged steam tables. Lond., Edward Arnold & Co., 1926. 30 x 40 in. paper. $1.35. (Gift of Longmans, Green & Co., N. Y.)

An excellent diagram, clearly printed on heavy paper and sufficiently large to be read easily.

General Chemistry.

By Hamilton P. Cady. 2nd edition. N. Y., McGraw-Hill Book Co., 1926. (International chemical series). 540 pp., illus., 8 x 6 in., cloth. $3.25.

A textbook intended to meet the usual requirements of a general college course in chemistry. It is based on the author's "Inorganic Chemistry," being to some extent an abridgment and simplification of that work. The new edition has been carefully revised and considerable new matter has been added.

Introduction to the Theory of Infinite Series.

By T. J. I'a. Bromwich. 2nd ed., revised. Lond. & N. Y., Macmillan Co., 1926. 535 pp., 9 x 6 in., cloth. $10.50.

Beginners with an adequate knowledge of the differential and integral calculus will find this book a very satisfactory introduction to the study of infinite series. The author includes much material that is not easily accessible elsewhere to English readers and has also provided a great number of examples.

The new edition consists largely of a reproduction of the first edition, with additional theorems and examples.

Mechanics for Engineering Students.

By G. W. Bird. N. Y. & Lond., Isaac Pitman & Sons, 1926. (Technical School Series). 142 pp., diagrs., 9 x 6 in., cloth. $1.50.

A concise textbook covering the subjects required as preparation for the British National Certificate examination. The course is designed for one year and is marked by the large number of worked examples.

Petroleum Register.

1926. N. Y., Holland S. Reavis, 1926. 587 pp., 12 x 9 in., cloth. $10.00.

A reference book for those in the oil industry. Contains a buyers' guide to manufacturers and dealers in all kinds of equipment, and directories of refiners, marketers, jobbers, producers, pipe lines and producers of natural gasoline. Other features are an index of trade names, a traffic guide to refineries and a directory of drilling contractors, a list of oil associations and an alphabetical list of the chief executives of the companies in the oil business. Various tables of statistics are given and there are outline maps of the oil-producing countries, showing the location of the oil fields.

Photographic Photometry.

By G. M. B. Dobson, I. O. Griffith and D. N. Harrison. Oxford, Clarendon Press, 1926. 121 pp., plates, diagrs., tables, 8 x 5 in., cloth. 7s 6d. (Gift of Oxford Univ. Press, Amer. Branch, N. Y.)

In view of the increasing applications of photographic methods for measuring the intensity of light, this book by authors who have spent much time and research during recent years on the best technique for photographic photometry, will be welcome. In it is reviewed the whole subject, theory and practise. The principal methods employed, the sources of errors, how these errors can be minimized, and generally how to find the best method of working, are the topics here discussed. The book should prove most usful to any one starting work in this subject.

Principles Underlying the Design of Electrical Machinery.

By W. I. Slichter. N. Y., John Wiley & Sons, 1926. 312 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.75.

Contents: General principles and fundamental relations.—Gontinuous-current generator.—Salient-pole alternating-current generator.—Turbine-driven alternating-current generator.—Transformer.—Induction motor.—Index.

Dr. Slichter's book is developed from a course of lectures given at Columbia University and from his experience as a designing engineer. It is to some extent an amplification of his articles on the subject written for Pender's "Handbook of Electrical Engineering."

The purpose throughout is to give a practical method of design, with explanations of the physical meaning of the arbitrary constants used by the professional designer. To assist in this, the author derives the formulas from fundamental principles, explains each of them and gives the reasons for the various standards of practise. He gives a systematic method of procedure for the design of each type of machine treated, with a complete sample calculation in each case.

The book is intended as a text for a course on design. It will also be an aid to young engineers through its explanation of the reasons for certain conventional practises.

Railroad Freight Service.

By Grover G. Huebner and Emory R. Johnson. N. Y., D. Appleton & Co., 1926. 589 pp., diagrs., forms, maps, 9 x 6 in., cloth. $5.00.

Written to assist railroad officials and those in charge of the traffic and transportation activities of industries. The book describes in detail the railroad freight services, freight traffic rules and practises, and the organization of the departments that perform the services. The authors have succeeded in compressing a comprehensive acccount of the railroad freight service, in all its phases, into a single volume.

Der Ruhrverband.

By Karl Imhoff. Berlin-Dahlem, Verlag Wasser, Druck von C. W. Haarfeld in Essen, 1926. 29 pp., map, 12 x 8 in., paper. 3,-r. m.

The Ruhr industrial region has a population of 1,266,000 wholly dependent for its water supply on the Ruhr river. The problem of keeping the river water sufficiently pure, a difficult one in so thickly populated a district, has been met by the erection of large purifying works. These works are administered by the Ruhrverband, at the expense of the waterworks that serve the district.

This pamphlet briefly sets forth the history and administration of the Ruhrverband and describes briefly the plants that have been erected.

Story of Steel.

By J. Bernard Walker. N. Y., Harper & Bros., 1926. 208 pp., illus., 8 x 6 in., cloth. $4.00.

A non-technical description of the manufacture of steel as carried on in this country, based on an extended inspection of the properties and methods of the United States Steel Corporation. Starting at the Minnesota mines, the author traces the processes through the blast-furnace and the steel furnace to the finished sheet, pipe and section. Chapters are also devoted to the social and economic policies of the Corporation.

Theorie der Brennkraftmaschinen und Deren Brennstoffe vom Standpunkte der Chemischen Gleichgewichtslehre.

By Markus Brutzkus. Halle (Saale), Wilhelm Knapp, 1926. 62 pp., diagrs., tables, 10 x 7 in., paper. 3, 80 r. m.

While most branches of modern engineering owe their origin and development principally to theoretical knowledge, according to this author, the industrial development of the internal combustion engine is, even today, more advanced than its theory. Only once, in the case of Diesel, has theoretical contemplation led to any important improvement.

This condition arises, he thinks, because students of the theory and designers have turned their attention principally to pure thermodynamics, and left out of consideration theoretical chemistry, in which field lie the most important problems of the theory of these motors. The problem of best converting a given quantity of heat into mechanical energy has been constantly studied, but the equally important problem of achieving the combustion in a time not greater than four one-hundredths of a second has scarcely been considered. To answer the latter question, from the point of view of chemical theory, is the task undertaken in this book.

Der Zugversuch.

By G. Sachs and G. Fick. Lpz., Akademische verlagsgesellschaft. 1926. 252 pp., illus., diagrs., 9 x 6 in., paper. 12-mk.

A discussion of tensile strength tests by two experienced German engineers, addressed to those who have the task of drawing useful conclusions from tests of materials, especially makers and users of structural materials, and engineers of tests. It contains, in addition to directions for the practical conduct of our most important test of materials, a thorough discussion of all the points of view which are of importance for the process of testing, on the one hand, and for the interpretation of the results on the other.

In the first part of the book the authors discuss thoroughly the signification of strength, ductility and other characteristics, the influence of nicks and other flaws, and the relation of tensile tests to other tests. A section is devoted to the influence of combined requirements.

The second part briefly reviews the structure of materials and also those influences on tensile tests, such as temperature, speed and cold working, which presuppose a knowledge of structure. The third section discusses the choice of equipment for testing for any given purpose.

An appendix, describing the shapes of test pieces used in different countries, and a bibliography are given.

DOMESTIC ENGINEERING CATALOG DIRECTORY.

1926. Chic., Domestic Engineering Co., 1926. 1972 pp., illus., 11 x 8 in., bound. $5.00.

A convenient collection of condensed catalogs representing several hundred manufacturers of plumbing and heating supplies, classified by products for the convenience of buyers. The book also contains a directory of manufacturers with addresses; a list of all materials used by the plumbing and heating industry, with the names of manufacturers and an exhaustive index; and a collection of useful standard tables and rules.

METHODS OF TEACHING INDUSTRIAL SUBJECTS.

By Arthur F. Payne. N. Y., McGraw-Hill Book Co., 1926. 293 pp., 9 x 6 in., cloth. $3.00.

The teacher of industrial subjects, selected because of his mastership of some trade, usually finds himself to be a novice in the profession of teaching and handicapped by his ignorance of the philosophy, principles and technique of teaching.

To remedy this situation, he must master the techniques of his new profession, and the present book is a contribution toward that end. It brings together the fundamentals of the techniques of teaching, presents them as simply as possible and indicates their use in the teaching of industrial subjects. Good bibliographies are given.

Past Section and Branch Meetings

SECTION MEETINGS

Chicago

Flames of Atomic Hydrogen, by Dr. Irving Langmuir. September 27. Attendance 400.

Detroit-Ann Arbor

Social Meeting. A talk was given by Therman Miller. September 29. Attendance 109.

Fort Wayne

Social Meeting. September 30. Attendance 50.

Los Angeles

Standardization in the Development of A-C. Systems, by C. C. Chesney, National President, A. I. E. E.;

Lightning, by F. W. Peek, Jr., General Electric Co. Illustrated; and

Lightning Protection, by K. B. McEachron, General Electric Co. The meeting was preceded by a dinner. September 14. Attendance 244.

Mexico

Business Meeting. The following officers were elected: Chairman, Carlos Macias; Secretary-Treasurer, G. Solis Payan. September 2. Attendance 37.

Pittsburgh

New Landmarks in Electrical Communication, by P. B. Findley, Bell Telephone Laboratories. Illustrated. September 14. Attendance 220.

Automatic Train Control, by L. F. Howard, Union Switch and Signal Company. October 12. Attendance 425.

Portland

Growth and Standardization, by C. C. Chesney, National President, A. I. E. E.;

Lightning Protection for Oil Tanks, by F. W. Peek, Jr.; General Electric Co. Illustrated; and

The Cathode-Ray Oscillograph, by K. B. McEachron, General Electric Co. September 20. Attendance 80.

St. Louis

Dinner Meeting. Joint with Engineers' Club of St. Louis. A talk was given by Lawrence McDaniel. September 15. Attendance 124.

Seattle

Research, by C. C. Chesney, National President, A. I. E. E.; and

Lightning Protection, by K. B. McEachron, General Electric Co. Illustrated. A motion picture showing the manufacture of transformers was also shown. A dinner preceded the meeting. September 22. Attendance 115.

Southern Virginia

Interconnection of Transmission Lines in Virginia and North Carolina, by W. C. Bell, Virginia Electric & Power Co.;

The Design of a High-Pressure Industrial Power Plant, by R. S. Boynton; and

The Opportunity of the Engineer in Industry, by Arthur Scrivenor. September 29. Attendance 45.

Spokane

The Development and Manufacture of Transformers, by C. C. Chesney, National President, A. I. E. E.; and

Lightning Protection, by K. B. McEachron, General Electric Co. Illustrated. A dinner preceded the meeting. September 24. Attendance 65.

Springfield

Some Recent Developments in Radio-Frequency Amplification, by W. F. Cotter and B. V. K. French, American Bosch Magneto Co. September 27. Attendance 51.

Toronto

A-C. and D-C. Current Rectification for Radio Uses, by Professors H. W. Price and T. R. Rosebrugh, Toronto University. September 24. Attendance 175.

Vancouver

Luncheon, Inspection Trip in Vancouver Harbor, and Dinner. Members of A. I. E. E., Engineering Institute of Canada and others. August 28. Attendance 64.

Inspection trip to Britannia Mining and Smelting Co. September 11. Attendance 93.

Standardization and Research, by C. C. Chesney, National President, A. I. E. E. A film, entitled "Development and Manufacture of Large Transformers," was shown.

Lightning Protection, by K. B. McEachron, General Electric Co. September 27. Attendance 90.

Washington

A short talk was given by Hon. Proctor L. Dougherty, District Commissioner. September 16. Attendance 52.

The Electrical Work of the Bureau of Standards, by E. C. Crittenden, Bureau of Standards. Motion pictures entitled "The World of Paper" and "The Magic of Communication" were shown. October 12. Attendance 244.

BRANCH MEETINGS

Alabama Polytechnic Institute

R. C. Crawford, student, gave a review of the paper by H. H. Henline, entitled *Engineering Education—Its History and Prospects*. September 22. Attendance 40.

The Development and Uses of Bakelite, by Professor C. R. Hixon. September 29. Attendance 70.

Talks on their experiences during the summer were given by J. L. Jones and J. B. Walters. October 6. Attendance 29.

University of Arkansas

A short talk was given by Professor W. B. Stelzner. September 28. Attendance 15.

University of California

The Use of the Trielectrode Vacuum Tube in Telephone Circuits, by H. G. Tasker, Pacific Telephone and Telegraph Co. A motion picture entitled "The Transmission of Voice by Electricity" was also shown. September 8. Attendance 50.

Banquet. September 14. Attendance 89.

Business Meeting. September 29. Attendance 23.

University of Colorado

Student Membership in the A. I. E. E., by Dean H. S. Evans. September 29. Attendance 85.

University of Denver

Business Meeting. October 1. Attendance 15.

Drexel Institute

The Greater View of the Engineering Profession, by Professor Disque. October 8. Attendance 33.

University of Florida

Business Meeting. The following officers were elected: Chairman, W. Stanwix-Hay; Vice-Chairman, R. T. Lundy; Secretary, R. D. Ross. September 27. Attendance 10.

University of Idaho

The Salt Lake City Convention of the A. I. E. E., by Professor J. H. Johnson. October 5. Attendance 18.

Kansas State College

My Summer Employment, by R. H. Mears, H. V. Rathbun and L. E. Woodman. October 4. Attendance 76.

University of Kansas

Social Meeting. October 7. Attendance 115.

Marquette University

Smoker. September 23. Attendance 55.

University of New Hampshire

Business Meeting. The following officers were elected: Chairman, T. C. Tappan; Secretary, F. W. Hussey. September 27. Attendance 38.

A motion picture entitled "White Coal" was shown. October 4. Attendance 40.

A motion picture entitled "The Single Ridge Method" was shown. October 11. Attendance 42.

College of the City of New York

Inspection Trip to the Schenectady Plant of the General Electric Co. September 20 and 21. Attendance 8.

Business Meeting. October 7. Attendance 20.

North Carolina State College

Business Meeting. October 5. Attendance 17.

Ohio Northern University

Smoker. September 23. Attendance 44.

Radio, by Messrs. Wadsworth and Neff. October 7. Attendance 34.

Pennsylvania State College

Business Meeting. September 29. Attendance 39.

A talk was given by Dr. E. C. Woodruff on his trip to Europe last summer. October 6. Attendance 200.

Purdue University

Central American Experiences, by Dr. Bray, and

A. I. E. E. and the Purdue Branch, by Professors C. F. Harding and A. N. Topping. October 5. Attendance 250.

Rensselaer Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, F. M. Sebast; Secretary-Treasurer, W. C. Michels. October 6. Attendance 25.

South Dakota State School of Mines

The Training of Young Men by the General Electric Company, by Professor J. O. Kammerman. September 29. Attendance 15.

University of South Dakota

Kinetic Theory of Gases, by Maurice Nelles. The following officers were elected: Chairman, Maurice Nelles; Secretary, Stanley Boegler. September 29. Attendance 12.

Stevens Institute of Technology

Independence in Engineering, by L. A. Hazeltine, Research Engineer. September 29. Attendance 66.

Texas Agricultural and Mechanical College

Business Meeting. The following officers were elected: Chairman, C. A. Altenbern; Vice-Chairman, G. D. Heye; Secretary, J. L. Pratt. October 1. Attendance 160.

West Virginia University

Business Meeting. The following officers were elected: Chairman, I. L. Smith; Vice-Chairman, H. S. Muller; Secretary, P. E. Davis. September 27. Attendance 37.

The Current-Carrying Capacity of Busses, by G. H. Cornell; *The Dipping and Baking of Armature Coils*, by W. W. Reed; *The Use of Electric Power in Steel Mills*, by A. L. P. Schmiechel; *Life of George Westinghouse*, by L. T. Kight; *Industry*, by G. E. Phillips; *Method of Testing Insulated Rotary Parts*, by H. S. Muller; *Porcelain Insulators*, by H. S. McGowan; *Cone Loud Speakers*, by H. H. Hunter, and *Routine Test of Telephone Engineers*, by S. C. Hill. October 4. Attendance 37.

Safety and the Engineer, by W. F. Davis; *High-Power D-C. Line Tests*, by W. E. Vellines; *Florida East Coast Railway*, by D. Carle; *Re-Determination of the Velocity of Light*, by E. W. Conway; *New Ships for Old*, by P. E. Davis; *Using X-Ray to Solve Puzzles*, by E. R. Long; *Accelerometers*, by A. M. Kalo; *Testing Radio Sets*, by P. L. Johnston; and *How a Long-Distance Call is Made*, by J. P. Paine. October 11. Attendance 37.

Yale University

Social Meeting. September 14. Attendance 35.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
63 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York City, and should be received prior to the 15th of the month.

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL DESIGN ENGINEER, on large direct current machines having at least five years' design experience; experience in steel mill applications of direct current motors is desirable. Apply by letter giving full particulars concerning age, technical education, design experience, references, salary expected, and date when available. Apply by letter. Location, Pennsylvania. X-819-C.

SALES ENGINEER, must be thoroughly conversant with air compressors. Apply by letter. Salary $1000 a year, and commission. Location, East. X-955.

MEN AVAILABLE

COMMERCIAL ENGINEER, E. E. graduate, 26. Westinghouse graduate engineering course and test, application engineering experience, railway operating investigation. Desires position with public utility or holding and management company which will lead to administrative work. Can furnish good reference. Available on reasonable notice. B-9001.

TECHNICALLY TRAINED MAN, 36, married, thirteen years' experience in construction, operating and estimating, substation and power house work. Desires position with construction or holding company or contractor. New York City or vicinity preferred. Available on two weeks' notice. B-1011.

ELECTRICAL ENGINEER, 33, married, graduate B. S. in E. E., eight years' electrical engineering experience; one year steel mill engineering on electrical applications and equipment, three years telephone engineering and design of protective apparatus for telephone and telegraph equipment, over four years control engineering design and controlling equipment for industrial and special control applications. Executive accustomed to assuming responsibility. Good record and references. At present employed. Available month's notice. Location, East. C-1864.

JUNIOR ENGINEER, 1923 graduate electrical engineer, two years' experience as illuminating engineer, three years electrical testing and inspection, desires position in construction or power installation work. Would consider sales engineering position if located in East. B-8148.

A RECENT GRADUATE in science and electrical engineering seeks afternoon employment (part time 1 P. M. on) at either instructing in physics, mathematics or engineering, or in electrical engineering, radio engineering, or patent law. At present studying for a J. D. degree (in law) in the morning. Good draftsman. College experience with thermionic vacuum tubes. Location, New York City only. C-1969.

ELECTRICAL ENGINEER, college graduate '26, age 28, single, speaks Russian, English and French, desires to work in company that deals with foreign countries. Location, any place. Available at any time. C-1981.

EXECUTIVE with an E. E. degree, 36, married, desires an opportunity. Experienced in operation and distribution problems involving a large system using A. C. and D. C. Am particularly interested in relays and their application to protection problems and automatic control of operations. B-7701.

TECHNICAL GRADUATE, 28, single, with four years' experience with the Westinghouse E. & M. Co. Two years in testing department, and two years in their Electrical Service Engineering Dept. Desires position with industrial firm as Electrical Engineer or Chief Electrician. B-8985.

ELECTRICAL ENGINEER, age 34, technical graduate, will be available January 1st. Experience on factory test, service and construction, and general office engineering with large manufacturer. Now employed as field engineer on large hydro electric development. A total of thirteen years of broad experience. First class references. Location desired, East or Middlewest. B-9936-97.

EXECUTIVE, M. E., E. E. degrees, age 37, married: five years apprenticeship mechanical engineering; fifteen years' industrial engineering. Scientific management and business organization. Six years public utility, Chief Engineer in charge of design, construction, operation and maintenance of Power Plant, substations, transmission and distributing lines, desires position as General Superintendent, Manager, Chief Engineer, Mechanical Electrical Superintendent or Consultant. Available immediately. B-7944.

ELECTRICAL ENGINEER, University (Leeds, Eng.), 38, married, nine years operation and maintenance, two years Westinghouse Company, Ltd., on erection, service, drafting and design, seven months general electrical design for plant extension. Can organize and control men and plant. Desires executive position, anywhere in Canada, preferably east or B. C., as superintendent or assistant superintendent of plant, power supply or industrial, or as underwriter. Minimum salary $200.00 a month. Available after November 1st, 1926. C-1989.

TRANSMISSION LINE ENGINEER, university graduate, ten years' experience in design of transmission lines with special regard to mechanical features and safety. Experience includes formulation and application of safety codes, design of structures, standardization, sag and tension investigations, estimating, etc. At present assistant transmission line engineer in charge of design for a large public utility. Salary $4200 per annum. C-2014.

TECHNICAL GRADUATE in E. E., 32, married, able in assuming responsibility and handling of men with results. Three years mechanical installations and repairs, five and half years general electrical construction, installations, maintenance and tests power plant and substations, one year operating and plant problems, wishes position. Speaks French and some Spanish. Location, United States or abroad. Available at once, present station about completed. References present employer. C-2021.

SUPERINTENDENT OF POWER, electrical engineer with twelve years' experience steam power plants and electrical generating stations. Construction, operation, maintenance. Speaks Spanish. Location, preferably foreign. C-1372.

GENERAL SALES EXECUTIVE, 40, married, electrical and mechanical engineer, considered a keen analyst of business conditions, an organizer and successful negotiator of large contracts involving power and equipment. Specialist on power rates and application of power to large industries. Salary $7500. Now retiring from present position and will be available sixty days. B-4221.

MERCHANDISING OR SALES PROMOTION EXECUTIVE, nine years' central station commercial and merchandising experience, including department management, four years manager large industrial purchasing department, four years general manager gas and electric appliance jobbing and retail stores. Engineering university graduate. Services available November 1st. Location preferred, Eastern States. B-6619.

SALES EXECUTIVE ENGINEER, technical graduate, electrical design, construction, sales of power house equipment. Has large active clientele in New York City. Age 39. Location, New York. Salary $6000. B-2123.

COMMERCIAL ENGINEER, technical graduate, nine years' experience in the public utility business on design, construction and operation of hydroelectric machinery and substations. Desires position as commercial engineer with manufacturing or utility company with possibility for advancement. Available one month. C-2035.

ELECTRICAL ENGINEER, with twenty years' practical experience in industry and utility, desires position of responsibility in a growing organization with modern business policies. Research and developmental department on small electro-mechanical apparatus desired; meters and instruments a specialty. At present employed in charge of laboratory. C-1867.

SUPERINTENDENT of hydroelectric properties wishes new connection. Eighteen years' experience in operation, control and management, general public utility business, including maintenance, purchasing and financing. Recently discharged as "receiver" of international corporation. Age 35. Location immaterial. Salary $3000. B-6686.

PHYSICIST, honor graduate with Ph. D. degree. Three years of university practical postgraduate research in electrical and radio problems. Two years' experience in industrial research for electrical firms. At present head of department of physics and dean of college of pre-engineering at a prominent university. Inventor and owner of three famous basic radio patents. Salary must exceed $4500. Age 27. Available January 1, 1927, or June 1, 1927. C-2048.

ENGINEER, mechanical and construction, ten years' general experience in American methods, is returning to England on November 6th and is open to represent or execute commissions for a reliable American concern. Excellent connections in Europe. B-7433.

ELECTRICAL ENGINEER, 29, seven years' experience, layout and design of power house, substation, transmission line, with material requisition work. At present doing wiring plans, specifications, etc., on theatres, office buildings, hotels, desires similar position with architect or electrical contracting firm anywhere in United States or Canada. Available within four weeks. B-4217.

ELECTRICAL AND VALUATION ENGINEER, 33, married, with ten years' experience, formerly with New York State Public Service Commission, desires position with public utility establishing inventories and appraisals, classifying fixed capital accounting systems and property records. Location, New York City or New York State. B-9636.

CABLE ENGINEER, 36, married, cable engineer and inspector. Long experience on all kinds of wire and cable, especially high tension paper cable. Can write specifications, supervise manufacture, make tests at factory, supervise cable installation and final tests. Long experience with public utility and construction work. Location, prefers New York District or State. B-3625.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED OCTOBER 15, 1926

ATKINS, GEORGE E., Inspection Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; for mail, Jersey City, N. J.

ATKINSON, CHARLES SYDNEY, Chief Operator, Shawinigan Water & Power Co., Power Bldgs., Craig St., Montreal; res., Shawinigan Falls, P. Q., Can.

BANERJEE, ANIL CHANDRA, Asst. Electrical Engineer, Rampur State, Rampur, U. P., India.

BRANDT, ROBERT, Central Station Engg. Dept., General Electric Co., Schenectady, N. Y.

BRIGGS, MELVIN JOHN, Electrical Subforeman, Stone & Webster, Tampa, Fla.

CAMPBELL, IVOR S., Professor of Elec. Engg., Ohio Northern University, Ada, Ohio.

CARTER, THOMAS E., Asst. Load Dispatcher, Florida Power & Light Co., 523 N. W. 11th St., Miami, Fla.

COPELAND, WILLIAM T., Electrical Engineer, E. H. Faile & Co., 441 Lexington Ave., New York; res., Mt. Vernon, N. Y.

CULLWICK, ERNEST GEOFFREY, Draughtsman, Canadian General Electric Co., Peterboro, Ont., Can.

DANIELS, CLIFFORD CLAYTON, Power House Operator, Mystic Lake Plant, The Montana Power Co., Columbus, Mont.

DOWDY, JOSEPH WILSON, Electrician & Licensed Marine Engineer, 1086 Bush St., San Francisco, Calif.

DURE, HENRY J., Transformer Engineer, Edison Electric Illuminating Co. of Boston, 1165 Mass. Ave., Roxbury; res., Medford, Mass.

FINIGAN, WILLIAM, Supt., Federal Trust & Clinton Buildings, 24 Commerce St., Newark, N. J.

FITZGERALD, EDWARD BERNARD, 28 Meridian St., Greenfield, Mass.

FOLEY, JOHN RAYMOND, Asst. Engineer, Appalachian Electric Power Co., Roanoke, Va.

GAYLORD, CLAIR EUGENE, Outside Plant Engineer, New York Telephone Co., 63 E. Delavan Ave., Buffalo, N. Y.
HUFFMAN, GEORGE A., Telephone Equipment Engineer, New England Tel & Tel. Co., 50 Oliver St., Boston, Mass.
KEMPF, RUPERT EDWARD, Foreman, Pacific Oil & Lead Works, 155 Townsend St., San Francisco; res., Berkeley, Calif.
KUCHER, ANDREW ALBERT, Consulting Engineer, Westinghouse Elec. & Mfg. Co., 812 Glen Terrace, Chester, Pa.
LUNDGREEN, SVEN O. G., Draftsman, General Electric Co., 6801 Elmwood Ave., West Philadelphia, Pa.
MAIMAN, ABE 1430 Van Ness Ave., Fresno, Calif.
MAX, CHARLES, Draftsman, Elec. Dept., Central Railroad of New Jersey, Elizabethport; res., Dunellen, N. J.
MAYOR, ROMAN, Jr., Engineer, General Electric Co. of Cuba, Havana, Cuba.
McLEAN, MARCUS M. M., Student Electrical Engineer, General Electric Co., West Lynn, Mass.
REMALY, CURTIS E., Sales Engineer, The R. Thomas & Sons Co., East Liverpool; for mail, Sandusky, Ohio.
REMINGTON, HENRY NOYES, Special Sales Engineer, International Creosoting & Construction Co., 6748 Crandon Ave., Chicago, Ill.
RIENSTRA, ALBERT R., Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.
SCANAVINO, STEVEN ANGELO, Asst. Foreman Electrician, Pacific Gas & Electric Co., San Francisco; res., Stockton, Calif.
SHORTALL, WILBERT JOSEPH, Testing Dept., General Electric Co., 1 River Road, Schenectady, N. Y.
STOCKWELL, HARLAN LOOMIS, Substation Inspector, Tampa Electric Co., Tampa, Fla.
STORM, S. B., Secretary, Marine Electric Co., 104 E. Market St., Louisville, Ky.
*WAGNER, HERMAN H., Student, Automatic Electric Co., Inc., 1001 W. Van Buren St., Chicago, Ill.
WEINER, WILLIAM W., Electrical Engineers' Office, Pennsylvania Railroad System, Altoona, Pa.
WILSON, HORACE R., Electrical Designer, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.
ZUCKERMAN, HARRY, Wholesale Radio Equipment Co., 115 Leonard St., New York, N. Y.
Total 35
*Formerly Enrolled Student.

ASSOCIATE REELECTED OCTOBER 15, 1926

HALL, HENRY MONROE, Electrical Engineer-American Copper Products Corp., 233 Broadway, New York, N. Y.; res., Plainfield, N. J,

MEMBERS ELECTED OCTOBER 15, 1926

BRADT, ANDY WOODRE, General Supt., Hamilton Hydro Electric System, 12 King St., E., Hamilton, Ont., Can.
BROWN, WILLIAM WILBUR, Electrical Radio Engineer, General Electric Co., Schenectady, N. Y.
DELLA RICCIA, ANGELO, Consulting Electrical Engineer, 253 Chaussee d'Alsemberg, Brussels, Belgium.

TRANSFERRED TO GRADE OF MEMBER OCTOBER 15, 1926

ANDREWS, HARDAGE L., Assistant Engineer, Railway Engineering Dept., General Electric Co., Schenectady, N. Y.
ANDREWS, JOSEPH F., American Tel. & Tel. Co., New York, N. Y.
AUTY, CLARENCE, Assistant Electrical Engineer, C. H. Tenney & Co., Boston, Mass.
BALE, LAWRENCE D., Supt. of Power, Cleveland Railway Co., Cleveland, Ohio.
BATES, LOUIS I., Engineer of Electric Distribution, Bronx Gas & Electric Co., New York, N. Y.
BENTON, JOHN R., Professor of Physics and Electrical Engineering, University of Florida, Gainesville, Fla.
BETTANNIER, EUGENE L., Electrical Engineer, Municipal Light & Power Department, Pasadena, Calif.
BOWMAN, HAROLD L., Service Engineer, Westinghouse Electric & Mfg. Co., New York, N. Y.
BROWN, HUGH A., Assistant Professor of Electrical Engineering, University of Illinois, Urbana, Ill.
CAVE, JOSEPH, Electrical Superintendent, Canadian General Electric Co., Toronto, Ont.
DREW, ERNEST C., Assistant Engineer, Bell Tel. Co. of Pennsylvania, Philadelphia, Pa.
DUBOSE, McNEELY, Electrical Superintendent, Aluminum Co. of Canada, Ltd., Arvida, Que., Can.
FISHEL, ANTHONY D., Sales and Electrical Engineer, A. D. Fishel Co., Cleveland, Ohio.
FROM, OWEN C., Telephone Systems Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
GILLILAN, P. M., Railway Engineer, General Electric Co., Schenectady, N. Y.
HAMILTON, HAROLD C., Asst. Supt., Standardizing & Testing Dept., Edison Electric Illuminating Co. of Boston, Boston, Mass.
HART, R. PHILIP, Manager, Cazenovia Electric and Cazenovia Tel. Corp., Cazenovia, N. Y.
HENLINE, HENRY H., Associate Professor of Electrical Engineering, Stanford University, Stanford University, Calif.
HIGHT, WILLIAM R., Assistant Compass Engineer, Sperry Gyroscope Co., Brooklyn, N. Y.
JOHNSON, FRANCIS E., Professor of Electrical Engineering, University of Kansas, Lawrence, Kans.
KONGSTED, L. P., Research Engineer, American Bosch Magneto Corp., Springfield, Mass.
KURTZ, EDWIN, Professor and Head, Dept. of Electrical Engineering, Oklahoma A. & M. College, Stillwater, Okla.
LA ROQUE, HAROLD B., Switchboard Engineering Dept., General Electric Co., Schenectady, N. Y.
McFARLIN, JOHN R., Electrical Engineer, Electric Service Supplies Co., Philadelphia, Pa.
McMILLAN, FRED O., Associate Professor of Electrical Engineering, Oregon State Agricultural College, Corvallis, Ore.
MICHENER, HAROLD, Asst. to Executive Engineer, Southern California Edison Co., Los Angeles, Calif.
MILLER, JOHN H., Chief Electrical Engineer, Jewell Electrical Instrument Co., Chicago, Ill.
MONG, CLIFFORD E., Engineer, Pacific Tel. & Tel. Co., Seattle, Wash.
MONROE, WENDELL P., Assistant Engineer, Illinois Central Railroad, Chicago, Ill.
MORROW, ALLEN, Department Head, Power Department, Standard Oil Co. of California, Richmond, Calif.
NETHERCUT, DONALD W., Distribution Supt., Ohio Public Service Co., Sandusky, Ohio.
NYMAN, ALEXANDER, Director, Radio Patents Corp., New York, N. Y.
O'NEAL, J. P., Westinghouse Electric & Mfg. Co., Sharon, Pa.
PACKARD, ANSEL A., Division Manager, Connecticut Power Co., Middletown, Conn.
PETERS, LEO J., Asst. Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.
POTTS, LOUIS M., Electrical Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
READ, WALTER V., Telephone Engineer, American Tel. & Tel. Co., New York, N. Y.
RODEY, BERNARD S., Jr., Engineer Accountant, United Electric Light & Power Co., New York, N. Y.
RYAN, FRANCIS M., Radio Engineer, Bell Tel. Laboratories, Inc., New York, N. Y.
SCHENCK, CHESTER, Materials Engineer, Elec. Engr. Dept., Commonwealth Power Corp., Jackson, Mich.
SHACKELFORD, BENJAMIN E., Chief Physicist, Westinghouse Lamp Co., Bloomfield, N. J.
THOMAS, RALPH L., Asst. to General Superintendent, Pennsylvania Water & Power Co., Baltimore, Md.
WORRALL, ROBERT H., Radio Engineer, U. S. Naval Research Laboratory, Bellevue, D. C.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held September 20 and October 11, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

BEAVER, J. LYNFORD, Associate Professor of Electrical Engineering, Lehigh University, Bethlehem, Pa.
LEE, LOUIS R., Engineer, Commonwealth Power Corporation, Jackson, Michigan.
MOURADIAN, H., Toll Fundamental Plan Engineer, Bell Tel. Co. of Pennsylvania, Philadelphia, Pa.
PANTER, THOMAS ALFRED, Electrical Engineer, Bureau of Power & Light, City of Los Angeles, Los Angeles, Calif.
ROSSMAN, ALLEN M., Electrical Engineer, Sargent & Lundy, Chicago, Ill.
SINDEBAND, M. L., Vice President, American Gas & Electric Company, New York, N. Y.

To Grade of Member

ADAMS, LEE F., Commercial Engineer, General Electric Company, Schenectady, N. Y.
ARMOR, JAMES C., Electrical Engineer, Pittsburgh Transformer Company, Pittsburgh, Pa.
BACHRACH, ALFRED, Commercial Engineer, General Electric Company, Los Angeles, Calif.
BENNETT, CLARENCE S., Construction Engineer, General Electric Company, Portland, Oregon.
BERKLEY, H. WALTER, Electrical Engineer, Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.
BILLHIMER, FRANK M., General Engineer, Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.
BOISSONNAULT, F. L., Control Engineer, Westinghouse Electric & Mfg. Company, San Francisco, Calif.
BROWN, STEWART K., Assistant Superintendent, Meter Department, Potomac Electric Power Company, Washington, D. C.
CAROTHERS, ROBERT M., In Administrative Charge, Flow Meter Regular Engineering Department, General Electric Company, Schenectady, N. Y.
CROSBY, GEORGE L., Vice President (Sales), Roller-Smith Company, New York, N. Y.
CURRIER, PHILLIP M., Electrical Engineer, General Electric Company, Schenectady, N. Y.
DART, HARRY F., Radio Engineer, Westinghouse Lamp Company, Bloomfield, N. J.
DICKINSON, WILBUR K., Electrical Engineer, General Electric Company, West Lynn, Mass.
DUNCAN, P. M., Electrical Engineer, Allis-Chalmers Mfg. Company, Milwaukee, Wis.
DUNN, STEPHEN E., Sales Engineer, Clapp and LaMorse, San Francisco, Calif.
EDWARDS, GEORGE De FOREST, Telephone Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

ELDER, L. R., Manager, Motor Department, General Electric Company, Portland, Oregon.
FALLOON, E. J., Hydraulic Engineer, Glen Alden Coal Company, Scranton, Pa.
FETHERLING, H. G., Sales Engineer, General Electric Company, Pittsburgh, Pa.
FLANNERY, DANIEL THOMAS, Assistant Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada.
FRIIS, HAROLD T., Research Engineer, Bell Telephone Laboratories, Inc., Cliffwood, N. J.
GARMAN, CHARLES P., Electrical Engineer, Dept. of Water and Power, Los Angeles, Calif.
GASSAWAY, STEPHEN G., Assistant Manager, Commercial Dept., Oklahoma Gas & Electric Company, Oklahoma City, Okla.
GEORGE, CLIFFORD H., Superintendent, Light and Power, Puget Sound Power & Light Company, Wenatchee, Washington.
HAGAR, GEORGE H., Assistant to General Superintendent, Great Western Power Company, San Francisco, Calif.
HAMILTON, WILLIAM STORRS H., Electrical Engineer, Railway Engineering Department, General Electric Company, Schenectady, N. Y.
HANSEN, EDMUND H., Research Engineer, Radio Corporation of America, New York, N. Y.
HOGG, CHARLES J., Engineer, New England Tel. & Tel. Company, Boston, Mass.
KNOWLES, EVERETT H., Assistant Chief, Operation of Substations, Chile Exploration Company, Chuquicamata, Chile, S. A.
KOBROCK, JOHN P., Division Plant Engineer, New England Tel. & Tel. Company, Boston, Mass.
KRIEGSMANN, ARNOLD E., Assistant Engineer, Hodenpyl, Hardy & Company, Inc., New York, N. Y.
LAMPE, J. HAROLD, Instructor in Electrical Engineering, Johns Hopkins University, Baltimore, Md.
LAWRENCE, ROGER C., Electrical Engineer, American Steel & Wire Company, Cleveland, Ohio.
LEWIS, HOWARD O., Assistant Engineer, Electrical Engineering Department, Boston Elevated Railway, Boston, Mass.
LOVELL, CLEMENS M., Designing Engineer, Moloney Electric Company, St. Louis, Mo.
LYON, WILLIAM R., Electrical Engineer, Products Protection Corporation, New Haven, Conn.
MARTIN, HARRISON A., Assistant Electrical Engineer, Electric Bond & Share Company, New York, N. Y.
MAXSTADT, FRANCIS W., Instructor of Electrical Engineering, California Institute of Technology, Pasadena, Calif.
McGRATH, MAURICE K., Managing Director, Le Materiel Telephonique, Paris, France.
McLAGAN, ERNEST G., Sales Engineer, Allis-Chalmers Mfg. Company, St. Louis, Mo.
MEREDITH, GAILEN E., Superintendent, Engineering Research Laboratory, Kansas City Power and Light Company, Kansas City, Mo.
MILLER, WILLIAM J., Dean of Engineering, Texas Technological College, Lubbock, Texas.
NEEDHAM, OLLIE, Electrical Engineer, Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.
NELSON, ARTHUR L., Manager, Construction Dept., Jackson & Moreland, Boston, Mass.
OSHIMA, HIROYOSHI, Director and Chief Engineer, Osaka Electric Lamp Co., Ltd., Osaka City, Japan.
PANCOAST, D. F., Consulting Engineer, Cleveland, Ohio.
ROBBINS, FRANCIS J., Supt. Distribution, Grays Harbor Railway and Light Company, Aberdeen, Washington.
SAMUELS, IRVING, President, Automatic Devices Company, President, Samuels Stabilarc Company, Allentown, Pa.
SHEPARD, WILLIAM M., Vice President and General Agent, The California Oregon Power Company, Medford, Oregon.
SMITH, CHARLES GROVER, Physicist, Raytheon Mfg. Company, Cambridge, Mass.
SMITH, WALTER C., Sales Engineer, Meters and Transformers, General Electric Company, San Francisco, Calif.
STAUFFACHER, EDWIN R., Superintendent of Protection, Southern California Edison Company, Los Angeles, Calif.
THOMPSON, RUSSELL G., Assistant Superintendent, North East Electric Company, Rochester, N. Y.
TRAWICK, HENRY PHILLIPS, Proposal Engineer, Switchboard Sales, General Electric Company, Baltimore, Md.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1926.

Abbott, A. C., Shawinigan Water & Power Co., Montreal, P. Q., Can.
Abbott, T. A., Sheffield Scientific School, Yale Univ., New Haven, Conn.
Alger, E. C., Bethlehem Shipbuilding Corp., Quincy, Mass.
Andrews, J. L., Carolina Power & Light Co., Moncure, N. C.
Bair, B., with C. E. Wise, Detroit, Mich.
Barney, H. S., Chester County Light & Power Co., Kennett Square, Pa.
(Applicant for re-election.)
Beck, Partner, Beck Bros., Philadelphia, Pa.
Bell, N. W., Gibbs & Hill, Inc., New York, N. Y.
Bishop, N., Bell Telephone Laboratories, Inc., New York, N. Y.
Bowman, C. F., Pittsburgh & Lake Erie Railroad, Pittsburgh, Pa.
Brown, G. N., Okonite Co., Atlanta, Ga.
Bruno, S. F., General Electric Co., New York, N. Y.
Buresch, E. E., Contracting, 1016 Caton Ave., Brooklyn, N. Y.
Bryant, L. A., The Dayton Power & Light Co., Dayton, Ohio
Carlson, L., Western Electric Co., New York, N. Y.
Chunko, P. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Cleaveland, V. M., General Electric Co., Pittsfield, Mass.
Close, G. A., Electrical Engineer & Contractor, Portland, Me.
Cole, I. V., Lexington Electric Prod. Co., New York, N. Y.
Colyer, A. R., New York Edison Co., New York, N. Y.
Cone, W. B., Shevlin-Hixon Co., Bend, Ore.
Connor, F. A., (Member), General Electric Co., Pittsburgh, Pa.
Cooley, G. R., (Member), Electrical Engr., 90 Columbia St., Seattle, Wash.
Doolittle, F. B., So. California Edison Co., Los Angeles, Calif.
English, J. R., (Member), Erie Lighting Co., Penn Public System, Erie, Pa.
Eschmann, W. G., Splitdorf Electrical Co., Newark, N. J.
Evans, L. E., General Electric Co., Kansas City, Mo.
Gates, S. H., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Georgies, A. M., Eisemann Magneto Corp., Brooklyn, N. Y.
Gillmor, J., Toronto Hydro-Electric System, Toronto, Ont., Can.
Glasgow, E. M., Russell & Stoll Co., New York, N. Y.
Greene, R. E., Detroit Edison Co., Detroit, Mich.
Greenwood, J., (Member), Electrical Engineer, New York, N. Y.
Gullette, D. P., Public Ledger Co., Philadelphia, Pa.
Haberer, J. P. A., General Electric Co., Lynn, Mass.
Hammond, C. S., Georgia Railway & Power Co., Atlanta, Ga.
Hammond, R. A., General Electric Co., Kansas City, Mo.
Heim, H. J., Purdue University, Lafayette, Ind.
Hendrickson, H. A., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Hildebrand, T. F., American Gas & Electric Co., New York, N. Y.
Hodgman, J. W., General Electric Co., Fort Wayne, Ind.
Holbrook, P. H., (Member), Turners Falls Pr. & Elec. Co., Agawam, Mass.
Holmes, M. C., General Electric Co., West Lynn, Mass.
Hornberger, R. G., U. S. Bureau of Reclamation, Denver, Colo.
Hull, R. M., Alabama Power Co., Birmingham, Ala.
Jorgenson, L. M., Kansas State Agricultural College, Manhattan, Kans.
Kaminsky, M. M., W. J. Holliday & Co., Indianapolis, Ind.
Kasindorf, S., Commodore Radio Corp., New York, N. Y.
Keonig, E. L., Engineer, 4130 Fifth St., Washington, D. C.
Komives, L. I., The Detroit Edison Co., Detroit, Mich.
Kormendy, L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Kovach, A. J., with Richard Bros., Detroit, Mich.
Kroneberg, A. A., So. California Edison Co., Los Angeles, Calif.
LeWald, H. P., K & B., Elec. Equipment Co., Inc., New York, N. Y.
Malmstrom, A. L., Detroit Edison Co., Detroit, Mich.
Manaseri, B. B., Postal Telegraph Cable Co., New York, N. Y.
Manuel, E. J., Detroit Edison Co., Detroit, Mich.
McCrea, W. S., Jr., Washington Water Power Co., Spokane, Wash.
McHenry, W. C., Pennsylvania Power & Light Co., Allentown, Pa.
Miller, J. E., Kentucky Utilities Co., Four Mile, Ky.
Moore, E. R., Detroit Edison Co., Detroit, Mich.
Morrison, L. H., Cia Mexicana de Terrenos Y Petroleo, S. A., Grontera, Tabasco, Mex.
Neimoeller, E., The Pacific Tel. & Tel. Co., Los Angeles, Calif.
Nelson, W. L., The Ohio Public Service Co., Elyria, Ohio
Olving, B. G., New York Edison Co., New York, N. Y.
Peruzzi, E., Detroit Edison Co., Detroit, Mich.
Poggemeyer, B. H., U. S. Gypsum Co., Genoa, Ohio
Pringle, J. B., Northern Electric Co., Montreal, P. Q., Can.
Rasmussen, F. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Rodgard, H., The New York Edison Co., New York, N. Y.
Rowland, W. B., Union Carbide & Carbon Corporations, Havana, Cuba
Russell, W., (Member), The New York Edison Co., New York, N. Y.
Schenck, F. W., Pine Hill Coal Co., Minersville, Pa.
Shears, C. C., Otis Elevator Co., Los Angeles, Calif.
Siewert, D. R., General Electric Co., Kansas City, Mo.
Sinclair, D., 218 Garfield Place, Brooklyn, N. Y.
Skeels, W. R., Postal Telegraph Co., Chicago, Ill.
Slepian, A., Wheeler Insulated Wire Co., Bridgeport, Conn.

Taylor, H. B., (Member), The William Cramp & Sons Ship & Engine Building Co., Philadelphia, Pa.
Thomas, A. J., L. J. Healing & Co., Ltd., Tokyo, Japan.
Thornwell, E. A., (Member), Manufacturer's Agent, Atlanta, Ga.
Turpin, C. E., American Smelting & Refining Co., Omaha, Nebr.
Warfield, C. N., University of Richmond, Richmond, Va.
Widell, B. A., Jr., (Member), General Electric Co., Erie, Pa.
Work, H. R., Crocker-Wheeler Electric Mfg. Co., Ampere, N. J.
Zielinksi, F. J., General Electric Co., Worcester, Mass.

Total 86

Foreign

Cater, C., c/o Bank of London & South America, Santiago, Chile, S. A.
Hopkins, H. D., Melbourne City Council, Melbourne, Victoria, Aust.
Iyer, A. V. D., Kanadukathan Elec. Supply Co. Kanadukathan, Ramnad Dt., Madras Pres., India
Knighton, D. W. R., Ste. Madeleine Sugar Co.; Ltd., Usine Ste. Madeleine, San Fernando, Trinidad, B. W. I.
Leino, A. P., "Svetlana" Incandescent Lamp Works, Lesnoj, Leningrad, Russia
Mani, R. S., Tata Hydro-Elec. Supply Co., Ltd., Lalwady, Bombay 12, India
Pillay, J. M. P., Kastoorchand Mills, Dadar, Bombay, India
Shimidzu, K., Sumitomo Elec. & Wire Cable Works, Okijimaminamino-cho, Konohanaku, Osaka, Japan
Telmo, P. M., (Member), Public Utility Commission, Manila, P. I.

Total 9

STUDENTS ENROLLED

Ackley, Norman D., Ohio Northern University
Anderson, Rudolph W., University of So. Dak.
Anewalt, Samuel B., Lafayette College
Annand, George I., University of California
Baily, L. W., Kansas State Agricultural College
Baker, Lyle W., Pennsylvania State College
Ballantyne, Thomas J., Drexel Institute
Baumgartner, Alfred G., Iowa State College
Berry, Paul, Missouri School of Mines
Black, William F., Rice Institute
Blau, Elmer W., University of California
Blickkle, Herbert G., Case School of Applied Science
Bradley, Richard D., Kansas State Agricultural College
Brandt, Eugene S., Case School of Applied Science
Bridges, James M., University of Maine
Broadbent, John H., Drexel Institute
Brown, Clyde L., Alabama Polytechnic Institute
Brown, Robert E., Alabama Poly. Institute
Butcher, John H., Rice Institute
Byther, Harry S., Jr., State College of Washington
Cameron, A. L., Alabama Poly. Institute
Chappell, George R., University of Maine
Chew, Louis, University of California
Chinn, Howard A., Mass. Inst. of Technology
Coffman, Melvin C., Kansas State Agricultural College
Coles, Francis A., University of California
Cook, Kenneth H., Kansas State Agricultural College
Craddock, Gerald V., Drexel Institute
Crema, Francis V., Drexel Institute
Crosby, Lynn B., Case School of Applied Science
Crowell, Lysle E., University of So. Dak.
Daniels, Harold H., University of California
Ditchman, Joseph P., Case School of Applied Science
Dobson, Ellsworth S., Lafayette College
Dodge, Ernest H., Mass. Inst. of Technology
Drane, Henry Tupper Alabama Poly. Institute
Duncan, Curtis H., University of California
Earl, Edwin O., Kansas State Agricultural College
Earle, Clifford, Marquette University
Eddy, George A., Rhode Island State College
Ellard, Walter, Northeastern University
Evans, Kennis, Kansas State Agricultural College
Fenander, Walter A., University of California
Fifield, Sumner H., University of Maine
Flanders, Norton B., University of California
Folsom, Elwood E., Jr., University of Maine
Foulon, Fred., University of California
Fraser, S. M., Kansas State Agricultural College
Fulwiler, Harry, Jr., Alabama Polytechnic Institute
Gabert, Ronald E., Lafayette College
Gilbert, Walter E., Drexel Institute
Goeller, Charles P., Northeastern University
Gorman, Walter J., Pennsylvania State College
Gove, Kenneth G., Mass. Inst. of Tech.
Grant, D. William, Kansas State Agricultural College
Gray, Carl J., Pennsylvania State College
Gregory, Claude H., University of California
Griswold, Elmer Prescott, Northeastern University
Hale, Stuart G., University of California
Hancock, John L., Kansas State Agricultural College
Hansen, Joseph, Washington State College
Heal, John E., Drexel Institute
Hottle, Warren M., Drexel Institute
Hunter, James H., Rice Institute
Ishimura, Henry M., University of California
Ivanof, Vladimir, University of California
Jacobs, Frank C., University of California
Johnson, Harry A., University of California
Johnson, Thomas J., Rice Institute
Johnston, Richard H., Jr., Lafayette College
Jones, Samuel C., Drexel Institute
King, Arthur W., Pennsylvania State College
Kirkland, Robert D., University of California
Knerr, Lewis R., University of California
Kozel, Henry C., Oklahoma A. & M. College
Kranenburg, P. J., Iowa State College
Lagrone, George N., Alabama Polytechnic Institute
Larson, Oscar C., Rhode Island State College
Laufenberg, Clemens W., University of California
Lindsay, James R., University of California
Linscott, Jack H., Kansas State Agricultural College
Lubcke, Harry R., University of California
Lundry, Victor E., Kansas State Agr. College
Lymburner, Lawrence E., University of Maine
Lynch, Thomas S., Alabama Poly. Institute
Lynip, Benjamin F., Jr., University of California
Maxwell, John F., University of California
Melson, George H., Drexel Institute
Merrels, Joseph E., Lafayette College
Merrill, Oliver E., Northeastern University
Meyers, Clifford R., University of So. Dak.
Michaels, Henry J., South Dakota State College
Michelman, Edward A., Mass. Inst. of Technology
Mikulasek, George W., University of California
Montin, J. Ragnar, University of California
Moore, John P., University of Maine
Morgan, Archie Le Roy, Kansas State Agr. College
Morgan, Howard K., University of California
Mortimer, Harold E., Rice Institute
Nathanson, M., McGill University
Newbold, Wm. Herbert, Pennsylvania State College
Nixon, Henry C., University of California
Obrecht, R. Gardiner, Kansas State Agr. College
Oishi, Ta, University of California
Olsen, Raymond C., University of California
O'Neil, William H., Jr., Northeastern University
Pastoret, J. Eugene, Drexel Institute
Perron, Raymond T., Rhode Island State College
Petersen, Wilbur C., Case School of Applied Science
Pethick, Frank I., Jr., Pennsylvania State College
Phillips, William H., Mass. Inst. of Technology
Pickett, Gerald, Oklahoma A. & M. College
Poling, Virgil D., Ohio Northern University
Potter, James L., Kansas State Agr. College
Power, James R., Carnegie Inst. of Technology
Putnam, William H. H., Alabama Polytechnic Institute
Ravenscroft, Henry A., University of California
Reinero, Fred P., Univ. of California
Rezos, George, University of California
Richards, Amyle P., Oklahoma A. & M. College
Richardson, Harvey C., State Col. of Washington
Ricker, Raymond A., Northeastern University
Rigby, William H., Drexel Institute
Ritchie, Edward C., University of California
Robinson, Edward P., Ohio Northern University
Rogers, Thomas A., University of California
Rose, Harry B., University of New Hampshire
Sacco, Benjamin J., Northeastern University
Sauter, John D., The Pennsylvania State College
Schmidhamer, Stephen F., Pennsylvania State College
Schrock, John E., Kansas State Agr. College
Seaman, Blair C., Pennsylvania State College
Seeburg, Albert L., University of California
Shattuck, Orris C., Jr., University of So. Dak.
Shenk, Eli, C., Kansas State Agr. College
Sisk, Harland P., Mass. Inst. of Tech.
Sloan, Claude W., Kansas State Agr. College
Smith, Arthur A., University of Maine
Soorin, Andrew J., University of California
Sorg, Harold E., University of California
Southwick, Alva F., Michigan State College
Stephens, Paul E., Pennsylvania State College
Stevens, John F., University of New Hampshire
Stewart, James D., Alabama Polytechnic Institute
Stockwell, Donald P., University of So. Dak.
Stone, Leighton A., University of California
Tabor, Howard L., Alabama Poly. Institute
Thompson, Wesley A., Kansas State Agr. College
Thurber, Walter P., University of New Hampshire
Tilles, Abe, University of California
Touraine, Edgar J., University of California
Vaile, Robert B., Jr., California Inst. of Tech.
Vallin, Gordon, University of So. Dak.
Vogel, M. Augustus, Lafayette College
Vologodsky, Nicholas T., University of California
Wagener, Winfield G., University of California
Wahlander, Adrian A., University of California
Walker, Robert I., Pennsylvania State College
Wendel, William R., Pennsylvania State College
Wheeler, Henry J., University of North Carolina
White, Harold D., University of California
White, Harry J., University of California
Wilkins, Frank F., Pennsylvania State College
Winer, John, Pennsylvania State College
Woolman, Harold A., Drexel Institute
Zbradovsky, Boris V., California Inst. of Tech.
Zehner, Richard W., Pennsylvania State College

Total 167

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H. W. Flashman, Aus. Westinghouse Elec. Co. Ltd., Cathcart House, 11 Castelreagh St., Sydney, N. S. W., Australia.
Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janeiro, Brazil, S. A.
Charles le Maistre, 28 Victoria St., London, S. W. 1, England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
F. W. Willis, Tata Power Companies, Bombay House, Bombay, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

A. I. E. E. COMMITTEES

(A list of the personnel of Institute committees may be found in the September issue of the Journal and will be published again in the January 1927 issue.)

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Applications to Marine Work, G. A. Pierce
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Protective Devices, F. L. Hunt
Research, John B. Whitehead
Transportation, J. V. B. Duer

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the Journal and will be published again in the January 1927 issue.)

American Association for the Advancement of Science, Council
American Bureau of Welding
American Committee of Electrolysis
American Engineering Council
American Engineering Standards Committee
American Marine Standards Committee
American Year Book, Advisory Board
Apparatus Makers and Users Committee
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National Safety Council, Electrical Committee of Engineering Section
The Newcomen Society
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Society for the Promotion of Engineering Education, Board if Investigation and Coordination
U. S. National Committee of the International Electrotechnical Commission
U. S. National Committee of the International Illumination Commission
Washington Award, Commission of

LIST OF SECTIONS

Name	Chairman	Secretary
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Atlanta	C. E. Bennett	W. F. Oliver, Box 2211, Atlanta, Ga.
Baltimore	W.B. Kouwenhoven	R. T. Greer, Madison St. Building, Baltimore, Md.
Boston	Hartley Rowe	W. H. Colburn, 39 Boylston St., Boston, Mass.
Chicago	K. A. Auty	William Wurth, 1634 Peoples Gas Bldg., Michigan Ave. at Adams St., Chicago, Ill.
Cincinnati	W. P. Beattie	L. J. Gregory, Union Gas & Electric Co., Cincinnati, Ohio
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Yale University, New Haven, Conn	W. W. Parker	J. W. Hinkley	Charles F. Scott
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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Circuit Breakers.—Bulletin 1004, 40 pp. "The Selection and Application of Oil Circuit Breakers." Condit Electrical Manufacturing Corporation, Boston, Mass.

Air Filters.—Bulletin 2223, 12 pp. Describes American Blower air filters, cell construction type. American Blower Company, Detroit, Mich.

Tree Wire.—Bulletin, 24 pp. Describes Okonite tree wire, for use when electric light and power lines must be placed through trees. The Okonite Company, Passaic, N. J.

Power Rectifiers.—Bulletin 301, 20 pp. Describes mercury arc power rectifiers, manual or automatic control. American Brown Boveri Electric Corporation, 165 Broadway, New York.

Motors.—Bulletin 111, 4 pp. Describes Type H-O self starting, squirrel cage motors, equipped with only one rotor winding. Northwestern Manufacturing Company, Milwaukee, Wis.

Ball Bearings.—Bulletin, 32 pp. "Ball Bearings for Electric Motors." Describes the advantages of ball bearings for electrical machinery and economies effected by their use. Illustrations show applications of ball bearing equipped motors in the various industries. The Fafnir Bearing Company, New Britain, Conn.

Control Apparatus.—Bulletin 600, 8 pp., A-C. Resistance Starters; Bulletin 710, 4 pp., Across-The-Line Starting Switch; Bulletin 740, 4 pp., Automatic Resistance Starters. All bulletins with price lists. Allen-Bradley Company, 496 Clinton Street, Milwaukee, Wis.

Ball Bearings.—Bulletin, 20 pp., "Cutting Your Costs or What New Departure Ball Bearings Mean In Your Motor." Describes the advantages of New Departure ball bearings when applied to electric motors, and gives figures showing upkeep savings resulting through their use. The New Departure Manufacturing Company, Bristol, Conn.

Mica.—Bulletin, 24 pp., "Mica and Mica Products." Material from which this publication has been compiled was taken from a series of lectures on electrical insulating materials by Professor H. Schering, of Berlin, and describes the varieties and applications of mica for electrical insulation principally. William Brand & Company, 27 East 22nd Street, New York.

Roller Bearings.—The new Timken Engineering Journal, a loose-leaf book of 110 pp., contains technical information relative to the application of Timken bearings to automotive and industrial machinery. Typical problems, with the solutions, involving the calculation of various loads and the selection of suitable bearings are given. Tables showing bearing ratings, capacities and dimensions, as well as speed capacity-curves, are included. A full set of dimension sheets accurately drawn to scale, together with formulas and recommendations for the application of Timken bearings, developed through experience gained in applying more than 150,000,000 bearings, comprise another section. The Timken Roller Bearing Company, Canton, Ohio.

NOTES OF THE INDUSTRY

New Sales Manager for Wagner Electric Corporation.—Edward H. Cheney has been appointed sales manager of the Wagner Electric Corporation at St. Louis, succeeding Thomas T. Richards, who resigned October 1st. Mr. Cheney has been with the Wagner Corporation since 1905, when he was appointed Chicago office manager. In 1909 he was promoted to Chicago district manager, in which position he served up until his recent appointment as sales manager.

General Electric Sales.—The statement of sales and net earnings of the General Electric Company for the nine months ending September 30, announced by President Gerard Swope, shows the net sales totalled $229,638,216 and the profit available for dividends on common stock and surplus was $30,051,619. Orders received for the three months ending September 30, totalled $81,587,917, as compared with $73,561,483 for the same quarter in 1925, an increase of 11%.

The Power Plant Supply Company, Widener Building, Philadelphia, has been organized to furnish power plants in Philadelphia and vicinity with engineering equipment and supplies. The activities of the company will be devoted between two departments; the supply department will act as jobbers or agents for power plant supply material, and the engineering department will handle the consulting and special service work of its customers.

Ohio Brass Will Have New Office Building.—Much needed larger working quarters will be provided for the general offices of the Ohio Brass Company when the new administration building is completed, on which construction work started October 1st. The new office building will cost approximately $500,000. It is to be a five-story steel and brick structure, fire-proof throughout.

Pennsylvania Railroad Orders More Electrical Equipment.—The Pennsylvania Railroad has recently placed an order with the Westinghouse Electric & Manufacturing Company for electrical equipment for ninety-three coaches. In addition, the contract calls for motors and control for four large electrical passenger locomotives. These coaches will be put into service on the Wilmington Division now being modified for electrical operation.

American Brown Boveri Appointments.—G. C. Barry has been appointed assistant to Earle T. Hines, general sales manager of the American Brown Boveri Corporation at 165 Broadway, manufacturers of heavy electrical equipment. Mr. Barry began his electrical career with the Western Electric Company in 1912, and later became associated with the Hart Manufacturing Company at Hartford. Major James R. Worth has been placed in charge of the Holding Company sales. Previously he had been in charge of power plant construction in the U. S. Army and was subsequently connected with other power companies.

Large New York Building To Be Floodlighted.—The Paramount Building on Times Square, New York, now nearing completion, will have the largest installation of floodlights which has ever been made, according to the General Electric Company. The building is thirty-five stories high, and from the thirteenth to the thirty-fifth floor it will be floodlighted. These upper stories are set back to conform to the new zoning law in New York. The lighting equipment consists of 473 G-E types L9-11-15 floodlights, with a total load of 230 kilowatts.

Cleveland Honors Electrical Industry.—The electrical industry of Cleveland, on October 26, was toasted by 2,000 of the city's leading business men attending a huge luncheon meeting in the mammoth convention hall to learn about Cleveland's position in the electrical world. A special census developed the fact that Cleveland has 135 manufacturers of electrical products which utilize $75,000,000 of capital, outsidoe f the many millions invested in the electrical public utilities. The output of these manufacturers in the last year had a value of $130,000,000 exclusive of the value of public utility services. Among those presented to the meeting were R. C. Norberg, vice-president of the Willard Storage Battery Company; Charles F. Brush, inventor of the arc lamp; Joseph H. Alexander, the new president of the Cleveland Railway Company; and Edwin F. Carter, new president of the Ohio Bell Telephone Company. The two principal speakers were J. F. Lincoln, vice-president of the Lincoln Electric Company, and M. H. Aylesworth, president of the newly formed National Broadcasting Company, Inc.

JOURNAL OF THE A·I·E·E·

DECEMBER 1926

A E E I

PUBLISHED MONTHLY BY THE
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33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

WINTER CONVENTION, New York, N. Y., February 7-11

REGIONAL MEETINGS

Southwest District No. 7, Kansas City, Mo., March 17-18

Middle Eastern District No. 2, Bethlehem, Pa., April 14-16

MEETINGS OF OTHER SOCIETIES

The American Society of Mechanical Engineers, New York, N. Y., Dec. 6-9

The American Physical Society, Annual Meeting, Philadelphia, Pa., Dec. 27-29

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OF THE

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Current Electrical Articles Published by Other Societies

Agricultural Engineering, October 1926

Rural Electrification from an Economic and Engineering Standpoint, by L. S. Wing

Institute of Radio Engineers, Proceedings, October 1926

A Method for Maximization in Circuit Calculation, by W. van B. Roberts

Combines Electromagnetic and Electrostatic Coupling and Some Uses of the Combination, by E. H. Loftin and S. Y. White

Field Distribution and Radiation Resistance of a Straight Vertical Unloaded Antenna Radiating at One of Its Harmonics, by S. A. Levin and C. J. Young

Long Distance Radio Receiving Measurements and Atmospheric Disturbances at the Bureau of Standards, in 1925, by L. W. Austin

On the Origin of the Superheterodyne Method, by W. Schottky

Reduction of Interference in Broadcast Reception, by A. N. Goldsmith

Some Measurements of Short-Wave Transmission, by R. A. Heising, T. C. Schelleng and G. C. Southworth

Theory of Detection in a High Vacuum Thermionic Tube, by L. P. Smith

Journal, Franklin Institute, October 1926

Theory and Development of the Interpole Motor, by M. MacLaren

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Engineering Education

The engineering graduate has often been criticised of late years for various shortcomings. These criticisms naturally reflect upon the institutions that give education in engineering subjects. As an educator, I would like to say a few words concerning this matter and set forth briefly both some of the reasons for criticism and some of the measures that educational institutions are using to rectify the causes of criticism. In this connection, I might point out that before becoming an educator I spent more than twenty-five years in the actual practise of engineering, and therefore have been able to observe this problem from both sides.

Of the many criticisms that have been leveled at the engineering graduate of the present day, I believe that the two most frequent are:

1st. That he lacks a proper appreciation of the economics of his chosen field.

2nd. That he lacks ability to express himself adequately either in writing or in speech.

Both of these criticisms are undoubtedly often justified. The obvious cure is more and better instruction in economics, English and public speaking. But how can more time be taken from engineering subjects for such additional instruction in these non-engineering subjects? Engineering has become much more complex and far reaching in its demands on the curricula for engineering subjects during the last twenty or thirty years than was even dreamed of in the early days of engineering education. To cite a specific example, the steam turbine is only about twenty-five years old, but its place in the field of deriving power from heat is today supreme. No engineering curriculum would today be adequate that did not undertake to inculcate the principles underlying the steam turbine. However, the steam turbine has not displaced the reciprocating machine and the principles underlying the latter must be inculcated as well as for the turbine. In other words, the rise of the steam turbine has placed an additional burden on the present day engineering curriculum that did not exist twenty-five years ago. And this specific example is only one out of dozens of the same nature that might be cited. The existing knowledge today is vastly greater than that of yesterday and this statement is particularly true of engineering subjects.

To repeat my previous question then, how can the engineering curriculum cover adequately the basic principles of engineering as expanded at the present day and still devote adequate attention to non-engineering subjects? One answer to this question is to increase the time; extend the usual four year course to five or even to six years. This remedy has often been proposed and in a few cases has been applied. Where tried it has not met with any great favor if the number of students may be taken as a criterion. My own personal reaction to this proposal is adverse: I do not believe that the embryo engineer can afford to take more than four years out of his life for his technical education. If we accept the proposition that the engineering course should not cover more than four years (as I believe we must) it follows that our engineering curricula must not only cover the vastly increased technical field during that four years, but also must cover adequately those non-technical subjects, the lack of which has in the past provoked so much adverse criticism.

I wish to point out specifically that engineering educators are acutely alive to the problems that confront them. The Society for Promotion of Engineering Education is now and for some years past has been undertaking a comprehensive study of engineering curricula. This study covers all phases of these curricula, both engineering and non-engineering. To be still more specific, a committee of the S. P. E. E. on "Economic Content of Engineering Education" is now at work on this particular phase of the problem. In its endeavor to find the answer to this problem, the committee proposes to consult not only educators but also, so far as possible, every point of contact between the engineer and the community that he serves. This is only one of the many studies that is now being carried on by the S. P. E. E. These studies will cover every part of the engineering curriculum—technical and non-technical. The engineering educator is quite alive to the problems confronting him.

No engineering school pretends to produce a finished engineer; it simply turns out a man who, if he continues to progress in the direction in which he is pointed when he obtains his degree, will eventually become an engineer. His education is by no means completed when he receives his degree; education is a process that ceases only with death. It is the aim of the engineering school to give an inspiration—an impetus—that will continue and without which no man can hope to become an engineer in the true sense.

In closing I might add that the educator does not resent criticism; he welcomes it. But there are two kinds of criticism—destructive and constructive. The destructive kind simply wishes to destroy that which it aims at without setting up anything in its place.

The constructive variety does set up a substitute. It is obvious that constructive criticism is the only kind that is worthy of any real consideration.

P. M. LINCOLN, *Chairman*
Committee on Education

Some Leaders of the A. I. E. E.

William McClellan, thirty-fourth president of the Institute (1921-1922), was born in the city of Philadelphia, Pa., November 5, 1872. Here he also received his education, first at the Manual Training School and later at the University of Pennsylvania, from which, in 1900, he received his B. S. degree; in 1903 he obtained the degree of Ph.D, and in 1914 his degree in Electrical Engineering.

In 1900 Mr. McClellan entered the service of the Philadelphia Rapid Transit Company, at the same time occupying the office of instructor in Physics at the University of Pennsylvania. He next accepted a position with Westinghouse, Church, Kerr & Company in 1905, remaining with them until the formation of his own company, the Champion-McClellan Company, in 1907, with him as one of its directors. In 1915 this Company was reorganized under the name of Paine, McClellan and Champion, Consulting Engineers, New York City, and in 1922, Mr. McClellan's present Company, McClellan & Junkersfeld, Inc., was formed with Mr. McClellan as president.

From 1911 to 1913 he was consulting engineer for the Public Service Commission, Second District of New York, remaining in that capacity until 1919, when he was chosen dean of the Wharton School, University of Pennsylvania. From this date until 1921 he also served the Cleveland Electrical Illuminating Company as vice-president. In 1925 he was elected president of the Commission on Muscle Shoals.

Mr. McClellan's contributions to science have been noteworthy, both as regards the numerous articles published in technical magazines and papers presented before the representative professional bodies. This is true also of his personal work in the many executive offices which he has occupied. He is at present a member of the American Railway Association, The American Society of Mechanical Engineers, the National Electric Light Association; past-president of the Associated Pennsylvania Clubs, member of Alpha Chi Rho, Phi Beta Sigma, Sigma Xi and Beta Gamma Sigma; director of the Intercollegiate Intelligence Bureau, Washington, D. C.; and a member of the following clubs: the India House, Engineers, Bankers, University of Pa. of New York, Union League and University of Philadelphia, University and Cosmos clubs of Washington; the Huntington Valley Country Club and the Huntington Valley Hunt Club of Pennsylvania.

The Federal Judges' Salaries Bill

This Bill has passed the Senate and is definitely set for a vote in the House of Representatives December 9th. It is a public measure, important to the country at large, and particularly to those interested in patents, since sole jurisdiction over suits enforcing or annulling patents rests with the Federal Judges.

The present salaries of the District Judges ($7500) and of the Circuit Judges ($8500) are so inadequate, particularly in the larger cities, that due to a feeling of an injustice done them there is general dissatisfaction among the Judges in those cities. A number of the Judges have resigned and not a few are merely holding on to see whether the Bill of December 9th will be passed.

The Bill only increases the salaries of the District Judges to $10,000, those of the Circuit Judges to $12,500, and other Federal Judges accordingly. It *must be passed* if the quality of the Federal Judiciary is to be maintained.

American Engineering Council and practically all of the Engineering Societies are making final effort to enact this Bill now, for if it does not pass on December 9th, it will be many years probably before another attempt will be made. Every member of the Institute is therefore requested to write his member of the House of Representatives, urging him to be present on December 9th when the Graham Bill, H. R. 10,554, will be voted upon, and to give to this Bill his hearty support.

A New Type of Rectifier

Preliminary announcements have been made of a new type of rectifier which is extremely simple in principle and operation and which will be described in detail in a forthcoming paper before the Institute. The discoverer of the principle is Dr. L. O. Grondahl, who described it in a recent number of *Science*. The rectifier consists of a disk of copper having a coating of oxide formed on its surface and another metallic disk forming the opposite electrode. Under suitable conditions current flows more readily from the oxide to the copper than in the reverse direction.

The peculiarity of the new rectifier lies in the fact that the direction of the electron flow is opposite to that indicated by the theory underlying the electron tube. Explanations of contact rectification that appear most prominently in the literature, as, for example, electrolysis and thermoelectricity, are shown by Dr. Grondahl to be untenable for the new electronic solid-junction rectifier. The seat of rectification is apparently restricted to the layer near the junction between the copper and the compound formed on it.

Vacuum Switching Experiments
at California Institute of Technology

ROYAL W. SORENSEN* and HALLAN E. MENDENHALL*
Fellow, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*Successful experiments in switching or breaking a circuit in a high vacuum have been made at the California Institute of Technology. This paper is a report on three sets of these experiments which extended over a period of three years. The conclusions drawn from the experiments may be summed up in the statement that vacuum breakers of laboratory type have been successful in breaking circuits and offer a possible solution of the circuit-breaker problem. The results show that switching in vacuum affords the advantages of no pitting of contacts, quick break, the arc always going out on the first half cycle, small voltage rise across the switch, and small distance of travel necessary for the switch blades.*

Making the vacuum switch practical calls for a solution of the problem of making commercial apparatus with vacuum-tight joints, and the elimination of the use of liquid air with the vacuum pump.

EXPERIMENTS on breaking an electrical circuit in a high vacuum have been made during the last three years at the California Institute of Technology in connection with the study of switching high-voltage, high-power circuits. These experiments were undertaken as a result of the well-known limitations of oil circuit breakers. A large number of tests was made on high-vacuum breakers of laboratory type. Some very promising results were obtained in interrupting large currents.

When these experiments were suggested, the question immediately presenting itself was: Will the vacuum maintain itself at the time the arc is formed between the separating metallic parts of an opening switch?

This doubt was quite generally substantiated by the commonly recognized theory of the electric arc,[1] *viz.*, that the maintenance of an arc is dependent upon the giving out of thermions from hot spots on the electrodes between which the arc is formed, with the attendant vaporization of the metal. If this were true, a large current could not be interrupted in a vacuum because the formation of even a small amount of gas would reduce the vacuum and cause it to become a conducting vacuum rather than an insulating vacuum.

The fact of the matter, however, is that if the vacuum is sufficiently high and all adsorbed gases have been removed from the metal electrodes, very large currents can be broken without formation of enough vapor to maintain an arc.

Dr. R. A. Millikan has shown[2] that, with cold electrodes suitably prepared, millions of volts of potential gradient are required to obtain discharges of any kind between metal surfaces. He has also worked out with much care the conditions necessary for denuding metal surfaces of gases and preventing the impairment of the vacuum through the evolution of gases. A. Janitzky[3] also has reported experiments showing that currents will not flow across the space between cold electrodes in a vacuum provided the electrodes have been completely outgassed.

*Both of the California Institute of Technology, Pasadena, Calif.

1. For references, see Bibliography.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

According to the older theory, it would seem that considerable vapor might be formed in the vacuum on breaking a circuit. P. Charpentier[4] has given the following equation:

$$W = 0.07\, E\, I\, t$$

as the equation for the energy to be dissipated in an oil switch at the time of opening. In this equation, E = voltage, I = current, and t = the time in seconds between the initial separation of the switch contacts and the complete extinguishing of the arc. Charpentier's experiments, and also those made by Swiss engineers in 1915 and 1916, indicate that this energy is used in vaporizing oil at the rate of 46.5 cu. cm. per kw-sec. Some of the tests made on oil switches show the vaporization of smaller amounts of oil per kw-sec. and also show power factors of less than 0.07 across the switch at the time of interruption. Applying Charpentier's equation to a single-pole switch opening a 15,000-volt, 100-ampere, 50-cycle circuit, we find that the switch must dissipate 1.05 kw-sec. if it opens on the first half cycle. Assuming as an extreme case, for the vacuum switch, all of this energy available to vaporize copper at the switch blades, we find that it would vaporize approximately one-fifth gram. This amount of copper turned into vapor would reduce an insulating vacuum in a container of considerable size to a vacuum which would be conducting for 15,000 volts applied between electrodes extending into the container.

However, the later theories to which reference has been made indicate that such an amount of vapor will not be formed provided the vacuum is high and the electrodes are free from gas.

Therefore, in making the experiments, the prime requisites were to have the electrodes entirely free of adsorbed gases and to obtain a good vacuum. Dr. Millikan was immediately interested in the proposal of the tests and placed at our disposition the facilities and high-vacuum experience of the Norman Bridge Laboratory; also he cooperated in the development of the switch by making many valuable suggestions and by assigning to the work two graduate students of the physics department, H. E. Mendenhall and Russell Otis.

Three switches were developed and tested. The first

switch is shown in Fig. 1. It consists of a glass envelope with two fixed electrodes as shown, separated by one-half inch. These have crescent-shaped contact surfaces, *a* and *b*, as shown. The contact area of each of the fixed terminals is 1/8 sq. in. The circuit is closed by a flat circular copper disk resting upon them with no contact pressure other than the weight of the disk, to which is attached a light plunger. The switch is opened in operation by a

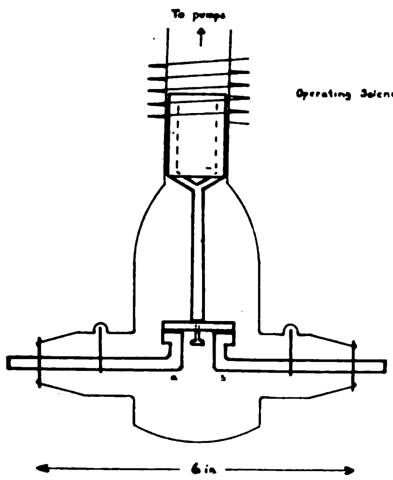

FIG. 1—CROSS-SECTION VIEWS OF SWITCH NO. 1

solenoid which, when energized, raises the plunger. In interrupting the circuit, the bridging circuit contact is raised 1/2 in. by the solenoid. This type of construction gives two breaks in series when the switch is open.

Vacuum-tight joints between the lead-in conductors

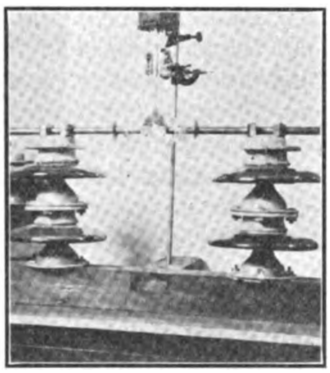

FIG. 2—VACUUM SWITCH NO. 2

and the glass envelope of the switch were easily obtained by means of W. G. Houskeeper's disk seals.[5] This switch was evacuated down to 10^{-6} centimeters of mercury pressure. An initial test was made by using this switch to interrupt currents up to 125 amperes at 110 volts d-c. The results were encouraging, and the switch was connected to an a-c. supply and the test repeated with very satisfactory results, the interruption of current being accomplished with less arcing than occurred when direct current was used.

The switch was then successively used on a-c. circuits for 220 volts, 2300 volts, and 15,000 volts. The load in every case was a single-phase load connected and disconnected by means of the switch used as a single-pole switch. There was no apparent difference in the operation of the switch at the different voltages with the exception that the switch was not properly designed to guard against arcing over the outside at 15,000 volts. This trouble was eliminated by immersing the switch in oil. When so immersed the switch was operated many times as a single-pole switch to interrupt 100 amperes at 15,000 volts. Every operation was successful.

The terminals of this switch, however, were very

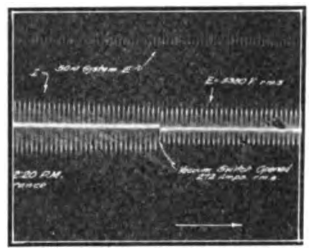

FIG. 3—VACUUM SWITCH INTERRUPTING 272 AMPERES AT 5380 VOLTS

small and therefore a second switch having terminals with more contact surface and leads of greater carrying capacity was built. Fig. 2 shows switch No. 2. This switch was constructed in the same manner as switch No. 1, but is larger and has better contacts, the bridge being made of spring-copper laminations. When the switch is closed, the edges of the laminations are held

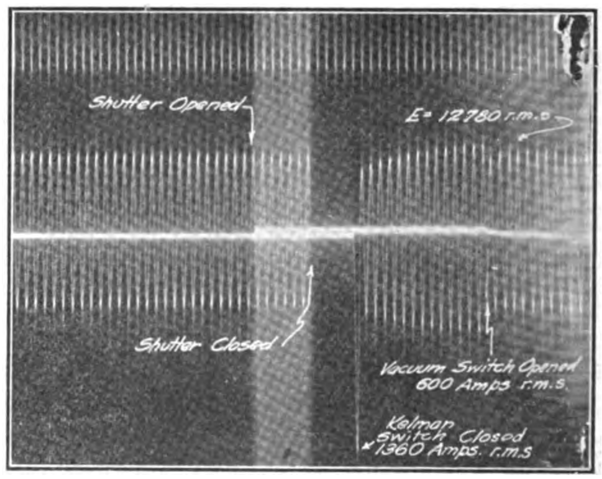

FIG. 4—VACUUM SWITCH INTERRUPTING 600 AMPERES AT 12,780 VOLTS

against the fixed contacts by the weight of the bridge and its lifting solenoid, the total weight being two pounds. The contact area of each fixed terminal is 3/4 sq. in., the distance between the fixed terminals being one inch. In interrupting circuit the bridge is raised one inch.

This switch was given laboratory tests on a 15,000-volt, single-phase circuit providing currents up to 120

amperes at this voltage. The switch was operated as a single-pole switch to open and close this circuit more than 500 times without showing any burning of the switch contacts. It was then sealed off from the vacuum pump and allowed to stand in the laboratory for three months, during which time it was tested occasionally to determine its condition. At the end of the three months the switch was taken to the Torrence substation of the Southern California Edison Company and used to open short circuits made on a synchronous

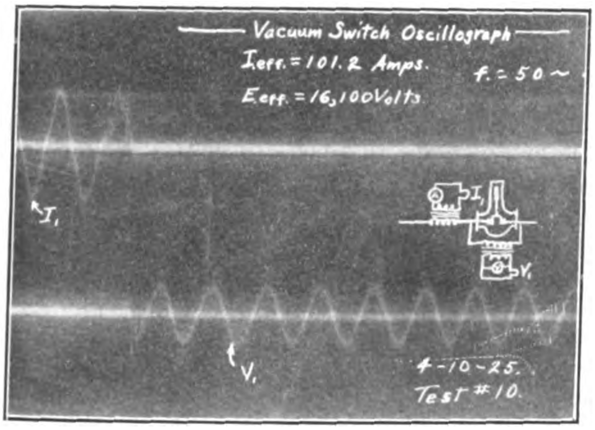

FIG. 5—OSCILLOGRAM SHOWING CURRENT OPENED BY VACUUM SWITCH AND VOLTAGE ACROSS SWITCH AT OPENING

I_{eff} = 101.2 amperes E_{eff} = 16,100 volts f = 50 cycles

condenser just as the condenser was disconnected from the Edison distribution system. The current was supplied to the switch from the condenser through step-up transformers. The switch repeatedly opened the single-phase short circuit thus provided without any failure

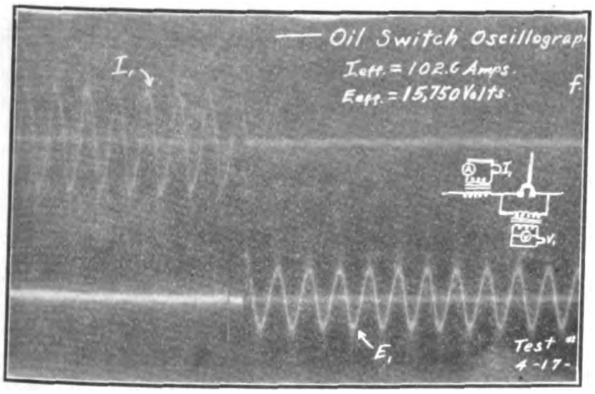

FIG. 6—OSCILLOGRAM SHOWING CURRENT OPENED BY OIL SWITCH AND VOLTAGE ACROSS SWITCH AT OPENING

Note that 12 cycles are between initial contact separation and extinguishing of arc

I_{eff} = 102 amperes E_{eff} = 15,750 volts f = 50 cycles

to interrupt the circuit or any burning of the switch contacts. Figs. 3 and 4 show oscillograms of switch No. 2 opening 272 amperes at 5380 volts and 600 amperes at 12,780 volts, respectively.

Figs. 5 and 6 show oscillographic records of vacuum switch No. 2 and a standard make of oil switch opening the same circuit on a load of 100 amperes at 15,000 volts. The tests were made under conditions as nearly identical as possible, and within a few minutes of each other. It will be noted from these graphs that the rise in voltage when the circuit is opened with the oil switch is greater than when the circuit is opened with the vacuum switch. The oil switch in a large number of tests failed to open the circuit on the first half cycle, while the vacuum switch always opened the circuit on the first half cycle. An examination of a number of oscillograph records for oil switches and for the vacuum switching showed that when the circuit was opened the rise in voltage above normal circuit voltage was higher for the oil switch than for the vacuum switch. The klydonograph[6] was used in some of the switching tests to record any high-frequency surges that might occur.

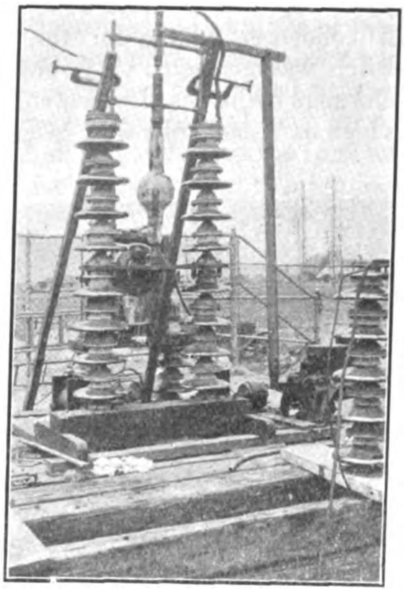

FIG. 7—VACUUM SWITCH NO. 3

In no case did the instrument indicate voltages much above normal.

Following these tests, switch No. 3 shown in Fig. 7 was constructed. The figure shows the switch in the closed position. Switch No. 3 was constructed primarily to overcome the disadvantage, in switches Nos. 1 and 2, of having all moving parts sealed inside the glass envelope of the switch, a condition requiring the operating solenoid to be kept energized when the switch is open, unless a rather intricate locking mechanism also be installed inside the switch to hold it open.

In switch No. 3, the moving contact is of the bayonet type, the bayonet sliding into a cylindrical socket. The bayonet is a 3/4-in. copper rod projecting into the socket when closed so as to give a contact length of one in., the total contact surface obtained in this way being 2.3 sq. in. With this construction, there is only a single break, the contacts opening so as to separate them a distance of one in. when the switch is completely open.

The single break appeared to function as well as the double break used in switches 1 and 2. The switch was operated by a standard switch-operating mechanism borrowed from an oil switch. With such an arrangement, the switch can be left open or closed at will. Vacuum-tight joints for the lead-in conductors of this switch were made by cementing to the glass envelope metal caps attached to the leads and forming a part of the leads.

After some preliminary testing in the laboratory, this switch was taken to the Laguna-Bell substation of the Southern California Edison Company and used as a single-pole switch to open single-phase short circuits on a 30,000-kv-a., synchronous condenser. In performing the tests, the synchronous condenser was brought up to speed on the distribution system of the Edison Company, disconnected from the system and immediately short-circuited through the switch. The condenser used was a 6600-volt, three-phase, Westinghouse condenser which, for the purpose of testing the switch, was connected to the switch through step-up transformers by means of which voltages across the switch as high as 41,500 volts were reached. Fig. 8 shows an oscillogram for this switch interrupting 926 amperes at 41,500 volts.

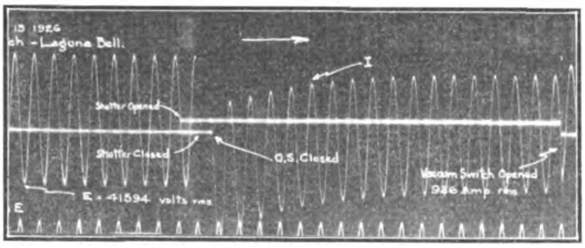

FIG. 8—VACUUM SWITCH OPENING 926 AMPERES AT 41,594 VOLTS

A noticeable feature of the vacuum-switch tests is that every oscillographic record shows that the arc produced at the opening of the switch is extinguished at the end of the first half cycle after the separation of the contacts. Only the very best oil-switch operations give this result.

The absence of any pitting of switch contacts and the fact that the vacuum is not reduced appreciably when the switch is in operation is evidence that very little of the energy dissipated when the switch is opened is used in vaporizing metal from the contacts.

When the contacts separate, there is a visible arc, just as when a switch is opened in air or oil. The magnitude of this arc, however, is much less than that of an arc made by like values of voltage and current in air or oil. This is to be expected because there is nothing in a vacuum switch to burn or to support combustion, as is the case when a switch is opened in oil or air.

The action of the arc in vacuum also indicates a doubt as to the soundness of the theory that an arc to be maintained must be supported by thermions emanating from hot spots on the electrodes between which the arc is formed. J. Slepian[7] has shown that an arc is probably formed near the surface of metal electrodes by very high temperatures caused by the concentration of electric current in the gas immediately surrounding the electrodes. The experiments at California Institute of Technology show that the vacuum switch, when opened, fails to interrupt an electric circuit if the metal forming the contacts has not been freed of the adsorbed gases; that is, gases adhering to the surface of the metal.

The results of these experiments cannot be taken as conclusive evidence that a new type of electric switch has been developed, because the limits of performance have not been determined and there are many problems relating to details that must be solved to make the switch practical. The switch, however, was never the limiting factor in any of the tests made. There is, therefore, certainly sufficient encouragement to warrant further investigation of the subject for the purpose of determining the fundamentals of switching phenomena, if for no other reason. Also, we have the encouraging fact that many practical devices in use today presented, in the early stages of their development, obstacles which appeared greater than those which these tests indicate.

The authors of this paper are indebted to those already mentioned as having a part in the program, and in addition, to graduate students in the Department of Electrical Engineering, J. J. DeVoe, J. H. Hamilton, and F. C. Lindvall, for assisting in laboratory and field tests; to Julius Pearson and William Clancy for their skill in doing the machine work and glass blowing; and also to the many members of the Southern California Edison Company who made provision for having switches Nos. 2 and 3 tested on the Edison system and helped in making the tests.

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Transmission and Distribution

Annual Report Committee on Power Transmission and Distribution*

PERCY H. THOMAS, Chairman

To the Board of Directors:

Introductory

The present report of the Committee on Power Transmission and Distribution has been prepared through the cooperative efforts of the members of the Committee and does not represent the views of any particular member or group of members. Each of the several topics found below has been considered by those particular committee members who are the best qualified to discuss that subject and the subject matter herein is substantially that prepared by such members.

The purpose of the report is to cover the present state of the art of Power Transmission and Distribution, or the progress during the year, in such a way as to present a clear view of what has been accomplished, this being intended for the consideration not only of transmission and distribution engineers but of other members of the Institute interested in different branches of the electric power field.

Where appropriate, at the end of each section there is added for purposes of discussion a series of topics covering subject matter now being investigated or subject to controversy.

Transmission Line Structures

The trend of the year in transmission structures is a continuation of the study to move large blocks of power over considerable distances. Attention has been given to the design of lighter, cheaper, and simpler structures by careful utilization of materials and by great attention to prevention of corrosion or other forms of rapid depreciation.

A number of new construction methods and ideas have arisen during the year for 220-kv. lines. In eastern Pennsylvania a single-circuit, 220-kv. tower line has just been completed, designed for a general condition of one-in. radial ice, with exposed sections at higher elevations designed for a loading of one and one-half in. radial ice. To limit the stress that can be thrown upon the tower by unbalanced conductor pull due to unequal loading or a broken conductor, a clamp has been designed to slip at a moderate value. By this means it is possible to secure economies in the weight of tower steel and a decrease in the strain on and consequently the cost of foundations and still assure the safety of the structure.

The same line has brought forward a new structure for heavy angles and dead-ends. To avoid the heavy expense of the tower and footings of the conventional self-supporting structure, use has been made of a guyed mast. This structure is pivoted at the bottom and guyed at the top so that all load upon the tower is vertical and all side pull from the conductors is carried to suitable anchorage through tension members.

In connection with this job a new splice for the steel reinforced aluminum conductor has been developed. This splice combines the advantages of small diameter, ease of make up in the field, and high efficiency. The usual twisted sleeve for the joining of the steel cores has been replaced by a soft iron compression sleeve. A single piece aluminum sleeve is then compressed over the iron sleeve and the aluminum strands.

In California an extension to the Pit River—Vaca Dixon, 220-kv. lines has brought out novel construction for the crossing of the Sacramento and San Joaquin Rivers and the interlying lowlands. The crossing has an overall length of approximately 24,000 ft. and is accomplished by the use of twelve suspension structures and four anchor towers. The special suspension towers (the conductor resting in a saddle supported by suspension insulator strings) vary in height from 200 ft. to 460 ft., while the anchor towers and three suspension towers on the island are standard structures. The two river crossing spans are respectively 4135 and 3175 ft., but the adjacent structures bring the total distance between anchor towers for these sections to 8000 and 8500 ft. Insulation and clearance to towers for the crossing sections have been materially increased above the general transmission design values to reduce hazard of electrical trouble at these points. The entire project is particularly novel because of the difficulties of obtaining suitable footings and because of the extreme height of the crossing towers.

In the Philadelphia region there has been a novel development in double-circuit tower design for operation at 132 kv. Throughout this line the horizontal

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W. A. Del Mar,		R. J. C. Wood.

Presented at the Annual Convention of the A. I. E. E. at White Sulphur Springs, June 21-25, 1926.

offset of the middle conductor has been toward the center line of the tower rather than outward, as is customary. In other words, the top and bottom crossarms are longer than the middle one. This was done to provide greater clearance, the minimum for the top conductor being six in. greater than for the other two conductors, and the effect of the batter of the tower in reducing clearance for the bottom conductor being avoided. This line has been designed with special care to maintain clearance to tower equal to the length of the insulator string even under a condition of 30-deg. side swing.

This matter of conductor spacing and clearance to tower members deserves special consideration at this time. Clearance and spacings for the vertical configurations now in common use for double-circuit towers have become somewhat standardized, but for the new types of towers using horizontal configuration a new problem arises. If the double-circuit tower with horizontal arrangement of conductors, such as is now in operation in New England, comes into general use, it would be handicapped should unnecessarily large spacing be adopted at the beginning. We have experience on steel-tower, long-span construction with horizontal configuration at 220 kv., 165 kv., and 150 kv., and at lower voltages with wood pole construction. It seems desirable to give attention to this matter of horizontal spacing for long-span, moderate voltage, double-circuit lines and to determine the relationship of length of span and operating voltage to width of spacing necessary for reliable transmission.

Distribution

A-C. Low Voltage Networks. The subject of a-c., low-voltage networks, particularly as applied to underground distribution in heavily loaded areas, has received fully as much attention during the current year as any other distribution problem. A number of installations have already been made and a number are being contemplated. The main features of the problem relate particularly to (a) the method of protection against failure of the transformers and primary feeders supplying the network, in order to insure proper continuity of service, and (b) the most selective isolation of any portion of the system which has developed fault.

During the year there have been developed new types of network protectors consisting of low voltage circuit-breakers with relay and automatic reclosing features, and also submersion-proof, automatic oil-circuit breakers for primary voltages up to 15,000 volts. These two types of equipment are used respectively with two general methods of supply for a-c. networks:

1. Interlaced radial primary feeders with secondary network breakers and reverse power protection.

2. Loop primary feeders sectionalized by circuit-breakers and balanced pilot wire protection.

Secondary Distribution Systems and Voltages. Secondary a-c. systems and voltages have received extended attention. This has arisen primarily from network situations and the desire to establish combined lighting and power secondaries.

Owing to the square root of three relation which exists between phase, voltage and normal neutral of a three-phase system, it is necessary either to sacrifice an entirely balanced loaded system, or else to deviate from either or both of the lighting or polyphase motor voltage standards, as the ratio between these voltages is two to one. This has resulted in some engineers advocating the modification of the present standard motor voltages, the development of special distribution equipment such as translators, etc.

Often the problems of secondary distribution are greatly influenced by local conditions, principally by the type of system already in existence, when the inherent economies of the different systems do not differ widely. Also the costs of changeover may outweigh the potential savings.

System Grounding Practise. There has been considerable discussion with reference to grounding practise on distribution systems, particularly on the 4000-volt, three-phase, grounded neutral primary systems with a common neutral for both the primary and secondary, and having distributed grounds. This type of system, which it is claimed offers very considerable economies and decreased operating hazards, is receiving increased attention on the part of central station engineers and has been the subject of papers before the Institute during the past year.

High-Voltage Distribution. Using the term "high voltage" with reference to primary distribution voltages above the 4000- to 4800-volt class, the past year has seen more extensive use of the higher voltages and the improvement of methods of construction and protective devices for minimizing costs and operating hazards. There is an increased tendency toward the utilization of voltages of the magnitude of 13,200 volts, which often are the generated voltages, and even higher, for the supply of power for general distribution instead of only for large power consumers. The simplicity and economy of this method in territory having sufficiently great density of load are apparent from the saving in sub-station investment, the avoidance of one transformation, less complication, and decreased primary distribution copper, as compared with the lower voltages. The problems of voltage regulation, insurance to service, and decreased operating hazards have been given such study that very favorable results have been reported.

Street Lighting Distribution. The advantages of supplying the street lighting system from the general distribution system instead of from specialized equipment located in sub-stations have become increasingly apparent. The past year has witnessed a greater application of decentralized supply for street lighting. The choice between multiple lighting with individual or group supply from secondary mains, and series circuits supplied from pole or subway type constant-

current transformers depends very largely upon local conditions such as the availability of lighting mains over the entire territory. The development of reliable outdoor control equipment for both multiple and series systems has made substantial progress.

Power Factor. Power factor conditions on distribution systems have received increased attention. This has led to the development of motors for industrial service which operate at higher power factors. Increased attention has also been given to the possibility of power factor correction by means of synchronous or static condensers. The use of these latter devices in smaller sizes than heretofore considered feasible is now being advocated in many instances. There is a general tendency to raise the power factor on the individual distribution feeder as resulting benefits will be broader than with correction at sub-stations.

Single- Vs. Multiple-Conductor Cable. Particular attention has been directed toward the possibility of using single rather than multiple-conductor cable for distribution purposes. Where local conditions warrant, the single-conductor cable has many advantages, among which may be noted its superiority as regards connection to apparatus, localization of faults, and possibility of replacement of only a single phase of the circuit rather than the entire circuit. These points are particularly true in regard to distributing mains, secondary mains, and services.

For primary feeders the tendency is still to favor the multiple-conductor cable, although in several instances, depending upon local conditions, it is probable that some saving in yearly operating costs could be made by using single-conductor.

Continuity of Service. Continuity of service to customers has been improved by improved methods in fusing of distribution transformers and by the greater utilization of automatic reclosing feeder circuit breakers.

As distinguished from the earlier practise of fusing transformers mainly to protect them against overloads, the practise now tends toward higher fusing, to clear the transformers only in case of short circuits and for the protection of the primary circuit. With proper coordination with the relaying of the feeder breakers in the sub-station, there is increased assurance that failure of a transformer will not trip the entire circuit and, with radial secondary mains, only the customers supplied from the faulty transformer are interrupted.

Continued experience with automatic reclosing equipment on sub-station feeder circuit breakers has shown that the continuity of service to customers is greatly improved owing to the interruptions being usually momentary in the event of trouble on the circuit such as tree contacts, momentary heavy overloads, short circuits, etc.

Group Feeder Voltage Regulation. The past year has shown a tendency to make use of group, rather than individual, regulation for distribution feeders. This results in a simplification of the apparatus necessary in the sub-station and accordingly affords some economies. Group regulation is made possible for those feeders having approximately the same per cent drop from the sub-station to the load center and which carry approximately the same magnitude and type of load, such as in an a-c. network.

Interconnection of Power Utilities

The practise of interconnecting adjacent utilities and of the transfer or exchange of power continues. This practise differs fundamentally from the interchange of power between power plants in a given system in that, in place of the unitary operation and one-man control of the single system, interconnection usually involves independent operation and independent control of the separate utilities. The result of actual operation indicates that unless attention is paid to the synchronizing characteristics of the interconnections and sufficiently close cooperation is secured in operation, each company must be prepared, at least on occasion, to care for its own load, since at times of disturbance it sometimes happens that synchronism between the utilities is lost and the systems separated. This difficulty is especially to be feared in territory subject to disturbance from lightning.

While the benefits of continuity of operation may of course be obtained with interconnected utilities by the same technical methods used in the operation of single large systems, namely, by one-man control and the proper design of governor and other apparatus and connecting lines, such coordination has not so far been undertaken on any large scale.

One of the most notable and extensive interconnections exists in the southeastern states and recent experience in this district is important. There has existed for several years a connection at 110,000 volts between the Alabama Power Company system and the Georgia Railway & Power Company system, the connection being between Gadsden, Alabama and Lindale, Ga. In the late fall of 1924 interconnection was completed at 110,000 volts between the North Auburn Sub-station of the Alabama Power Company and the Columbus Electric and Power Company's sub-station at West Point, Ga. An interconnection at 110,000 volts was also completed in 1925 between Columbus Electric & Power Company's Bartlett's Ferry plant and the Central Georgia Power Company at Macon, Ga. During the dry season of 1925, these interconnections were used to the limit of their capacity in order to transmit power from the steam plants in Alabama to supply the deficiency of the three above mentioned companies in Georgia and also to Augusta, Ga., to which point the Georgia Railway & Power Company extended one of their 110,000-volt circuits.

In 1925 no particularly new problems in operation came up and it was found feasible to interchange blocks of power as large as 40,000 kw. over tie lines which were originally constructed for capacity of 25,000 kw

The principal features to be worked out in connection with the interchange of large blocks of power as far as we have seen in the south are the maintenance of proper frequency and the absolute necessity of the receiving system taking care of not only the wattless current of their own system, but also part of that for the sending system. The necessity of having synchronous condensers or other regulating equipment in order to maintain satisfactory voltage conditions at the receiving load centers if entirely satisfactory service was to be given was clearly demonstrated. Practically none of the interconnected systems in the south have sufficient condenser capacity for conditions such as existed during the drought of 1925. It was frequently necessary to operate large hydro generators as condensers in order to take care of wattless current and voltage regulation. Not being primarily designed for such work, these generators, of course, are not as satisfactory as synchronous condensers.

It was demonstrated that many of the apparently difficult problems of coordination and of technical details as to handling of an individual company's load in a group of interconnected but independently operated systems largely disappeared when it became a question of subordinating these things to the necessity of obtaining power to take care of one's customers. The dry season of 1925 further showed the possibility of steam plants taking care of a serious shortage of hydro power. Power was actually relayed a distance of approximately 500 mi. at 110,000 volts. It was found necessary in some cases to revise relay set-ups of the interconnected companies from their normal set-up in order to take advantage of the maximum interchange. Necessity made many things possible which would not have been done under normal operating conditions. An Operating Committee has been functioning among the power companies of the southeast for some two years, exchanging data on load and generating conditions. This committee worked exceedingly well coordinating to make the maximum use of the power available. Through this committee, load dispatchers gained a better perspective of the interconnected systems, and while each system was operated independently, they were so coordinated that there was no difficulty in making the maximum use of the transmission lines and generating plants.

Speaking generally, it is felt to be proved with reasonable satisfaction that the interconnection of independent systems has been of material benefit in reducing the period of outage due to serious trouble on any one system. Without absolutely unified control of the operation, it is somewhat questionable just how far the interconnection of systems has operated to prevent momentary outages. Unquestionably, it has reduced the duration of outages, however. During the progress of interconnection, from experience in the southeast, the following seem to be the most important items to be considered:

1. A more careful investigation of relay protective equipment of each individual system and their coordination with other systems so that the maximum benefit of interconnection may be made use of.
2. The installation of more synchronous condenser capacity at most centers to take care of wattless current and for voltage regulation.
3. A more thorough understanding on the part of load dispatchers and operating superintendents of each other's system requirements so that shortages may be foreseen as far in advance as possible.
4. A careful study of the value of booster transformers at the point of interconnection between systems, these transformers to be equipped with tap circuits so that the voltage may be changed as required to supply current in either direction without disturbing the balance of either of the two interconnected systems.

The following additional topics for discussion are of general importance:

5. What is the most feasible method of interconnecting large systems, whether under one-man control or not, so that continuity of supply may be assured to all from a base load plant?
6. How should the interchange of power between particular systems and the power factor at various points be controlled where three or more independently operated systems are mutually interconnected by several links?

Underground Cables

The outstanding advance in the field of underground transmission during the past year has been the development of a radically new type of single-conductor cable for operation at 132 kv., three-phase. The New York Edison-United Companies and the Commonwealth Edison Company have placed orders for such cable for lines about 10 and 6 mi. long, respectively, for installation this year. The carrying capacity will be about 90,000 kv-a. per circuit.

The cable will have a 600,000-cir. mil. hollow conductor insulated with 23/32 in. of impregnated-paper insulation. This thickness is less than has been used on single-conductor cables recently installed on 66- and 75-kv., three-phase circuits in this country. The overall diameter will be about 3.1 in. The cable will be impregnated with a thin oil which will be under pressure during operation, in order to minimize the possibility of the formation of voids in the insulation.

The lengths will be connected so that the hollow space will be continuous through the ordinary joints. The line will be divided into sections about one mi. long, each section ending in barrier joints, wherein the copper conductors will be connected, but the central hollow spaces of adjacent sections will be blocked from each other. Elevated reservoirs will be connected by pipe lines which connect through the barrier joints to the hollow space in the conductor and thereby maintain a hydrostatic pressure on the oil. When the cable be-

comes warm during operation, oil will flow from it into the reservoir and vice versa.

An unusual feature of this cable is the large charging current which amounts to about 2400 kv-a. three-phase per mi. of line at a leading power factor of about one per cent.

Several manufacturers are developing other types of 132-kv. cable and making length for short experimental installations.

There has been an increasing interest in three-conductor cable which has a metallic covering over the insulation of each conductor and no belt insulation. A number of commercial installations are at present being made in this country at 27 and 33 kv.; and it is reported that several installations of similar type cable have been made in Europe at various voltages including higher voltages.

The data accumulated by the Electrical Testing Laboratories on their inspection and tests of several million feet of high-tension cable as reported by F. M. Farmer at the Madison meeting, A. I. E. E., May 6th and 7th, show a marked improvement in the quality of the cable made during the last few years. This is shown by the increase in the dielectric strength and reduction of damage to insulation due to bending test. The improvements in quality shown by such test data, combined with operating experience, has led to considerable reductions in the insulation thickness used by some operating companies, and the use of higher voltages for given thicknesses of insulation.

Several American manufacturers are now using wood pulp paper for a portion or all of the insulation in the cable. In some cases the paper is entirely wood pulp, while in other cases the paper is a combination of wood pulp and manila hemp stock. Some manufacturers report that this paper will lead to improved dielectric strength and decreased cost.

It has been learned that one of the principal causes of the failures in high-voltage cable was the use of impregnating compounds that were unstable under the dielectric stresses and temperatures of normal operation. Some of the manufacturers and the Electrical Testing Laboratories have developed tests which will aid in the selection of compounds free from this difficulty.

Some questions now under discussion are as follows:

1. The use of wood-pulp paper insulation instead of paper made from manila hemp rope fiber.
2. The use of three-conductor cable which has a metallic covering over the insulation of each conductor and no belt insulation for voltages above 33 kv.
3. The limiting voltage for three-conductor cables of standard construction.
4. Changes in the test requirements now included in specifications for high tension cables so as to secure more satisfactory operation.
5. Possibilities of increasing the maximum operating voltage of underground cables by changing the type of construction.

Stability and Load Limit in Long Transmission Lines

During the past three years, very considerable progress has been made in the subject of transmission stability and load limit, and it seems appropriate at this time to make a resumé of the present status of this problem.

It is now generally recognized that stability constitutes an important problem in the transmission of power over long distances, or for large amounts per circuit. Furthermore, many of the interruptions to service on existing systems have been due to instability at times of transient disturbances, which situation has been recognized as a result of increased knowledge of system operations during and after an abnormal disturbance condition. The extensive investigations which have been made during the last few years have increased our technical knowledge of the stability problem, so that at the present time, given the necessary basic data and machine performance circuit constants, etc., the performance of any system in regard to load limit or static or transient limits can be predicted with a sufficient degree of accuracy for the present purposes. It is believed that the various groups which have been working on the problem would give substantially the same results for identical assumptions as to the layout of the power system, and as to the rate of variation of prime mover governors, kind of voltage regulators, duration of disturbance, etc. The way in which the stability problem affects the design of layout is understood from the technical side, and a number of schemes have been proposed for increasing the stability of systems.

In the actual operation of power systems, the way in which stability studies will manifest themselves is by reducing the number or duration of interruptions to service or by permitting the increased amount of power to be handled without reducing the standard of service. At the present time, the principal problem is not one of determining how the system will act for a definite set of conditions, but to what extent it is desirable to modify the design of systems in order to improve them from this standpoint. In order to do this, it will be necessary to get the cooperation of the operating companies so as to interpret on an economic basis the costs of interruptions to service. When this has been done, it will be a relatively simple matter to determine the additional expense in remedial measures for improving stability which should be employed in any particular case.

The practical value of means to increase the stability or load limit of any system may be evaluated on the basis of the amount of additional power that may be delivered over the system based on the conditions that the transient stability or load limit of the system will

be the same for a given fault condition as it would be for the system without the means with the lower quantity of power delivered. The determination of the actual load at which the systems will be run is a matter for the operating engineers themselves to decide, as this involves the income value of the good will obtained by increased reliability of service which is difficult to define and which will vary with different localities and at different times. In connection with the stability problem, there are certain speculative factors which can be evaluated only by the statistical method. Such factors include the value of fault resistance, the average duration and character of various types of disturbance, etc. In this connection, it should be pointed out that the ordinary records obtained on systems are entirely unsuitable for interpreting the stability conditions, because such instruments are not adapted for recording the high frequency electromechanical transients which take place at times of a disturbance. Of particular significance is the move taken by one or two power companies to install specially designed recording apparatus for obtaining adequate records on operating experience from the standpoint of stability. This will logically lead to increased information as to the operation of existing systems, and will utimately result in the obtaining of sufficient statistical data from which one can predict the operation of future systems.

During the past year, much progress has been made in increasing our technical knowledge of the subject of transmission stability and load limit. Probably the most important investigations are those of tests on an actual system. These tests included both switching operations and short circuit tests, and are, described in a paper presented at the Midwinter Convention by Mr. Roy Wilkins. At the Seattle Convention, two papers dealing with the general aspects of the stability problem were presented, one by Messrs. Doherty and Dewey and another by Mr. Fortescue. At the Midwinter Convention, Messrs. Nickle and Lawton presented the results of recent laboratory and shop tests on stability. Miss Clarke presented a method for the determination of static stability limits. Mr. Wilkins presented the paper describing the stability tests on the system of the Pacific Gas & Electric Company. Messrs. Evans and Wagner presented a method for the determination of static stability limits and gave the results of calculations by this method with comparisons of the test results obtained on the P. G. & E. Company system.

Certain power limits have been defined in these papers and it is recognized now that with absolutely fixed excitation for both sending and receiving systems there is a definite power limit under steady load conditions. This power limit depends in this case upon the synchronous impedance of the machines at the sending and receiving ends. If we take the value of excitation which gives the desired terminal voltage at the power limit we have the static stability or load limit with "fixed excitation" or what is termed hand regulation. It is also recognized that the load limit under transient conditions may be lower. It is not determined by the synchronous reactance solely, but is affected also by what is known as the transient reactance, and the "leakage reactance" of a machine in varying degrees depending upon conditions. It may be stated perhaps more consistently, however, that this action depends upon the actual field being maintained essentially constant for a short period due to internal currents induced in the damper and field windings. In the case of machines operated with automatic voltage regulators there is a theoretical possibility of further extending the limits of stable operation over those obtainable with hand operation. Full agreement on this point has not been reached. One group reports that considerable increase in the limits has been obtained experimentally and the other group reports inability to secure any increase in the limit over that obtained with "fixed excitation."

In view of the fact that the operation of power systems at times of transient disturbances is a relatively complicated phenomenon, it is quite natural that the extensive discussions which have taken place on this subject should have tended to emphasize the relatively minor points on which full agreement has not been secured, and has tended to obscure the major points which have been established. It has, therefore, seemed desirable to present at this time a statement of those underlying principles requisite for good stability conditions. They are as follows:

1. Low series reactance.
2. The supply of reactive kv-a. as close as practicable to the point at which the demand originates.
3. The maintenance of internal voltages in machines by special excitation schemes, or by the use of special machine characteristics.
4. Such a layout of the system as to reduce to a minimum the effect on stability of any abnormal condition. For example, the avoidance of a concentration of power in any particular piece of equipment such that a single fault could render a large part of the system ineffective.
5. The rapid and selective isolation of faults.

In line with the policy which has been laid down for the Annual Convention of presenting committee reports and inviting discussions, the following topics are suggested as worthy of further study and suitable for discussion at the Annual Convention:

1. Further investigations of the stability problem require a more exact knowledge of the characteristics of machines under transient conditions, including among other factors the effect of damper windings.
2. Further work will be required in connection with schemes of excitation designed for the purpose of maintaining internal voltages in machines constant during transient conditions.

3. Special designs of machines such as compensated machines will be subjects for further discussion and study.

4. A number of measures for increasing stability have been investigated, but are of such great importance that actual operation experience will be required before their true value in improving stability can definitely be ascertained. In this category is included the intermediate condenser station, the special governor control, and the compensated machine.

5. A somewhat different line of discussion would be advantageous to bring out the relation between the probability of outages and system loads.

6. Also the determination of the safe operating angle between internal voltages of synchronous machines, or the relation of this angle to the probability of outage.

Insulators

During the year there have been no outstanding changes in the design of line insulators either of the pin or suspension types, though the art appears to be developing slowly but surely toward increased reliability in service. This improvement is largely in the mechanical sense and relates principally to suspension insulators. On the electrical side, there is a gradual crystallization of ideas on the means of safeguarding high-voltage, insulator strings from flashover.

Mechanical. Owing to the relatively severe requirements of heavy high-voltage lines, it has been necessary for both manufacturers and prospective users to make extensive tests on the behavior of insulator units, particularly under long sustained mechanical loads. As a result, there are already in use insulator units of so-called high strength type which are capable of supporting for short periods loads of the order of 25,000 lb. Units of this type, when subjected to a continuously applied load, will sustain 16,000 to 17,000 lb. for periods of a year or more without undue failures. Types of still higher duty have also been developed, and it is possible to purchase units having a combined electrical and mechanical strength of approximately 45,000 lb. Results of these studies are also reflected in a marked increase in strength of some of the standard 10-in. units.

Although such tests have been able to furnish much information upon the ultimate strength of insulators under various loading conditions, but little is known of the factor of safety that should be employed. It has been customary to assume a maximum safe working load of 3000 lb. on the ordinary 10-in. suspension unit of 11,000 lb. ultimate strength. A disposition to use somewhat higher loadings has now become evident. Likewise, in the case of the above described high-strength units capable of indefinitely withstanding test loads as high as 16,000 lb., the assumed maximum safe loads in service have been fixed by some companies at 6000 to 8000 lb. The question naturally arises as to whether it might not be safe to use much higher assumed maximum loadings.

The design of pin-type insulators is tending toward the use of fewer insulator shells for a given voltage and this practise leads to an important saving in cost without lowering the dry flashover value and without appreciable sacrifice in reliability. The latter is made possible because of perfected methods in manufacture leading to a uniformity of product not heretofore attainable.

The subject of porosity has practically ceased to be an important factor in insulators manufactured by any of the older and well established companies.

One manufacturer in this country is engaged upon the problem of commercially producing Pyrex insulators. Apparently much developmental work yet remains to be done, but the material has considerable promise, particularly because of its high immunity against shattering when exposed to heavy arcs.

Foreign development in insulators is different from American practise, in that much effort has been devoted to avoiding the use of cement in assembling. The German manufacturers have been particularly active in this direction and have produced various cementless types, of which the "Kugelkopf" and "Motor" are typical. The latter insulator consists of a heavy cylindrical section of porcelain carrying a porcelain skirt at one end and either a porcelain skirt or a metal shield at the other end. Mechanical loads are supported by means of a metal cap attached at each end of the cylindrical section by means of a lead alloy. In pin-type insulators, foreign practise has adhered largely to the use of hemp in binding the shells together and for attaching pins.

Electrical. For extra high voltage lines, much work has been done during the past year in connection with the grading and shielding of insulator strings. The results indicate that it is entirely feasible to safeguard insulator strings for operating voltages up to 220 kv., but entire agreement has not yet been reached as to the most satisfactory method to apply. Discussion turns upon whether such protection should take the form of arcing horns, rings or shields which also provide a reasonable degree of potential grading, or whether the protection should consist of insulated horns, which arrangement has been designated as "flux control." Generally speaking, these two methods are predicated upon opposing theories as to the origin of certain types of flashover. This is a subject upon which it is expected operating data will be rapidly collected.

General. Pillar insulator designs have been changed but little during the past year, but a pressing demand exists for insulators of this type having greater mechanical strength both in the low-voltage and high-voltage ranges. It is possible to obtain certain types of pillar insulators of considerable strength which are suitable for heavy duty at the low voltages, but these are quite expensive.

During the year some of the highest voltage catenary insulators yet designed have been installed.

Closely related to the subject of insulators is the development during the past two or three years of large coupling condensers for carrier current work on high-tension transmission lines. These condensers, while experimental at first, have later demonstrated a reliability in keeping with insulator bushings and other similar high-voltage equipment.

Inductive Coordination of Power and Communication Circuits

During the past year the work of the Joint General Committee of the N. E. L. A. and the Bell Telephone System has been continued and progress has been made by the Joint Subcommittee on Development and Research in its studies of a number of specific problems, among which may be mentioned coordination of transpositions in power and telephone circuits, induction under conditions of jointly used poles including the effects of unbalances in local telephone circuits and power distribution circuits, the origin and regulation of harmonies in power circuits, survey, composition, and effects of noise in telephone circuits, residual voltages and currents of power systems, induction in carrier communication channels, and energy level of telephone circuits. The studies of many of these subjects have been facilitated by the development of improved measuring apparatus and methods, particularly in connection with the wave analysis of power circuit voltages and currents and induced voltages and currents in telephone circuits, and also in connection with the measurement of carrier frequency currents on working power lines.

The organization of the American Committee on Inductive Coordination has been completed and the committee has issued a preliminary report.

Two papers dealing with the subject of inductive relations between power distribution circuits and telephone circuits were presented at the Seattle Convention in September as part of a symposium on power distribution.

Rural Distribution

Interest in the satisfactory and economic supply of energy to the farmer has increased considerably in the past year. Rural supply has undoubtedly been most highly developed on the Pacific Coast, yet the year has seen a greater study given the subject both in the middle west and in the east. Twenty states have set up organized analyses of the situation and experimental projects are now under way.

The small number of customers per mile (averaging perhaps two to three) makes necessary a cheap type of construction which must, however, be sufficiently rugged to demand little maintenance and assure fair service. Three-phase, four-wire main feeders with single-phase and neutral legs to outlying farms seem to be a reasonable answer to the problem, and have come into use in the middle west. On these single branches galvanized iron wire is used in some sections of the country for obvious economies, the neutral is stapled directly to the pole top, and the phase wire is carried on a bracket with suitable insulator. These extensions are connected to the main feeders through expulsion fuses. While this represents the cheapest type of construction, there are many cases where it is adequate.

Transformers suitable for farm work have been on the market for some time but even this new apparatus has been expensive. Some transformer makers have now come forward with good designs for this service and there are now available transformers that are in line with the general economies needed to make a rural line a paying proposition.

There has been given considerable thought to the development of portable equipment for transient needs and many new ideas have been evolved to render this service. Portable transformer, metering, and motor apparatus is generally available to furnish power to the farmer for wood cutting, threshing, and the like. This equipment is now generally furnished by the power company and a service man usually supervises its use, the general trend being away from the ownership of such apparatus by cooperative groups.

Foreign Practise

The Committee has secured this year one paper on foreign practise on power transmission and distribution, this paper being presented at the Niagara Falls Regional Meeting. More variety of design and much less uniformity of construction is noticeable in this country than abroad.

One of the most notable events of the year abroad is perhaps the Wier Report, recommending the adoption of a universal electric power distribution system serving all England and southern Scotland, with some exceptions as regards the city of London. It is proposed in this report that all the power for use by the system shall be generated in some 50 to 60 power houses, this constituting about 10 per cent of the present number of power houses. It is proposed that the National Government own the transmission lines and buy and sell the power at a price based essentially on cost allowing a fixed return on capital,—6½ per cent plus depreciation on money now invested. The distribution systems and the power generating plants, although subject to close government control, would be privately owned. The most important of the generating plants are proposed as mine mouth plants.

It is reported that a bill has passed the second reading in the House of Commons which is intended to carry out some such scheme although departing somewhat from the recommendations of the Wier Report.

Conclusion. In general it may be said that steady progress is being made in many directions in the field of power transmission and distribution and that a continuous expansion in the number and capacity of transmission systems may be expected.

The Vincent 220-Kv. Transmission Line

Engineering and Construction Features

BY C. B. CARLSON[1] and H. MICHENER[1]

Non-member — Associate, A. I. E. E.

Synopsis.—*This paper deals with the design and construction of the third 220,000-volt line between Los Angeles and Big Creek, giving the results and brief descriptions of the research engineering investigations which were carried out in connection with the design.*

The salient features of the line are:

Terminals—Big Creek No. 3 and Gould Switching Station, near Los Angeles.

Length—223.5 mi.

Route—Direct route with few angles.

Dead-ends—Dead-ends only at station terminals and heavy angles.

Small angles—Small angles up to 11 deg. 40 min., in some cases, turned on suspension insulators.

Conductors—Steel reinforced aluminum. 1,033,500 cir. mils aluminum, 54 strands. 134,000 cir. mils steel, 7 strands. Weight: 1.33 lb. per ft. Diameter: 1.247 in.

Overhead Ground Wire—None.

Towers—Towers of high elastic limit steel. Height of standard towers, 64 ft. to crossarm. Height of anchor tower, 56 ft. to crossarm. Weight of standard tower, 8890 lb. Weight of anchor tower, 13,600 lb.

Tower Footings—Grillage footings in earth. For standard towers, 4 ft. 8 in. sq. at base and 8 ft. deep. Weight, 2040 lb. For anchor towers, 7 ft. 6 in. sq. at base and 9 ft. deep. Weight, 6720 lb.

Tower Extensions—Height 7, 14, or 21 ft. Any of these heights may be placed on any or all corners of the tower and in a few special cases in combination with an additional 14-ft. extension on all corners.

Insulators—10-in. cap and pin having minimum combined electrical and mechanical strength of not less than 18,000 lb.

Suspension insulator assembly: Single string of 13 units where maximum stress in string will not exceed 6000 lb. Double string 13 units in length where maximum load will exceed 6000 lb.

Dead-end assembly: Double string, 15 units in length.

Tie-down assembly: Single string of 14 units.

Shield Rings—Hoops of 3-in. by $^3/_{16}$-in. strap iron.

Bird Guards—Pans and saw-tooth guards on all towers.

Increases in the generator capacity at Big Creek, which are scheduled to be completed in 1928, will require more transmission capacity to deliver the power to Los Angeles. For this reason, a third 220,000-volt line is being built between those points.

As indicated in Fig. 1, which shows the general location, the line starts from Gould, crosses the San Gabriel Mountains where it reaches an elevation of 5609 ft., and then crosses the Antelope Valley. Thereafter it passes over the Tehachipi Mountains at an elevation of 5361 ft., beyond which it crosses the southern end of the San Joaquin Valley, and then stays in the foothills along the eastern edge of that valley until it reaches the mountains at Big Creek where it crosses Pine Ridge at an elevation of 4827 ft.

The first fifteen-mile section through the San Gabriel Mountains is the roughest and most inaccessible part of the route. Through this section it was necessary to construct a road to serve the line,—more than two miles of road for every mile of line. But this heavy road expense is less than the right of way expense would have been for a route paralleling the old Big Creek lines. The remainder of the line is very accessible to already existing lines of travel with a few exceptions where short pieces of road are being constructed

The average number of towers per mi. is 3.94. The normal span in level country for standard towers without extensions is 850 ft. in heavy loading districts and 1000 ft. in light loading districts. As a matter of fact, there are very few, if any, normal spans because of the man-made obstructions in the level country, such as roads, power lines, etc. The span lengths for the whole line range from a minimum of 336 ft. to a maximum of 5191 ft. The two longest spans are the same length. It happens that a change from heavy to light loading occurs at one end of one of these spans, so the conductors are dead-ended there. Otherwise these two long spans are supported on double-string suspension insulators.

Location and Survey

The general route of the line was chosen from a study of maps and from a general knowledge of the country. Reconnaissance along this route was carried out by airplane, automobile, horse, or on foot, the choice between the last three means being made according to the terrain. The whole route was flown over at least once and parts of it several times. In two highly developed sections, airplane photographs were taken.

After the reconnaissance work was done, the line was run with transit and chain. It was so located with regard to topography and man-made improvements that a total of four circuits can be placed side by side with 80-ft. center line separation, but a 200-ft. right of way to accommodate two circuits is all that has been obtained. The line actually run on the ground was the center line of the west tower line. In the rough country where there were no control points, a triangulation system was laid out as a check on the line survey.

The profile of this center line was run, using vertical angles and slope distances, and checking on U. S. G. S. and other bench marks of known elevation wherever such were available. Side slopes were taken at the probable tower locations and at all points where the clearance from one of the outside conductors to the ground would be near or less than the allowable minimum.

1. Both of the Southern California Edison Company, Los Angeles, Calif.

Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

With this information on the profile the towers were located by means of a celluloid template. Survey crews took these paper locations into the field and staked out

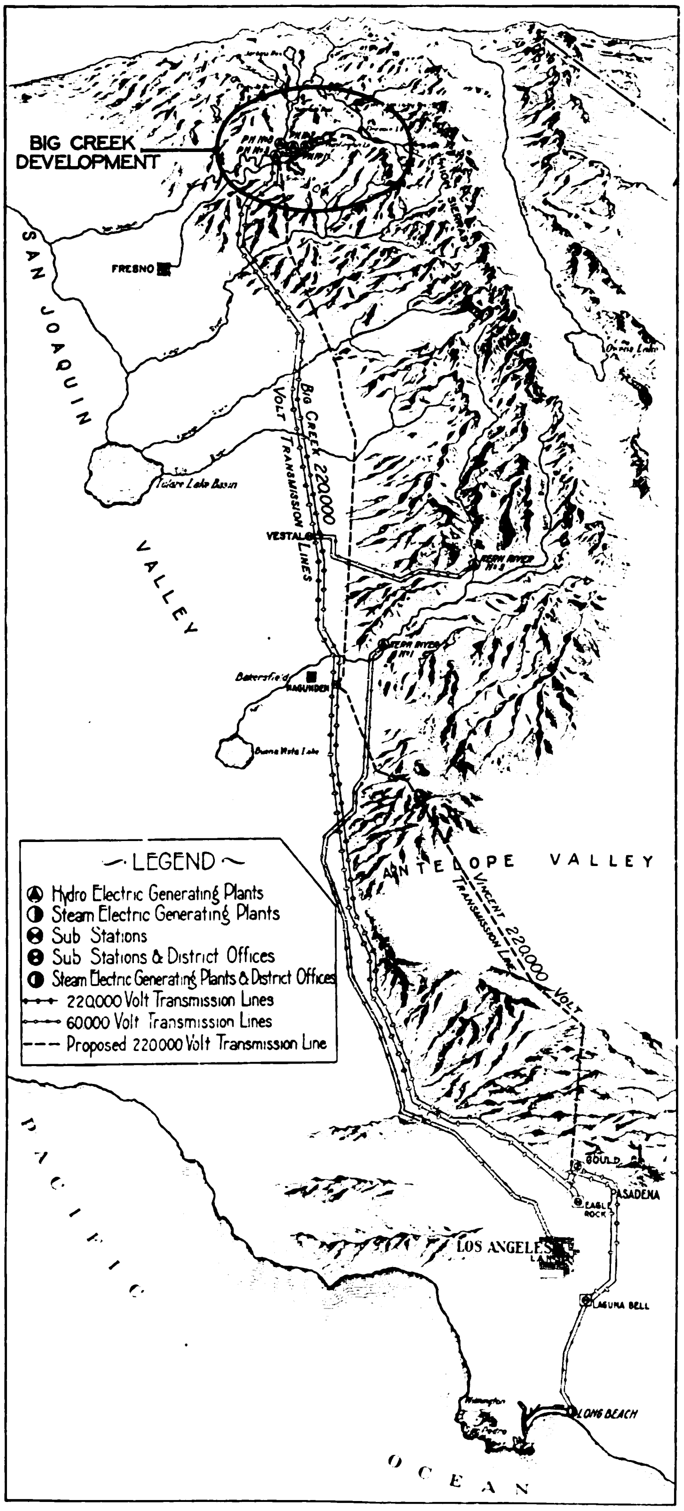

Fig. 1—System Map of Southern California Edison Company

Showing route of 220-kv. Vincent transmission line

the tower footings, moving the towers along the line if this improved the setting of the towers without decreasing the conductor clearances below the allowable amount. In staking the footing locations, the proper elevations of the footings were determined consistent with the use of the various lengths of leg extensions and downward footing extensions. This information was turned into the office where it was checked in regard to the proper footing elevations and the economic balance between cost of extension and cost of excavation. After checking, it was used for making bills of material for tower and footing extensions.

Telephone Line

A four-wire telephone lead supported on pressure-treated, southern pine poles is being built. It is located mostly along the roads near the transmission line. It will serve the Construction Department until the transmission line is completed, and after that it will be used for the routine operation of the line and as an additional communicational facility between Los Angeles and Big Creek.

Loading Assumptions

The line from Gould to the south end of the San Joaquin Valley and for 10 mi. south from Big Creek No. 3 is in so-called heavy loading territory where it is assumed that the most severe loading conditions will be one-half in. radial thickness of ice at zero deg. fahr., with a wind pressure of six lb. per sq. ft. on the projected area of the ice-covering. These sections are generally above 3000-ft. elevation except the 18 mi. across the Antelope Valley, which has an elevation of 2500 to 2700 ft. where the line crosses but which is subject to high winds and low temperature. The remainder of the line is in light loading territory where the maximum loading conditions are assumed to be no ice at 25 deg. fahr. with a wind pressure of eight lb. per sq. ft. on the projected area of the wire.

Conductor

The preliminary mechanical and electrical studies to determine the most economical conductor, tower height, and conductor tension were described by Messrs. Carlson and Shaw at the Pasadena, 1924 Convention.[2] Since that time the design has been completed. Construction of the necessary roads began in August, 1925, and actual line construction began about January 1st, 1926. It is expected to have the 96 mi. between Gould and Magunden in operation by November, 1926, and the whole line in operating condition by the early months of 1928.

The conductors are steel reinforced aluminum cables having 54 aluminum strands and seven steel strands each 0.1385 in. in diameter. The total diameter is 1.247 in. and the cross-sectional area of the aluminum is 1,033,500 cir. mils. This is equivalent in conductivity to 650,000-cir. mil copper. The weight is 1.33 lb. per ft. The approximate ultimate strengths are 20,000 lb.

2. *Transmission at 220 Kv. on the Southern California Edison System*, Sections 3-A and 3-B, *Economic Studies of Transmission Line Design*, C. B. Carlson and W. D. Shaw, A. I. E. E. Journal, Vol. 43, Oct. and Nov., 1924, pp. 907 and 1025.

for the core and 36,000 lb. for the composite cable. This is probably the largest cable ever used as a transmission line conductor.

The line was designed for a maximum conductor tension of 12,000 lb. in both heavy and light loading territory, which gave practically the same unit stress as had existed in the old Big Creek lines for 11 years, but when it came to fitting the wire curve to the profile it was found that strict adherence to the 12,000-lb. maximum would give low clearance from conductor to ground in several spans where the topography made it very diffiult to move the towers to get the required clearance. If the 12,000-lb. maximum could not be exceeded, one or more additional towers would be required in these spans and they would be in very costly locations. A slight increase in maximum tension would give ample clearance in these locations at which it was believed that neither maximum wind nor minimum temperature would occur at any time and surely not simultaneously. For these reasons it was decided to allow the maximum tension in these cases to go as high as 13,500 lb. in the heavy loading district and 12,600 lb. in the light loading district, when calculated on the maximum loading assumptions stated above.

Conductor Splices

The conductor splices are being furnished by the manufacturers of the cable and are of the latest type. The main improvement over the old type is in the method of splicing the steel core. Instead of using a twisted McIntyre joint, the two ends of core to be joined are each inserted from opposite ends half-way into a single-bore, soft steel sleeve, and then the sleeve is compressed onto the core. On test the core breaks approximately at its calculated ultimate strength and does not slip out of the sleeve. The use of this compression sleeve on the core permits the use of a single-piece, aluminum compression sleeve for connecting the aluminum strands instead of the two-piece, screwed-together compression joint used in the past. These improvements make better and cheaper joints than those previously used.

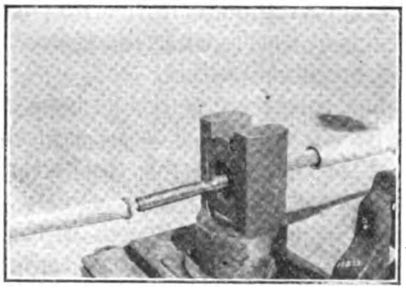

Fig. 2—Conductor Splice Being Made

Steel sleeve on core partially compressed. Aluminum sleeve slipped over cable to the right

The steel sleeve and the then exposed parts of the core are given a coating of hot asphaltic compound and then wrapped with a layer of cambric tape after the compression has been made and before the aluminum sleeve has been slipped into place. This is to prevent the black-iron sleeve from starting a rusting reaction which may be communicated to the steel core and eventually destroy it. The tape is to prevent the compound from being wiped onto the inside of the aluminum sleeve as it is slipped into place. Accelerated tests have led to the belief that such a coating will protect the core from rusting at least for the life of the galvanized steel and aluminum wires elsewhere in the line. Fig. 2 shows these splices being made.

Ground Wire

No overhead ground wire is being installed, but the towers are designed with sufficient strength to carry one ground wire if it should prove desirable to install it later.

Towers

The preliminary economical calculations to which reference was made determined the height of structure necessary as well as the maximum tension which would occur in the cable. The design of tower proper, the extensions, transposition frames, footings, etc., involved types of framing and panel lengths which would prove most economical. Previous experience had shown the desirability of vertical legged extensions rather than continuing along the batter of the main tower.

Panel lengths of eight ft. in the main structure made the height of the tower to the crossarm 64 ft., while the panel length was reduced to seven ft. in the extensions to compensate for the increase in stress caused by change in direction. Extension heights of 7, 14, and 21 ft. were those which seemed to supply the needs of the profile. These extension legs were arranged to permit combinations of any of them on a tower to more economically fit the profile. This latter arrangement has proved useful, as much of the country traversed was very rocky and difficult to excavate.

Special cases required the combination of the 14-ft. and 21-ft. extensions making 35 ft. in all, and in the case of the Tule River Crossing two special 120-ft. towers were used. It was also necessary to supply certain other specialties such as transposition frames, attachments for towers to solid rock, footing extensions where uplift cover resistance was not available, and single leg extensions without bracing to main structure. These were developed to best suit field requirements which were reported in the field notes of the survey parties.

Material for the structures was specified which would have a high elastic limit, permitting the use of higher unit stress value. This value was 22,500 lb. per sq. in. or a factor of safety of two on the elastic limit.

For the light loading district, standard towers were designed to withstand (a) the strain caused by two broken wires having maximum tension (reduced by adding the length of the insulator string to the wire

length), plus (b) a wind pressure of 8 lb. per sq. ft. on the wire surface and on 1½ times the area of one tower face, plus (c) the vertical weight of the wire. In the heavy loading district the wind pressure was reduced to 6 lb. per sq. ft., but ½ in. of ice radially was added to the cable. Weight and surface area were calculated on this basis. All loads were assumed as being simultaneous for maximum conditions, which also included the component of the maximum angle, which was 11 deg. 40 sec., to be turned on suspension towers.

The anchor tower was designed for full breast pull, plus wind on line and tower, plus the component of the largest angle on the line, which was 35 deg. 14 sec. The maximum loads were all assumed to be simultaneous.

The footings were designed to use the 30-deg. cone of earth as resistance against uplift and to use a low unit value for bearing as resistance against settlement. They are of steel, soil conditions generally showing no bad effects toward corrosion. It is planned to coat those footings with bitumastic solution where alkali conditions prevail. The general practise in transmission line design of the use of hot dip galvanizing after fabrication and the use of galvanized bolts was maintained for this line. The Southern California Edison Company's experience seems to justify this method as proof against deterioration, but care must be taken to get well coated bolts.

In order to justify the design, tests were conducted on both types of towers and contrary to the usual method of test in which towers are fixed to heavy concrete and steel foundations, the tests were made on the earth footings set to conform to ordinary line conditions. These tests proved that deflections unavoidable in newly tamped earth back fills do not furnish absolute fixed support. This condition in turn sets up secondary stresses which must be recognized in the design. In light framed structures, where there are no contributing elements toward strength such as are found in buildings or like structures, extreme care must be taken to avoid the combination of bending and direct stress. Also, as the connections are all partially fixed, and the ordinary resolution of forces by graphic or analytical methods does not allow for the bending set up in fixed or partially fixed joints, considerable judgment must be exerted in the design of the towers.

It seems well worth while to spend the time on steel details to assure accuracy, as much time and trouble in erection is thereby saved. Also a small saving on parts will result in large aggregate saving due to the great numbers of parts required, but the designer should also guard against leaning too heavily toward saving which would result in the risk of the strength of the structure.

Conductor Stringing

The locating of towers on the profiles was done by means of a celluloid template representing sags at 130 deg. fahr. on the basis of 30-ft. clearance for all territory susceptible of agricultural development, and 25-ft. clearance elsewhere. Cross slopes were shown on the profiles and these clearances obtained under the up hill wire.

The 130-deg. sags for the template were calculated on the basis of equal tensions in all spans at 70 deg. fahr. This method was used instead of the more usual method of equal maximum tensions for the following reasons: In this line there are several very long spans which, in heavy loading, are stressed much higher than the other spans. To limit the tension by them would give low values not economical for the majority of spans. By making tensions equal at 70 deg., the desired maximum tension of 12,000 lb. could be attained in most of the spans, and exceeded in only a few. The proper value at 70 deg. was determined from preliminary profiles of representative sections of the line, one value being used for light loading and another for heavy loading.

After towers had been located on the profile, surveying parties made preliminary field stakings from which tower grades were determined and extensions fitted to each location. Then, knowing spans and difference of elevation, sags were calculated and all clearances checked. Special calculations were made to determine clearances over other electric lines, under the assumption of a broken wire in the span adjacent to the crossing span.

From the above field data, the horizontal and vertical loads on each tower were calculated to determine where double strings of suspension insulators were required, where the insulators should be tied down, and also to check conditions at towers where horizontal angles were turned on suspension insulators.

After much of the above work had been done, results from a 1060-ft. test span of the new cable showed that changes must be made in the calculations. Stress-deformation curves proved conclusively that there was a stretch of about 0.04 per cent in the cable after stringing, and that while the first or temporary value of the modulus of elasticity was 7,750,000 lb. per sq. in., the final or permanent value was 9,800,000 lb. per sq. in., this latter value being effective after the cable had been subjected to the maximum tension a number of times. Figs. 4 and 5 show the test span and the recording dynometers.

In order to string the cable under the above conditions and to maintain the 130-deg. clearances obtained from the template layout, the following method was used, all calculations being made on a catenary chart similar to the Thomas Curve:

1. From the 130-deg. sag, calculate the maximum tension (under light or heavy loading conditions, as the case may be) using the permanent modulus.
2. Reduce the stressed length by 0.04 per cent, thereby getting a temporary maximum tension for that loading, assuming no stretch from the increased tension.
3. From this temporary maximum tension, find

sags and tensions at any desired stringing temperature, using the temporary modulus.

From the tensions thus obtained, stringing values for 40 deg., 70 deg., and 100 deg. were chosen; such that the resulting maximum tensions would not exceed the values previously mentioned. These stringing values varied for different sections of the line, being dependent on the length and slope of the spans; and care was taken to have small changes in successive values, in order that the difference in tension would cause only a small deflection of the suspension insulators.

Since the line was to be strung to tension by sag measurements, and since the parabolic formula for sag is much simpler than the catenary formula, correction curves were plotted showing the difference between parabolic and catenary sags for various spans and tensions. Then the catenary sag used is equal to

$$\left(\frac{w\,l^2}{8\,H}\right) \sec.\,\theta + K,$$ where W = weight per ft., l = span, H = stringing tension at desired temperature, θ = angle of slope of span, and K = correction. Another curve was plotted showing the difference between the stringing sag and the final sag at 130 deg. after the cable had stretched, this latter value being used for determining all final ground clearances.

Two field engineers were assigned to each construction gang so that sags could be checked in at least two spans for each pulling section. The method used was to set a transit a distance below the point of support of the wire equal to the center sag, and sight along a line parallel to the chord of the span. The cable was pulled until it was tangent to this line of sight. Where the sag was less than the height of the tower, a specially designed clamp was used permitting the attachment of the head of the transit to the tower leg. In the longer spans, sag stakes were set at each end of the span, so that, for a fixed height of instrument, the transit was on the required line of sight, and the cable sagged in as before.

Previous to the stringing of the cable there had been considerable discussion in regard to the proper methods of attaching the insulators to the cable. The absence of frequent dead-end connections and the length and slope of the spans made a complicated problem. It was speedily found that the suspension insulators would be vertical in the mountainous sections of the line only at the stringing temperature, and that in some extreme cases, having them vertical, they would not give the required length of wire in each span. The method finally adopted was to attach the suspension clamp vertically below the crossarm in every case, adjusting tension and attaching clamps span by span in the extreme cases to insure having the wire lengths right.

Field experience has justified this method and shown that only in very rare cases is it necessary to insulate the spans separately.

Insulators

The insulators are practically the same electrically as those used on the Eagle Bell line. They differ mechanically from those, in that all the units are of the high strength type; that is, they have a combined electrical and mechanical strength on short time tests of not less than 18,000 lb. The suspension insulators consist of a single string of 13 units where the maximum load will not exceed 6000 lb. and of two parallel strings 13 units in length where the maximum load will be greater than 6000 lb. The dead-end insulators consist of two parallel strings 15 units in length. Fig. 3 shows these three arrangements. It will be noted that the double suspension and dead-end assemblies use the same yokes and clevises. A single string of 14 units is used in the tie-down insulators where such is required to limit the side swing of the suspension insulators.

About one-half of the units might have been standard 9000-lb. units because they would have given the required factor of safety of three in many of the suspension insulators. But it is very desirable to have units of only one kind in a line, so it was gratifying to find the bid prices such that the additional cost due to using high strength units throughout could be justified on the grounds of simplified construction, maintenance, and store stock.

Extensive long time loading tests were made on sample high strength suspension insulator units submitted by the various manufacturers for the purpose. A description and the results of these tests have been published in the National Electric Light Association 1926 Annual Report of the Overhead Systems Committee, Insulator Research Subcommittee, R. J. C. Wood, Chairman.

Briefly, the tests were as follows:

A frame was made in which four strings of 20 units each were suspended. Each string was composed of four units from each of five manufacturers. These strings were loaded at 9000, 11,000, 13,000, and 15,000 lb. each and the load maintained continuously except as interrupted by broken insulators and, at one time, by a modification in the supporting structure. At irregular intervals the insulators were tested electrically, one at a time. Quick-time, ultimate, mechanical tests also were made on each make of these insulators.

The conclusions drawn from these tests are worthy of quoting from the report; they are:

1. That the quick-time ultimate mechanical strength cannot be relied upon as a criterion upon which to base working load, the relation between the two depending upon either design or material, or both.

2. That more than one manufacturer can supply 10-in. insulators that will apparently sustain from 11,000 to 13,000 lb. dead load for very long periods of time, and it is safe to use them up to 6000 lb. dead load on long-span transmission lines.

3. That incipient mechanical failure occurs at the time of electrical failure under load and will probably

be followed by complete mechanical failure at some subsequent date without increase of load.

4. That there is some indication that at some period during the long time test of 11,000 hours, the average ultimate mechanical strength of all insulators loaded to 9000 and 11,000 lb. decreased some seven or eight per cent. Great caution must be observed, however, in generalizing from tests made upon an aggregate of only 83 insulators.

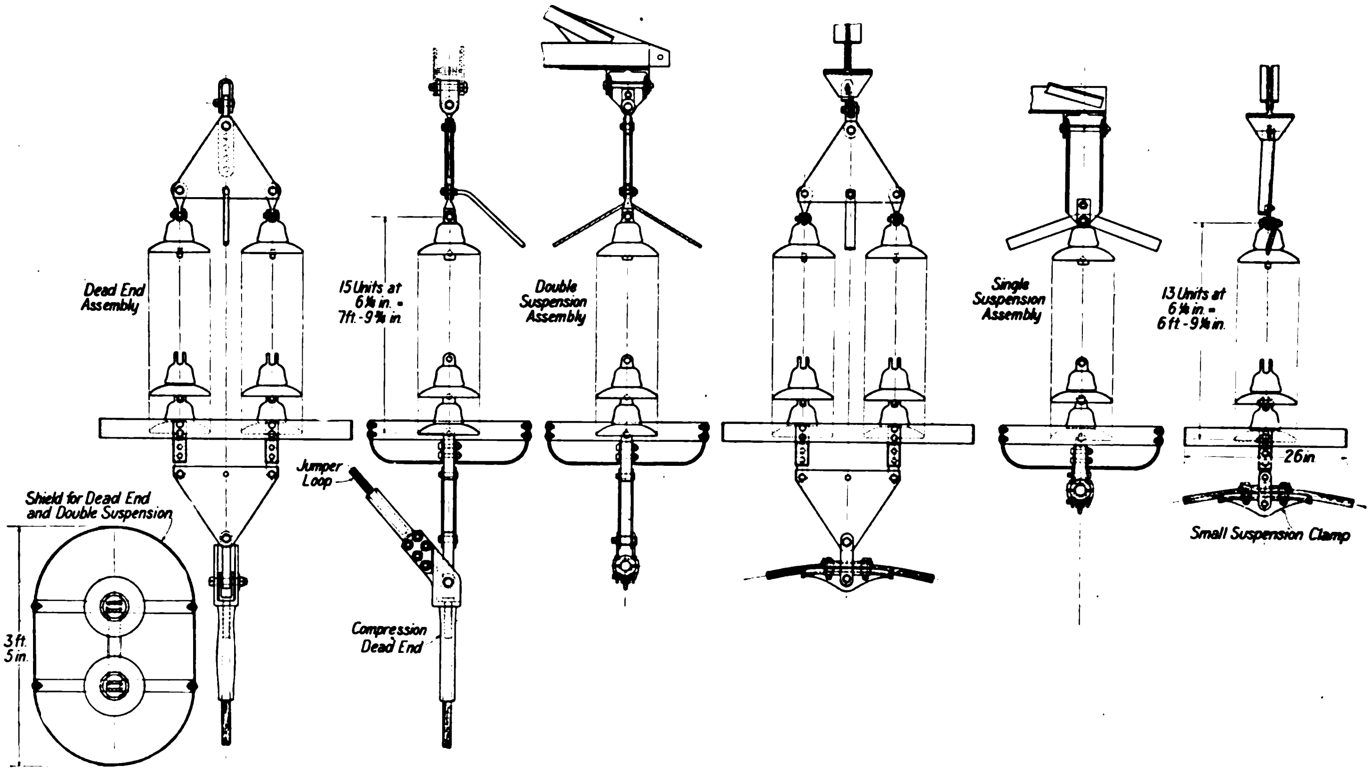

Fig. 3—Insulator and Insulator Hardware Assemblies

Showing single-string suspension, double-string suspension, and dead-end with compression clamp on cable

Insulator Hardware

All the insulator hardware is made of forged steel or wrought steel, except the aluminum part of the compression dead-ends and the long suspension clamps which latter are of malleable cast iron. All pins are of chrome-nickle steel.

Shield Rings

The insulator shield rings are practically the same, electrically and also mechanically, so far as over-all dimensions and position on the insulator strings are concerned, as those used on the present 220-kv. lines of this company. However, instead of being of cast aluminum of an inverted U-shaped cross-section, they are each made of a hoop of 3/16-in. by 3-in. steel strap. These are much less expensive than the old shield rings. Laboratory tests do not indicate any particular advantage in favor of the old shape of ring in either voltage grading or flashover characteristics.

Dead-Ends

The development (in so far as it had advanced by the summer of 1924) of a light weight, compression, dead-end fixture to minimize the effect on the conductor itself of conductor vibration has been described and illustrated.[3] The main features of this compression

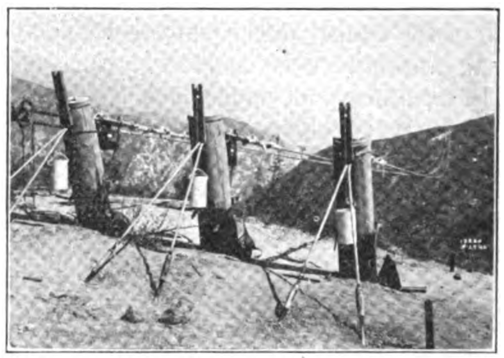

Fig. 4—Test Spans for Determining Amount of Permanent Stretch and Modulus of Elasticity of 1,033,500-Cir. Mil Steel Reinforced Aluminum Cable

dead-end had been worked out simultaneously by the Aluminum Company of America and the Southern California Edison Company. The main differences in

3. *Transmission at 220 kv. on the Southern California Edison System*, Section 4, *Vibration of Conductors and Overhead Ground Wires*, by J. M. Gaylord, Journal of A. I. E. E., Nov. 1924, p. 1026.

the two designs were that the former anchored the steel core in the steel clevis-socket by pouring melted zinc around the core in the socket while the latter accomplished the same results by means of conical wedges in a conical socket, and that the former transmitted the load to the insulator assembly from the aluminum compression body through aluminum clevis ears cast onto it while the latter accomplished this result by screwing the aluminum body onto the steel clevis-socket. Both of these schemes undoubtedly would have given satisfactory results in service as they did on test but they were not tried because the Aluminum Company put forward an improvement in the method of attaching the steel core to the steel clevis. Instead of a conical socket, a steel tube about six in. long was forged as a part of the clevis. Into this tube the end of the steel core was placed and then the steel tube was compressed using the same press with smaller dies as was used to press the aluminum. Tests proved that the core would break at approximately its calculated ultimate strength and would not pull out of the tube.

The idea of having the load transmitted from the

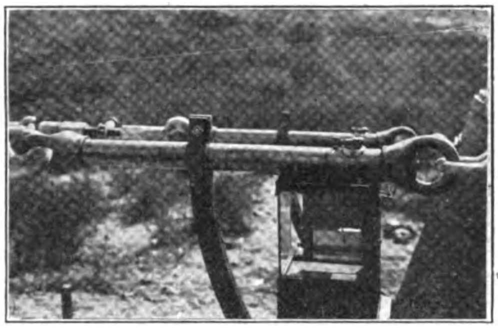

FIG. 5—RECORDING DYNOMOMETER ON TEST SPANS

aluminum compression body to the insulator assembly through an aluminum clevis cast as a part of the compression body was accepted, but a change was made in the position of the lug to which the jumper loop fastens which altered the appearance considerably. This change was due to the desire to have the centerline of the jumper loop, where it is attached to the dead-end, pass through the clevis pin of the dead-end and thus minimize the effect that the jumper loop has on the relative movement between the compression dead-end and the conductor immediately adjacent thereto, due to conductor vibration. A test briefly described below had indicated that the jumper loop very appreciably increases this relative movement and that all reasonable measures should be taken to minimize this effect.

On a span having vibrations forced upon it by a vibration machine, measurements of the relative movement of the compression dead-end and the cable were made by means of a pencil attached to one and a strip of paper in a holder attached to the other. With neither shield ring nor jumper loop attached to the dead-end, the mark drawn as the paper moved past the pencil was practically a straight line. With the shield ring but not the jumper loop attached, the waves in the pencil mark had an appreciable amplitude. And with both the shield ring and the jumper loop attached, the amplitude of these waves was several times as great as with the shield ring only; hence the conclusions stated above.

Careful consideration was given to the bolted connection between the jumper loop and the compression dead-end. Such bolted connections have been known to give considerable trouble when the bolts and the lugs are of dissimilar metal. In the case of aluminum lugs and steel bolts, the greater expansion of the aluminum with rise of temperature might cause either or both metals to be stressed beyond the elastic limit. In either case the joint would be loosened upon subsequent cooling. This accounts for the large number of bolts in this connection.

TROUBLE AT SUSPENSION CLAMPS

About the time the design of the suspension clamps was being considered, it was discovered that many of the aluminum strands were broken at the ends of many of the suspension clamps on the old Big Creek lines. This breakage was due to the repeated bending caused by conductor vibration. The old suspension clamps were divided on the vertical plane through the conductor axis and they ended with a very short radius of curvature on the part where the cable bore as it left the clamp. The conductor was protected by a sheet aluminum liner which hid the broken strands from outside inspection until a considerable number was broken.

DESIGN OF SUSPENSION CLAMPS

There seemed to be three main features which should be embodied in a new suspension clamp to avoid the troubles experienced with the old clamps:

First, a saddle in which the cable will rest entirely outside of the section gripped in the clamp so that the last point of contact between clamp and cable would never be coincident with the end of the gripped section. This would allow the bending of the cable, due to its rise and fall relative to the clamp, to be distributed over an appreciable length of the cable and not be constrained to one particular point.

Second, the radius of curvature of this saddle over which the cable would bend should be sufficiently large to prevent the repeated bending from breaking the cable strands.

Third, the clamp should be suspended in such a way that it would move with the cable as much as possible and thus keep the bending of the cable at the ends of the clamp to a minimum.

Although, at the time of designing this clamp, it was becoming apparent that the vibration in the conductors could be stopped, it was thought advisable to embody all three of these features in the clamp design.

The points of design which would satisfactorily meet

these requirements were determined in an order the reverse of that in which the requirements are enumerated.

The third was met by pivoting the clamp on a pin passing through it as close to the lower side of the conductor as possible. The clamp is free to move about this pivot through an angle of 23 and 30 deg. both ways, from the normal position for the short and long clamps respectively.

It was determined that the second requirement was reasonably fulfilled by giving the end portions of the clamp a radius of curvature of 16 in. Of course a longer radius would give easier bending conditions on the cable, but cost must be given consideration. Considerable experimental work was done to determine this radius. Single strands of aluminum wire stressed to unit tensions approximately the average of those expected in the line were bent around curves of various radii a sufficient number of times to break them. From these tests it was determined that if bending around a radius of 16 in., the life of the cable can be expected to be in the order of five times as long as if it were bending about a six-in. radius, which is approximately the radius of the old clamps. This was considered a reasonable balance between increase in cable life and increase in cost of suspension clamps.

The first feature specified required a straight section of clamp in which the cable is gripped with two end sections in each of which the cable merely rests for a part of the length. The length of the gripping section was determined to give the holding power desired. Tests show the first slips to occur at 20,000 and 16,000 lb. for the short and long clamps respectively.

It was decided to have the straight section of the bottom half of the clamp extend one inch beyond the grip of the clamp. At these points the two 16-in. radius end sections begin, the straight section being tangent to the two curved sections. To determine the length to which the end sections should be carried so that the most extreme points of contact between cable and clamp would be an inch inside the outer end of the 16-in. radius curve, one in. having been selected as a sufficient margin of safety, it was necessary to calculate from the profile of the line the various angles at which the cable would leave the clamps. It was found that these angles varied from practically nothing to 22.5 deg. and that a clamp to accommodate all these conditions should be 21.75 in. long. Since there were comparatively few of the large angles, two types of clamps were designed, one for angles up to nine deg. and the other for angles up to 22.5 deg. The former was made with a forged steel body 14.75 in. long and the latter was made of malleable cast iron 21.75 in. long. Both were equipped with cast aluminum liners. There are required for the line 2100 of the short clamps and 477 of the long ones.

Conductor Vibration

The experiences with conductor vibration, the methods of study, the causes, and the means of preventing conductor vibration have been previously described.[4-5-6] Vibration dampers similar to those described by Mr. Stockbridge, but consisting of two cast iron weights attached to a straight and approximately horizontal spring of guy cable, will be used on this line. Judging from the results obtained on the old line, these dampers will entirely eliminate all visible vibration. Fig. 6 shows this type of vibration damper as applied to the old lines.

Construction

Careful plans were made for the construction of the line, particularly with reference to construction equipment, and the results in the field have proved that the expense of this planning was well worth while.

The setting of footings was largely a matter of pick and shovel and powder for the excavation, transit

Fig. 6—Conductor Vibration Damper

and level for alinement and elevation, and shovel and tamper for back-filling. It pays to do this job well. Fig. 7 shows footings being set.

Tower Erection

When the Eagle Bell 220,000-volt line was built in 1923, several methods of erecting towers were tried, but the method of assembling piece by piece in the erected position was found to be the most economical if the erecting crews are selected and organized with care.

On the Vincent line this method has been modified somewhat in that wherever it is possible to get a line

4. *Transmission at 220 kv. at the Southern California Edison Company System*, Section 4, *Vibration of Conductors and Overhead Ground Wires*, by J. M. Gaylord, Journal of A. I. E. E., Vol. 43, November 1924, p. 1026.

5. *Notes on the Vibration of Transmission Line Conductors*, by Theodore Varney. Presented at Niagara Falls meeting, A. I. E. E., May, 1926.

6. Overcoming Vibration in Transmission Cables, by G. H. Stockbridge, *Electrical World*, December 26, 1925, p. 1304.

from a truck the panels of the tower sides are assembled on the ground or horizontally on the top of the completed portion of the tower and raised as a unit. Fig. 8. shows the first side-panel being raised into position on top of a 14-ft. extension. The truck is raising the panel.

In this way a crew of 14 men, including the gang foreman and the truck driver, has been able to erect a standard tower in 4 hours and 15 minutes. This tower was put on top of a 14-ft. extension which had been previously erected. When the work is running smoothly, an average of six hours for a standard tower on easily accessible ground should be maintained by a crew of 14 men and a two-ton truck.

Fig. 7—Setting Tower Footings

Looking southeasterly along line in southern edge of Antelope Valley

Conductor Stringing and Stringing Equipment

The most unsatisfactory part of transmission line construction in the past had been the conductor stringing. Many improvements have been made in the equipment for this work on this line.

The most notable improvement and the one which is paying the greatest dividends is in the stringing sheaves. There was nothing on the market at all adequate for the job. Plain bearings, small wheels, and flat grooves that let the cable flatten and rub on the sides of the blocks seemed to be the rule without exception. It was decided that the friction in the sheaves should be made as low as possible by the use of roller or ball bearings and that the sheave should be made of aluminum with a deep groove having a good fit to the cable and a bottom diameter of 12 in. These specifications led to the design shown in Fig. 9. With these sheaves the length of cable that can be pulled to tension at one time is not limited by the sheave friction. Lengths as long as four miles have been pulled and the tensions in the various spans adjusted with entire satisfaction. On level ground it seems that the limit to the length of pull will be set by the number of sheaves available.

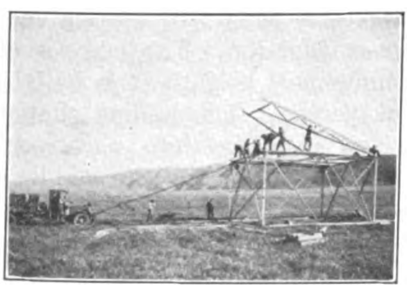

Fig. 8—Erecting Tower on Top of 14-Ft. Extension

Raising first side-panel

The sheave blocks are attached to the bottom of the suspension insulator strings while the conductor is being strung.

For pulling the conductor a 10-ton caterpillar tractor is used. Where the conductors have to be dragged out on the ground, all three are taken at the same time. The pulling of each conductor to final tension is done by the direct pull of the tractor wherever it is possible to find a place for the tractor to travel. The tractor is equipped with a winch, with both drum and spool, with which the pulling is done when the necessary traveling space for a direct pull is not available. The direct pull of this heavy tractor works very nicely and saves much time over any method of using lighter equipment with a winch or blocks and falls. On level ground with the conductor on the ground except at the sheaves, four mi. of one conductor have been pulled up and the tension adjusted to its proper value at three places in the section in 45 min., no splices having passed around the sheaves in this case. Three conductors of a four-mi. section have been pulled up in this way in three hours.

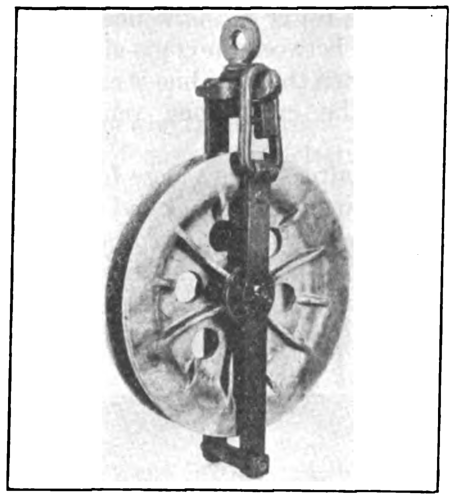

Fig. 9—Stringing Sheave

Telephones are used for communication between the engineers who give the tension orders and the foreman at the tractor end of the section. In some cases twisted pair taps are run to the locations of these men from the telephone line which roughly parallels the transmission line. In other cases, where the telephone line is too far away, a twisted pair is laid along the transmission line from end to end of the pull section. Signaling with flags was tried but was found to be very unsatisfactory for such long pull sections.

As the conductors are pulled to tension, they are anchored to deadmen near the foot of the next tower ahead of the pull section. The come-alongs to hold the two outside wires are placed near the deadmen but the one to hold the center wire is placed very near the sheave in the last tower of the pull section and a steel line is run to the deadman. These come-alongs hold the tension in the line until the cables in the next section to be pulled are spliced on and pulled to tension in the manner described below.

For the outside positions the conductors are not put into the sheaves on the tower where the deadmen are located until the conductors are pulled to sufficient tension to relieve the tension on the come-alongs and the come-alongs are taken off the conductors. This takes place at practically full tension and without appreciably lifting the conductor at the come-alongs from the ground. After the come-alongs are cast off the conductors are placed in the sheaves at that tower.

For the center position the conductor is put through the sheave at the tower near the deadmen and pulled until the steel line between the come-along and the deadmen is slack. Then the steel line is cast loose from the deadmen and the come-along removed from the conductor.

On each wire, after getting loose from the deadman as described, the man at the back end of the pull section tells the foreman at the tractor to pull ahead or back off, as the case may be, until the insulators are vertical on the tower which was at the front end of the last pull, these insulators having been clamped in vertically

Fig. 10—Completed Section of Line on Standard Towers with Extensions

on the conductor when it was anchored to the deadman. Then the engineer three or four spans farther into the section being pulled tells the man at the tractor to pull ahead or back, as required, until the sag in the span he is watching is right. Then another engineer, who is two or three spans back from the tractor, gives whatever orders are necessary to get his span right. If everything has gone well, no more adjusting need be done and the men at the tractor end put on a come-along and attach it to the deadman. After this is done the conductor can be transferred from the sheaves to the suspension clamps at will.

In rough country, where long and short spans and spans at different elevations are mixed together in the same pull section, some slight modifications of this simple level country procedure are necessary. The longest span, or the span at the lowest elevation, takes more than its share of the proper conductor length for the pull section so it is necessary to let such a span govern the pulling tension until its tension is right and

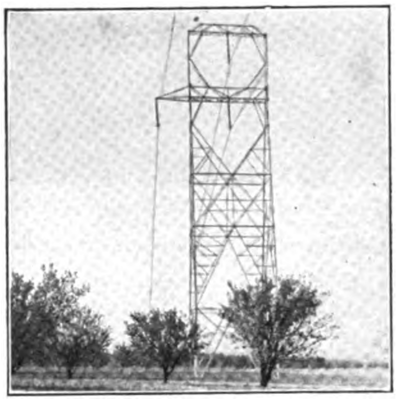

Fig. 11—Transposition Tower on Extension

its insulators are clamped to the conductor. Then that span is forgotten and the other spans are given their proper sags, any other spans being treated in this special way if necessary. Of course all the insulators will not hang vertically but there is no way to put up such a line and have all the insulators vertical at all times.

Come-Alongs

The come-alongs used on previous work had many bolts to be tightened in making one fast to the cable. To shorten the time necessary for this, one was designed with only three set screws to be tightened and it is giving entire satisfaction. The body is of cast steel with aluminum liners held to each half by means of counter sunk screws. The pulling sling is of ½-in. steel cable and is zinced into clevis-sockets which attach to the come-along and the middle of the sling passes around a forged eye to which the pulling line may be attached.

Fig. 10 shows a completed section of line on standard towers with extensions. This is looking north across the Antelope Valley.

Fig. 11 shows a transposition tower with an extension. Two such towers are required at each transposition, one with a right hand and the other with a left hand lower crossarm. These towers are not set off the center line as has been done in some cases. There are seven complete barrels in the line.

Bird Guards

The towers will be equipped with guards to prevent the hawks and other large birds from causing flash-

overs by their semi-liquid droppings bridging the air space between the crossarm and the conductor. Experience has shown such protection to be necessary.[7, 8] The center conductor position will be protected by a sheet iron pan approximately four ft. wide and ten ft. long on the lower members of the crossarm. This pan will catch the droppings from birds on the central portion of the tower top, their most favored perch. Birds will be prevented from perching above the outside conductor by saw-tooth guards placed on the crossarm members for a distance of about six ft. from the end of the crossarm. These saw-teeth are three in. long and are made of thin galvanized iron.

7. Avoiding Flashovers on 220-Kv. Transmission Lines, by G. H. Stockbridge, *Electrical World*, Vol. 85, No. 12, March 12, 1925, p. 611.

8. *Transmission at 220 Kv. on the Southern California Edison System*, Section 1, *Description of System and Operating Experience*, by H. Michener, JOURNAL of A. I. E. E., October 1924, p. 901.

CONCLUSION

It is the belief of the authors that the large amount of engineering investigation and careful design work in preparing for this line was decidedly advantageous, not only for this particular line but for the industry in general, parts of which already are profiting by the results of this work.

Phase Difference in Dielectrics

BY J. B. WHITEHEAD[1]
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Synopsis.—*A brief description of the origins and causes of phase difference in dielectrics.*

HIGH power factor is earnestly sought after in transmission, distribution, and all station loading. Low power factor is just as earnestly sought in the case of insulation, for the higher its value, the greater the internal loss, the higher the temperature, the lower the current capacity, the shorter the life. The term "power factor" in this case describes a property of the material, and as such is of quite different character and significance from its older connotation. It is no doubt largely for this reason that the custom has arisen of describing this property of dielectrics, not as the cosine of the angle of advance of the charging current over the applied voltage, but as the sine of the difference between that angle and 90 electrical deg. This angular difference is known as the "phase difference" or "phase defect" and its usage has the added advantage that up to about 2 deg., the phase difference, itself, in radians, its sine, its tangent, and obviously the power factor in its usual sense, all have the same value within a very small fraction of a per cent. This makes it possible to use these several quantities indiscriminately, thereby greatly simplifying many computations. The use of the tangent of the phase difference is especially convenient, as the ratio of the in-phase to the wattless components of the current.

The importance of phase difference in dielectrics was first appreciated in its influence on the performance of telegraph and telephone cables. Attenuation, distortion, and internal loss are all increased thereby, thus greatly restricting distances of communication. In the field of power transmission and utilization, attention was first focussed on dielectric-phase difference by the observations of Siemens in 1864 on the heating of condensers. This is an early date in the history of electrical engineering, and for many years thereafter the losses in dielectrics under alternating stress received the attention of physicists rather than that of engineers. It was in this early period also that residual charge, discovered in the Leyden jar in 1746, was still further stimulating the interest of physicists in dielectric phenomena. This interest showed its first fruits in the brilliant experiments of Hopkinson and in the unassailable theory of Maxwell of the phenomenon of dielectric absorption. It is not generally realized that since Maxwell's time it has been recognized by engineer-physicists, such as Rowland, Hess and a few others, that dielectric absorption necessarily causes alternating-dielectric loss; *i. e.*, dielectric-phase difference. Engineers became immediately concerned in the value of dielectric-phase difference with the first upward step in transmission voltages in the early '90s, and with the use of cables for transmission. The problem of the limitation of dielectric-phase difference thereafter was clear cut and has been with us ever since. Obviously the applications in which it assumes its greatest importance are the high-voltage cable and the commercial power condenser, but its presence and behavior must always be borne in mind in connection with all high-voltage insulation, especially that of composite or flexible character.

Although, as stated above, phase difference is a property of the material of the dielectric, and although this has been recognized for many years, and although an abundant literature is replete with experimental

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observations, it is astonishing to find that our knowledge even of the values to be assigned to particular materials is extremely indefinite, and that little has been accomplished towards a systematic understanding and regulation of the factors which control the values of phase difference. This is largely due to the fact that there are at least four and possibly more different classes of phenomena in dielectrics, any one of which will cause an angle of phase difference; and to the further fact that probably all these causes follow different laws under the influence of varying temperature, frequency, and electric intensity. Each of the following well-recognized properties or conditions of insulation, if present, will cause a dielectric-phase difference: (1) normal conductivity, (2) dielectric absorption, (3) anomalous conductivity, (4) absorbed moisture, (5) dielectric hysteresis and (6) gaseous ionization.

Normal Conductivity. Under the original theory of Faraday and Maxwell, still regarded by physicists as fundamental in spite of obvious insufficiency, dielectrics are treated as being perfect of their kind, *i. e.*, as possessing specific inductive capacity only. Maxwell, however, recognized that no such perfect solid dielectric exists, and he treated at considerable length the properties of dielectrics which also possess conductivity. We have then in conductivity one of the fundamental causes of dielectric-phase difference. It is usually assumed that conductivity contributes a negligible proportion of the losses in dielectrics. This is undoubtedly true for most pure and simple materials, especially at ordinary temperatures. It should be noted, however, that the values of conductivity of different dielectrics extend over a wide range and in many cases may contribute a considerable phase difference. The conductivity of most dielectrics increases rapidly with increasing temperature. The rapidly rising phase difference of such a composite material as impregnated paper, for example, under increasing temperature, may be accounted for in very large measure in some instances by the increase in conductivity alone. The important influence of water on conductivity is described below.

Dielectric Absorption. Probably the most important of all causes of dielectric-phase difference is dielectric absorption, *i. e.*, the phenomenon of after-charge and residual charge. It is obvious that if under applied continuous voltage, current continues to flow over a period of time into or through a dielectric, then under alternating voltage there will flow a component of current in phase with the voltage, which, of course, means a definite angle of phase difference. Absorbent dielectrics, in effect, have for a short interval after the application of voltage a greatly increased value of apparent conductivity. On short circuit a charge continues to flow out long after the electrostatic charge has disappeared, and on reversal of the applied voltage the high initial conductivity appears again. Thus, for the rapid reversals of alternating voltage, the dielectric behaves as though this increased conductivity were continuously present.

Absorption usually occurs whenever a dielectric is composed of two or more different materials. Further, it appears that a very small proportion of a foreign material may cause a large absorption effect. Thus, the absorption often observed in many supposedly pure, simple materials is usually attributed to impurities. This is one of the obscure questions in our imperfect knowledge of dielectric absorption. Although it has been known for years that absorption is one of the most important causes of phase difference, very little attention has been given to the problem of controlling its value, and to the study of the behavior of various dielectric materials singly and in combination. That such study would prove profitable is indicated by the fact that a few composite dielectrics have very low values of phase difference and of absorption. These materials apparently are few in number, and their properties obtained only by cut-and-try and by great care in preparation. However, there is no reason why a further study and control of composite materials should not lead to dielectrics having not only low phase difference, but also other desirable thermal and mechanical properties.

Moisture. Many insulating materials, particularly those of porous and fibrous character, absorb moisture readily from the air. Their conductivity is very often greatly increased thereby. In many cases the moisture is taken up quite rapidly and is completely driven off again only with considerable difficulty. As a consequence, exact statements as to the influence of moisture on conductivity and power factor are not possible. Several definite qualitative relations stand out, however, and the behavior of cable paper in this regard may be taken as generally characteristic. Cable paper when standing in the open will absorb from 10 to 15 per cent of weight of moisture. If continuous voltage is applied to the paper in this state, the current, which in this case is pure conduction current, will increase slowly with time, tending to a steady value. If the voltage is increased the final current will increase roughly as the square root of the voltage. A theory for this behavior has been proposed by Evershed and is based on the assumption that the variation in conductivity is traced to changes in the water films around air bubbles in the capillary fibers of the material. As the paper is heated above ordinary temperatures the conductivity increases and the general behavior outlined above continues up to about 50 deg. or 60 deg. cent. Above this point traces of the normal residual charge and discharge of dielectrics begin to appear, although the conductivity is still very high If allowed to stand at about 70 deg. for some hours, large quantities of the moisture are driven off, the Evershed effect has disappeared, and the paper begins to show the qualities of a good dielectric and insulator, having, however, pronounced absorption and conductivity. With further

increase in temperature both absorption and conductivity are decreased further, and on standing for long periods at temperatures from 95 deg. to 115 deg. cent. there is little change, and the paper appears to be in more or less steady condition, still showing pronounced absorption but with relatively low value of final conductivity.

Thus, it will be readily seen that the influence of moisture on the phase difference on insulating materials is very complex. The variation with both voltage and time is often to be found in the alternating case. Increase in the amount of absorbed moisture shows itself almost immediately in increased values of phase difference and loss. As a consequence every effort is made in the manufacture of commercial insulation to exclude moisture as completely as possible and to prevent its subsequent absorption. It is safe to say, however, that in few cases is it possible to completely eliminate moisture and that observed values of phase difference and loss are always in some measure increased by residual moisture.

Anomalous Conduction. Nearly all liquid dielectrics show some conductivity. Moreover, this conductivity generally varies with both time and voltage. On the application of continuous voltage the resulting current decreases, approaching a constant value. With increasing voltage the final constant values generally show a departure from Ohm's law. Many attempts have been made to coordinate the results of investigation of this property but without great success. This conductivity is undoubtedly ionic in character and in some cases follows closely the known laws of the ionic conductivity of gases. Values have been obtained for the mobilities of both positive and negative ions for particular materials, but in general the results of such investigations are far from definite in character and this is attributed to the presence of ions or molecular aggregates of different size. Phenomena of this character seem to be particularly susceptible to the presence of impurities in small amounts, to traces of water, etc.

Electrolytic dissociation and resulting conductivity is known to exist in some complex insulating materials. Glass is a remarkable example of this. The metallic constituents of some glasses may be separated out under continuous voltage and deposited on electrodes. Here is an instance of a rigid insulating material through which it is known beyond a doubt that electrolytic ions pass from one electrode to another.

As regards the influence of these two types of conductivity on the phase difference of commercial insulation, it may be said that very little is definitely known. There would appear to be good possibility of the presence of the former type, and it is probably true that the residual conductivities of composite dielectrics made up originally with liquid binders, is in considerable proportion due to the motion of ions of the type usually to be found in liquids.

Hysteresis. Since the days of Siemens, who first noted the heating of impregnated paper under alternating stress, it has been customary to attribute the losses in dielectrics to some form of molecular friction, apparently arising in the same types of cause pertaining to the case of magnetic hysteresis. There are many differences between the two phenomena which indicate that they are of essentially different character, and it is undesirable, therefore, to use the word hysteresis in connection with dielectric behavior. In addition to the differences mentioned it is to be noted that in the case of dielectrics there are many other factors, as enumerated above, that appear to be quite sufficient to account for all of the losses which are observed. It is, of course, possible that in addition to these well-recognized causes for loss there may be some residual type of loss arising in the orientation or deformation of molecules and atoms. In fact, there have been numerous suggestions that the phenomenon of absorption itself arises in frictional deformation or the motion of electrons within the atom itself. With due weight given to these considerations it may still be said that the evidence that the nature of the losses in dielectrics is of the character usually understood by the word hysteresis and is so small as to make it appear very unlikely.

Gaseous Ionization. Many forms of commercial insulation are composite in character and built up in layers. Conspicuous examples are the insulation of all electromagnetic machinery and of many types of high-voltage underground cable. The assembly and application of this type of insulation invariably provides opportunity for the enclosure or entrapping of certain amounts of air, which is never completely removed by such processes as evacuation and subsequent pressure impregnation. This air, when voltage is applied to the insulation, breaks down electrically under the process known as ionization. It is also known that in some cases the constituents of impregnating materials break down under stress, with the generation of gases and the further increase in the size of the voids in the body of the insulation. These gases are also subject to ionization. The products of this gaseous ionization are usually highly active oxygen and ozone. Not only is the ionized gas a good conductor but the products of the ionization attack the surrounding material rendering it conducting, thus further increasing the conductivity.

It will be seen, therefore, that this type of conductivity is not necessarily inherent in the material itself, but is a result of imperfect methods of assembling and applying the material. However, it is probable that even at very low stresses this type of conductivity is present to some extent in all insulations in the class mentioned. Standard specifications for cables, for example, include clauses giving tests for increase in power factor due to this cause, and limiting values for such increase, thereby recognizing its necessary presence. Power-factor curves of this type of insulation only show marked increase above certain values of

stress, and such increase is in all probability rightly attributed to this type of ionization.

It can not be emphasized too strongly, however, that internal ionization is highly destructive to the structure of composite insulation, and that if such insulation is operated above a stress at which ionization is known to occur, the days or months of the life of this insulation are already numbered.

Bearing in mind these various causes giving rise to a phase difference in dielectrics, it is not to be wondered at that there is much conflict of evidence as to the behavior under different conditions of insulation of any particular type. Of the several causes enumerated the laws of only two of them may be said to be well known, namely, conduction and absorption. Inherent conductivity of the type found in metals leads to a value of losses readily calculable. Dielectric absorption has been carefully studied and it is known that in insulation of comparatively simple structure absorption accounts for most of the loss. In the uncertain laws controlling the losses of other character there is plenty of explanation of the erratic behavior often reported. It may be pointed out, however, that these uncertain phenomena are usually of a type which seems to yield to care and control in preparation of materials and methods of assembly. Moisture may be largely driven out, anomalous conductivity reduced to extremely small proportions, and it is possible to reduce gaseous ionization to negligible proportions. With care of this character, therefore, it is legitimate to consider the behavior of dielectrics from the standpoint of conductivity and absorption alone. It has been shown that the extension of Maxwell's theory of absorption to the alternating case will account for the outstanding features of the behavior of composite insulation. For example, the loss is in proportion to the square of the voltage, and to the frequency. Moreover, it is shown that the variation of power factor with the frequency shows a maximum value, which may lie at a low or very high value of frequency, depending upon the constituents of the material. Further, and due to the same causes, variations of temperature within the usual range may cause either sharp increase or sharp decrease of power factor. The fact that variations of this character are in accord with the simple theory of absorption as the principal source of loss is extremely encouraging and a great step in advance.

In closing this brief discussion of the origin of phase difference in dielectrics, it may be pointed out that a moderate value of phase difference or power factor appears to be practically a necessary feature for composite insulation. On the other hand, there is no objection to a phase difference of moderate amount provided that it remains constant. If the phase difference of a given dielectric increases with the electric stress its cause should be carefully investigated and the insulation always operated below the stress at which such increase in phase difference begins. The increase due to temperature is more difficult to control, but there is reason to suppose that it has a definite value in any particular case, and that it is therefore subject to control. If these considerations are correct, there is good reason to hope that a well considered program of experimental research will result in the placing of the design of insulation on an engineering basis comparable to that pertaining to the other elements of circuits and machinery. The essentials of such a program would be principally the checking of the laws which now appear most probable, and the study of the properties of insulating materials, singly and in combination. The preparation and coordination of a program to meet this need is already under way in the work of the Committee of Insulation of the Division of Engineering and Industrial Research of the National Research Council.

INCREASE OF ELECTRIC POWER IN FACTORIES AND HOMES

In his Annual Report of the Department of Commerce Secretary Hoover states that there has been a large increase in the application of electrical power in manufacturing, and while there has been an increase during this period of between five and six million horse power used in factory production, there has been no increase in boilers and engines installed within these plants, the increase having been made almost entirely by electrical motors operated through purchased power. There has also been a transformation from direct-connected steam equipment within factories to factory electrical generation for distribution throughout the plants until at the present moment apparently 70 per cent of factory power is delivered to the machines electrically.

The application of electrical power to home use has received enormous expansion. The number of homes served has increased in six years from 5,700,000 to over 15,000,000. The number of farms served is expanding rapidly, and in some States, such as California, farm electrification far exceeds that in any other locality in the world. Owing to the economies brought about through central generation and interconnection and through the advances in electrical science the average price of power throughout the country is now somewhat less than before the war, it being one of the few commodities to be delivered on less than a pre-war basis.

This transformation, it may be said at once, has increased the productivity of our workmen beyond those of any other country; it contributes to our maintenance of high real wages and to the reduction of human sweat; it relieves the home makers of many irksome tasks and adds immeasurably to home comforts.

There is still further promise of great progress in the reduction of fuel consumption in the extension of electrification, particularly in the further replacement of factory steam plants, in the electrification of our large railway terminals, and in the expansion of household use of power.

Synchronizing Power in Synchronous Machines
Under Steady and Transient Conditions

BY H. V. PUTMAN[1]

Associate, A. I. E. E.

Synopsis.—*The accuracy of all calculations relating to the hunting of synchronous machines connected mechanically to reciprocating apparatus depends largely upon the correctness with which the value of the synchronizing power P_s may be determined. Thus, the calculation of flywheels necessary for the parallel operation of engine driven generators depends entirely on a correct value of P_s. Likewise, the $W R^2$ which it is necessary to incorporate in the rotors of synchronous motors when driving compressors or pumps can be calculated correctly only when P_s is accurately known.*

So far as the author is aware, no attempt at a complete analysis of the subject has been made heretofore. The object of this paper is to develop a method by which the synchronizing power P_s may be calculated fairly accurately under any condition likely to be met with. The method applies only to synchronous machines of the usual definite pole construction. Blondel's conception of two reactions with some modifications and extensions is followed generally throughout the paper.

* * * * *

SECTION I. INTRODUCTION

SYNCHRONIZING power, P_s, may be defined as the rate at which the input power to a synchronous motor changes with corresponding changes in the angular displacement. The displacement referred to here is not that which actually exists between the rotor and the rotating electrical field in the motor but it is the displacement between the rotor and an imaginary electrical field which corresponds in phase position to the terminal voltage. This will be explained more fully later.

P_s is often called a constant. It would be more correct to say that P_s is constant for a given set of operating conditions because its value changes with the load, the excitation, and with the frequency at which the mechanical load pulsates.

If, for a given synchronous motor operating under constant excitation, a curve is plotted showing the power input as function of the angular displacement, it will appear similar to that shown in Fig. 1.

Now it is obvious that if the mechanical load on the motor changes very slowly, the rate of change of power with displacement is given by the slope of the tangent to the curve at the point corresponding to the given load on the motor. If, however, the mechanical load pulsates up and down rapidly as it does in the case of a compressor, the rate of change of power with the displacement is no longer given by the slope of the tangent to the curve but by the slope of some other line similar to the dotted line in Fig. 1.

The reason for the above phenomenon is not hard to find. A sudden increase in the load on a motor is accompanied by a sudden increase in the armature reaction which tends to buck down, and distort the field flux. It is, however, impossible for the field flux to change immediately, and for the first instant the effect of the armature reaction on the field flux is practically offset by a sudden increase in the field current produced by an induced voltage due to the changing field flux. The result is that the armature reaction has not had time to function at least completely, and the field current has increased or decreased to make up for it. This is precisely what happens in a synchronous motor driving a compressor. The armature reaction functions only partially and the field is kept continually in a transient state. Oscillograms of the field current taken when a machine is hunting often show marked pulsations amounting to a considerable percentage of the average value.

The problem of calculating P_s is thus not simply that of calculating the slope of the tangent line in Fig. 1, but rather the more complicated problem of calculating the slope of the dotted line. In the theoretical analysis which follows, the angular displacement of the machine will be calculated first according to Blondel's theory, then the slope of the tangent line in Fig. 1, and finally that of the dotted line.

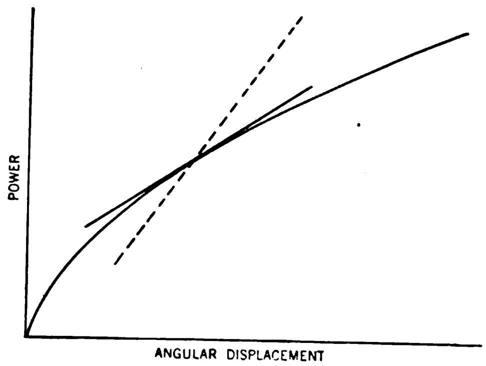

FIG. 1—CURVE SHOWING POWER AS FUNCTION OF DISPLACEMENT UNDER STEADY LOAD

Dotted line represents change of power with displacement under condition of pulsating load.

SECTION II. THEORETICAL TREATMENT

The following symbols will be used throughout the remainder of this paper:

$\dot{E}_i$ = Induced voltage
$\dot{E}_n$ = Nominal voltage
$\dot{E}_t$ = Terminal voltage
$\dot{E}_0$ = Impressed voltage

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I = Current
r = Resistance
x = Reactance
x_s = Synchronous reactance operating on the component of current at right angles to E_n
x_s' = Synchronous reactance operating on the component of current in phase with E_n
x_d = $x_s - x_s'$
x_e = Effective synchronous reactance, $x < x_e < x_s$
z = Impedance
z_s = $\sqrt{r^2 + x_s^2}$ = Synchronous impedance
z_s' = $\sqrt{r^2 + x_s'^2}$ = Synchronous impedance
m = Coef. of armature reaction. (Ratio of demagnetizing ampere-turns to the no-load excitation ampere-turns)
F_r = Resultant field excitation
F_f = Applied field excitation
θ = Power factor angle lagging
δ = Angle between I and E_n
ψ = Angular displacement of the rotor
P = Power input
P_s = $\dfrac{dP}{d\psi}$ = Synchronizing power
K' = Factor of effectiveness of armature reaction
N = No. of turns on field pole
L = Effective inductance of the field
r_f = Effective resistance of the field
K = Coef. of coupling between armature and field
E = D-c. voltage impressed on the field
p = Operator $\dfrac{d}{dt}$
i = Component of current in phase with E_n
i_1 = Component of current at right angles to E_n
t = Time in sec.
$\Phi \sin \omega t$ = Pulsating flux provided by the demagnetizing component of armature reaction
ω = Frequency of the mechanical pulsation in radians per sec.
i_f = Current in the field circuit
ψ_r = Resultant flux in the field pole

The fundamental equation of all electrical machines is:

$$E_i = E_t + I z \tag{1}$$

This equation simply states that the induced voltage is the vector sum of the terminal voltage and the impedance drop.

The induced voltage is proportioned to the flux producing it and lags behind the flux by 90 deg. This is expressed mathematically,[2]

2. The use of a linear relation here between F_r and E_i does not mean that the effect of saturation in the machine has been neglected. In fact, the proper value of c to be used for a given set of operating conditions must be determined from the saturation curve. c is really the slope of a straight line from the zero point through the operating point on the saturation curve.

$$F_r = j\, c\, E_i \tag{2}$$

where c is the proportionality factor.

The resultant excitation F_r is the sum of the armature reaction $I m$ and the applied excitation F_f; thus

$$F_r = F_f + I m \tag{3}$$

Substituting (3) in (2) and solving for E_i,

$$E_i = -j \frac{F_f}{c} - j I \frac{m}{c} \tag{4}$$

The term $-j \dfrac{F_f}{c}$ is defined by most writers as the nominal voltage and denoted by E_n. From (4) it may be seen that it is equal to the induced voltage at no load. Substituting (1) in (4) and replacing $-j \dfrac{F_f}{c}$ by E_n,

$$E_t + I z + j I \frac{m}{c} = E_n$$

or

$$E_t + I \left[r + j \left(x + \frac{m}{c} \right) \right] = E_n \tag{6}$$

The term $\left(x + \dfrac{m}{c} \right)$ is the synchronous reactance, x being the real reactance, and $\dfrac{m}{c}$ the reactance equivalent of the armature reaction. The complete bracket in equation (6) is, therefore, the synchronous impedance and represented by z_s.

$$E_n = E_t + I z_s \tag{7}$$

It is interesting to note the similarity between equations (1) and (7). The nominal voltage corresponds to the induced voltage, and the impedance has become synchronous impedance. Equation (1) applies to all electrical devices while equation (7) is the fundamental equation of, and applies only to, synchronous machines.

For a synchronous motor, equation (7) is more conveniently written

$$-E_n = E_0 - I z_s \tag{8}$$

E_0 being the impressed voltage.

The vector diagram for a synchronous motor based on equation (8) is shown in Fig. 2. $-E_n$ has been chosen as zero vector, so that vectorially

$$-E_n = E_n + o j$$

It should be noted in connection with Fig. 2 that θ is the power-factor angle lagging, and δ is the angle between I and E_n.

Now it can be shown that the angle between E_n and E_0 is the angular displacement of the machine. It is, however, somewhat different from the angular displacement between the rotor and the rotating electrical field.

It is actually the angular displacement between the rotor and an imaginary rotating electrical field corresponding in phase position to the terminal voltage, while the actual rotating electrical field corresponds in phase position to the induced voltage. There is a distinct advantage in calculating the displacement from the terminal voltage rather than from the induced voltage since the terminal voltage vector always rotates at uniform velocity provided the frequency of the impressed voltage is constant. But in a machine which is hunting, the induced voltage vector or the actual electrical field in the stator does not rotate uniformly because of the reactance, the $I\,x$ drop pulsating as the current pulsates. In problems involving hunting, it is necessary to calculate the variations in the speed of the rotor. This is done by calculating the angular displacement of the machine as function of time but it is evident that the angular displacement must be referred to a uniformly rotating vector. The advantage of referring the angular displacement to the terminal voltage rather than to the induced for all problems concerned with hunting and the calculation of P_s on this basis is thus apparent.

The angular displacement is therefore

$$\psi = (\theta + \delta) \tag{9}$$

The value of ψ corresponding to a given power input at

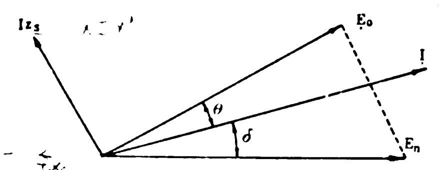

Fig. 2—Vector Diagram of Synchronous Motor Under Steady Load

a given power factor is easily determined from equation (8) as follows:

From Fig. (2),

$$\underline{I}\, z_s = I\,(\cos\delta + j\sin\delta)\,(r + j\,x_s)$$
$$= I\,[\,(r\cos\delta - x_s\sin\delta) + j\,(x_s{}'\cos\delta + r\sin\delta)\,] \tag{10}$$

It should be noted that an $x_s{}'$ is used with the component of current in phase with E_n or that component of the current which is maximum when the armature coils are directly under the centers of the field poles. This is according to Blondel's well known theory of two reactions and amounts to the same thing as Dr. Berg's[3] method with the exception that Dr. Berg based his equations on the induced voltage as zero vector which introduces a slight error especially at larger loads.

Substituting (10) in (8),

$$E_n = E_0\,[\,\cos(\delta + \theta) + j\sin(\delta + \theta)\,]$$
$$-\, I\,[r\cos\delta - x_s\sin\delta) + j\,(x_s{}'\cos\delta + r\sin\delta)\,] \tag{11}$$

Equation (11) may be separated into two equations, one involving only real terms, the other only imaginary.

3. Berg and Upson, "First Course in Electrical Engineering," Chapter XXXV, McGraw Hill & Co., 1916.

Thus, from the imaginary terms is obtained the equation,

$$E_0\,(\sin\delta\cos\theta + \cos\delta\sin\theta) = I\,(x_s{}'\cos\delta + r\sin\delta)$$

or

$$\sin\delta\,[E_0\cos\theta - I\,r] = \cos\delta\,[I\,x_s{}' - E_0\sin\theta] \tag{12}$$

or

$$\tan\delta = \frac{I\,x_s{}' - E_0\sin\theta}{E_0\cos\theta - I\,r} \tag{13}$$

This equation, which was derived by Blondel[4], gives the value of the angle δ for any load and power factor and consequently the displacement ψ, since $\psi = \delta + \theta$.

Very often, however, the field excitation and consequently the nominal voltage is fixed, and it is desired to find the displacement as function of the power under this condition.[5]

Equation (12) may be rewritten:

$$x_s{}'\,I\cos\delta + r\,I\sin\delta = E_0\sin\psi \tag{14}$$

In a similar manner the real terms of equation (11) give:

$$r\,I\cos\delta - x_s\,I\sin\delta = E_0\cos\psi - E_n \tag{15}$$

Equations (14) and (15) may be solved by determinants for $I\cos\delta$ and $I\sin\delta$ as follows:

$$I\cos\delta = \frac{r\,(E_0\cos\psi - E_n) + x_s\,E_0\sin\psi}{r^2 + x_s\,x_s{}'} \tag{16}$$

and

$$I\sin\delta = \frac{r\,E_0\sin\psi - x_s{}'\,(E_0\cos\psi - E_n)}{r^2 + x_s\,x_s{}'} \tag{17}$$

These are the two components of $\underline{I}$ along and at right angles to E_n, so that vectorially

$$\underline{I} = I\cos\delta + j\,I\sin\delta \tag{18}$$

Also from the vector diagram, Fig. 2,

$$\underline{E}_0 = E_0\cos\psi + j\,E_0\sin\psi \tag{19}$$

The input power may now be calculated by telescoping (18) and (19). Thus:

$$P = E_0\cos\psi\,I\cos\delta + E_0\sin\psi\,I\sin\delta \tag{20}$$

Substituting for $I\cos\delta$ and $I\sin\delta$ from equations (16) and (17) gives the input power as function of the displacement as follows:

$$P = E_0\cos\psi[r(E_0\cos\psi - E_n) + x_s\,E_0\sin\psi]\,\frac{1}{(r^2 + x_s x_s{}')}$$
$$+\, E_0\sin\psi[r\,E_0\sin\psi - x_s{}'(E_0\cos\psi - E_n)\,]\,\frac{1}{(r^2 + x_s x_s{}')} \tag{21}$$

4. "Synchronous Motors and Converters," McGraw Hill & Co., 1913. Blondel's equation involves + signs because it is derived for the alternator instead of the motor.

5. Incidentally, this is the problem involved in the calculation of P_s with the exception that the field transient must also be considered.

which reduces to

$$P = \frac{E_0^2}{(r^2 + x_s x_s')} \left\{ r - \frac{E_n}{E_0} (r \cos \psi - x_s' \sin \psi) + \sin \psi \cos \psi \, (x_s - x_s') \right\} \quad (22)$$

Equation (22) is useful as it gives the input power of a definite pole synchronous motor for a given angular displacement. A close approximation may be made to (22) by disregarding the resistance. This gives the somewhat simpler expression,

$$P = \frac{E_0^2}{x_s x_s'} \left\{ \frac{E_n}{E_0} x_s' \sin \psi + \sin \psi \cos \psi (x_s - x_s') \right\} \quad (23)$$

Differentiating (22) with respect to ψ, the slope of the tangent line shown in Fig. 1 is obtained:

$$P_s = \frac{dP}{d\psi} = \frac{E_0^2}{(r^2 + x_s x_s')} \left[x_d \cos 2\psi + \frac{E_n}{E_0} (x_s' \cos \psi + r \sin \psi) \right] \quad (24)$$

where

$$x_d = x_s - x_s'$$

or disregarding resistance terms

$$P_s = \frac{dP}{d\psi} = E_0^2 \left[\left(\frac{1}{x_s'} - \frac{1}{x_s} \right) \cos 2\psi + \frac{E_n}{E_0} \frac{1}{x_s} \cos \psi \right] \quad (25)$$

As pointed out in the beginning of this paper, this is not the P_s to be used in problems of hunting because it does not take into account the field transient. It does, however, represent the lowest limit of the value which P_s would approach if the forced oscillations were to take place very slowly—so slowly that the armature reaction and consequently the synchronous reactance would have time to function completely and there would be no field transient.

The Transient P_s of the Synchronous Motor Neglecting Resistance.[6]

If a machine which has been operating under steady load at displacement ψ is suddenly loaded so that its displacement increases by $\Delta \psi$ almost instantaneously, just what happens?

It is at once apparent from the vector diagram, Fig. 3, that the $\dot{I} \dot{z}_s$ vector is increased. This means an increase in the power, current, and armature reaction of the machine. Disregarding the resistance for the present, the $\dot{I} \dot{z}_s$ drop may be considered as made up of two components $i_1 x_s$ and $i x_s'$ according to Blondel's theory of two reactions. These components are shown in Fig. 3. The reactance x_s' which operates on the energy component of current which is i probably acts almost instantaneously. At least it is probable that the cross flux can build up and down as fast as any of the forced oscillations encountered in cases of hunting would require. The main flux, however, requires time to build up or down and so x_s cannot function instantly, or rather that part of x_s which is due to armature reaction cannot function instantly. Hence, the reactance which operates on a sudden increase in the wattless current is some transient or effective reactance which may be denoted by x_e and which lies between x, the real reactance, and x_s, the synchronous reactance, its value depending on the rate of change of the wattless current.

The power given by the motor, corresponding to an increase in the displacement from its average value of ψ to $(\psi + \Delta \psi)$, can be calculated as follows under the above assumptions. The method is simply to obtain expressions for $\dot{E}_0$ and $\dot{I}_0$ and telescope the vectors.

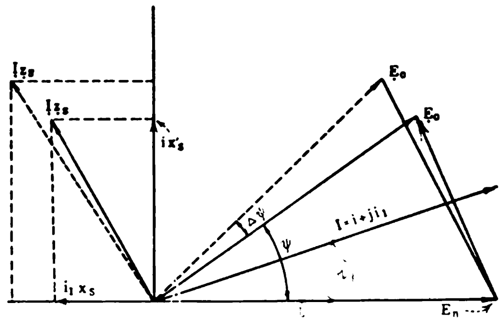

FIG. 3—VECTOR DIAGRAM OF SYNCHRONOUS MOTOR SHOWING EFFECT OF SUDDEN INCREASE IN LOAD

From Fig. 3,

$$\dot{E}_0 = E_0 [\cos (\psi + \Delta \psi) + j \sin (\psi + \Delta \psi)] \quad (26)$$

and before the displacement occurred

$$\dot{I} \dot{z}_s = -[E_n - E_0 \cos \psi] + j E_0 \sin \psi \quad (27)$$

Therefore, disregarding the resistance, the initial value of the current, corresponding to the average displacement ψ, is from (27).

$$\dot{I} = \frac{E_0 \sin \psi}{x_s'} + j \frac{E_n - E_0 \cos \psi}{x_s} \quad (28)$$

The real component of $\dot{I}$ corresponding to the increased displacement $(\psi + \Delta \psi)$ is

$$i = \frac{E_0 \sin (\psi + \Delta \psi)}{x_s'} \quad (29)$$

The *increase* in the wattless component is

$$\Delta i_1 = \frac{E_0 [\cos \psi - \cos (\psi + \Delta \psi)]}{x_e} \quad (30)$$

Note that the effective reactance is used here, since, as was shown above, it is the effective reactance which limits an increase in the wattless current. The wattless component of current corresponding to the increased displacement is then

6. A complete derivation taking resistance into account is given in the appendix.

$$i_1 = \frac{E_n - E_0 \cos \psi}{x_s} + \frac{E_0}{x_e} [\cos \psi - \cos (\psi + \Delta \psi)] \tag{31}$$

or

$$i_1 = E_0 \left\{ \left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos \psi - \frac{1}{x_e} \cos (\psi + \Delta \psi) + \frac{E_n}{E_0 x_s} \right\} \tag{32}$$

The power at displacement $(\psi + \Delta \psi)$ is therefore

$$P = \frac{E_0^2 \cos (\psi + \Delta \psi) \sin (\psi + \Delta \psi)}{x_s'} + E_0^2 \sin (\psi + \Delta \psi) \left\{ \left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos \psi - \frac{1}{x_e} \cos (\psi + \Delta \psi) + \frac{E_n}{E_0 x_s} \right\} \tag{33}$$

or

$$P = E_0^2 \left\{ \frac{\sin 2 (\psi + \Delta \psi)}{2 x_s'} + \sin (\psi + \Delta \psi) \left[\left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos \psi + \frac{E_n}{E_0 x_s} - \frac{1}{x_e} \cos (\psi + \Delta \psi) \right] \right\} \tag{34}$$

Differentiating P with respect to $\Delta \psi$, we obtain the rate of change of power with respect to an increase in the displacement which is P_s. Thus

$$P_s = E_0^2 \left\{ \left(\frac{1}{x_s'} - \frac{1}{x_e} \right) \cos 2 (\psi + \Delta \psi) + \cos (\psi + \Delta \psi) \left[\left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos \psi + \frac{E_n}{E_0 x_s} \right] \right\} \tag{35}$$

which is P_s at any displacement $(\psi + \Delta \psi)$.

At ψ

$$P_s = E_0^2 \left\{ \left(\frac{1}{x_s'} - \frac{1}{x_e} \right) \cos 2 \psi + \left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos^2 \psi + \frac{E_n}{E_0 x_s} \cos \psi \right\} \tag{36}$$

This is the value of P_s which should be used in all problems of hunting, and is represented by the slope of the dotted line in Fig. 1.

It still remains to calculate the value of x_e to be used in any given case. It has been shown that, in value, x_e lies in between x and $x_s = x + m/c$, where x is the real reactance and m/c is the armature reaction part of the synchronous reactance. Now when a motor is hunting, the demagnetizing component of armature reaction is a pulsating reaction against the field. If the pulsations take place slowly enough, the armature reaction will cause the field flux to pulsate the same amount. If, however, the pulsations are more rapid, the field flux will not have time to follow the pulsations in the armature reaction.

The problem then is merely to find out how much effect the armature reaction has on the field flux. This is a measure of the effectiveness of the m/c term in the synchronous reactance x_s. For very high speed pulsations $m/c = 0$. For very slow speed pulsations $m/c = m/c$, and in general,

$$x_e = x + K' \, m/c \tag{37}$$

where K' is the factor of *effectiveness* of *armature reaction* in destroying and building up the field flux in the main path.

K' may be determined from the following considerations:

Referring to Fig. 4, let the pulsating flux provided

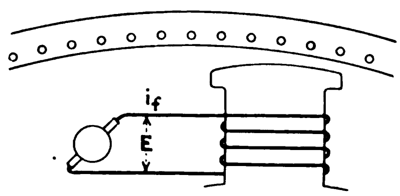

FIG. 4—DIAGRAM ILLUSTRATING PULSATING ARMATURE REACTION

by the demagnetizing component of armature reaction be represented by

$$\Phi \sin \omega t.$$

where

ω = frequency of the pulsations in radians per sec.

Let

N = No. of field turns per pole.
L = Effective inductance of the field.[7]
r_f = Effective resistance of the field.[7]
K = Coef. of coupling between armature and field.
E = D-c. voltage impressed on the field.

The equation of the field circuit is:

$$E = i_f (r_f + p L) + N K \Phi \omega \cos \omega t. \tag{38}$$

or

$$i_f = \frac{E - N K \Phi \omega \cos \omega t}{r_f + p L} \tag{39}$$

the permanent solution of which is:

$$i_f = \frac{E}{r_f} - \frac{N K \Phi \omega}{\sqrt{r^2 + L^2 \omega^2}} \cos \left(\omega t - \tan^{-1} \frac{L \omega}{r_f} \right) \tag{40}$$

This is the pulsating field current which exists in a machine when it is hunting. It may be seen from (40)

7. By "effective" resistance and inductance, the writer intends to consider the effect of the amortisseur winding, as will be seen later.

that if ω is small, there is little pulsation in the field current. If, however, ω is larger, there will be larger pulsations.

The resultant flux in the field pole can be obtained from the equation,

$$E - i_f r_f = N \frac{d \varphi_r}{d t} \tag{41}$$

or

$$\varphi_r = \frac{1}{N} \int (E - i_f r_f) dt \tag{42}$$

From equation (40)

$$E - i_f r_f = \frac{N r_f K \Phi \omega}{\sqrt{r_f^2 + L^2 \omega^2}} \cos \left(\omega t - \tan^{-1} \frac{L \omega}{r_f} \right) \tag{43}$$

$$\therefore \varphi_r = \frac{r_f K \Phi}{\sqrt{r_f^2 + L^2 \omega^2}} \sin \left(\omega t - \tan^{-1} \frac{L \omega}{r_f} \right) + C \tag{44}$$

The constant of integration in this case is the steady component of the resultant flux φ_r. From (44) it follows that the magnitude of the a-c. component of the resultant flux is

$$\Phi_r = \frac{r_f K \Phi}{\sqrt{r_f^2 + L^2 \omega^2}} \tag{45}$$

Now when ω is very small, the armature reaction is 100 per cent effective and

$$\Phi_r = K \Phi$$

$$\therefore K' = \frac{r_f K \Phi}{\sqrt{r_f^2 + L^2 \omega^2}} \div K \Phi = \frac{r_f}{\sqrt{r_f^2 + L^2 \omega^2}} \tag{46}$$

or

$$K' = \frac{1}{\sqrt{1 + \left(\frac{L}{r_f} \right)^2 \omega^2}} \tag{47}$$

In this formula $\left(\frac{L}{r} \right)$ refers to the field alone and is the time constant which determines the field transient occurring when the field circuit is closed on a constant voltage source. If this time constant is determined by an oscillogram of the starting current in the field, the effect of the amortisseur winding is automatically taken into consideration. K' is thus determined and from it x_e may be calculated by equation (37).

Section III. Examples and Conclusions

To determine the relative importance of the various factors which affect the value of P_s, consider a typical low-speed synchronous motor, the constants of which are:

$$\left.\begin{array}{ll} x_s = 0.85 & r = 0.06 \\ x_s' = 0.60 & x = 0.30 \\ & m/c = 0.55 \end{array}\right\} \tag{48}$$

$$\frac{L}{r_f} = 0.21 \quad \ldots \text{(from oscillogram of field transient)}$$

Assume that the speed of the above motor is 80 rev. per min. and that it is direct connected to a single-cylinder, double-acting compressor. A compressor of this type has two peaks in its torque curve every revolution so that the speed of the impressed pulsations is 160 per min. or $\omega = 16.75$ radians per sec.

From (37)

$$x_e = x + K' \frac{m}{c} \tag{37}$$

where

$$K' = \frac{1}{\sqrt{1 + \left(\frac{L}{r_f} \right)^2 \omega^2}} \tag{47}$$

Substituting the above values for L/r_f and ω in (47), it is found that $K' = 0.273$ which means that the armature reaction in the main field is only 27.3 per cent effective.

The effective reactance may be calculated from equation (37) thus:

$$x_e = 0.30 + 0.273 \times 0.55 = 0.45 \tag{48}$$

Having determined all the necessary constants, the behavior of the motor may now be calculated. Assume the machine to be operating at full-load unity power factor so that $\theta = 0$. The angular displacement may be calculated from (13).

$$\tan \delta = \frac{0.60 - 0}{1 - 0.06} = 0.638 \tag{49}$$

Since

$$\theta = 0, \quad \psi = \delta = 32.6 \text{ deg.}$$

The nominal voltage at full-load unity power factor may be determined from equation (15). Thus

$$E_n = 0.843 - (0.06 \times 0.843 - 0.85 \times 0.54) = 1.26 \tag{50}$$

Resumé of constants necessary for the calculation of P_s at full-load unity power factor, 80 rev. per min., single-cylinder double-acting compressor:

$$\begin{array}{ll} x_s = 0.85 & r = 0.06 \\ x_s' = 0.60 & x_e = 0.45 \\ \psi = 32.6 \text{ deg.} & E_n = 1.26 \end{array} \tag{51}$$

Neglecting resistance, the value of P_s may be obtained by substituting (51) in equation (36).

$$P_s = \left(\frac{1}{0.60} - \frac{1}{0.45} \right) 0.42 + \left(\frac{1}{0.45} - \frac{1}{0.85} \right) 0.71 + \frac{1.26}{0.85} \times 0.843 = 1.76^{8} \tag{52}$$

Effect of Frequency of Load Pulsations on P_s.

If the motor had been driving a two-cylinder, double-

8. This value of P_s is given on a percentage basis. To get it in kw. it must be multiplied by the kw. rating of the motor.

acting compressor, the torque curve of which would have four peaks per revolution, ω would be twice as great and

$$K' = 0.141$$

and

$$x_e = 0.378$$

With this value of x_e, P_s would be somewhat greater, thus:

$$P_s = \left(\frac{1}{0.60} - \frac{1}{0.378}\right) 0.42 + \left(\frac{1}{0.378} - \frac{1}{0.85}\right) 0.71 + \frac{1.26}{0.85} \times 0.843 = 1.88 \quad (53)$$

Thus it is evident that the value of P_s for this case is about 7 per cent greater when the motor is used to drive a two-cylinder, double-acting compressor, than it is when driving a single-cylinder, double acting

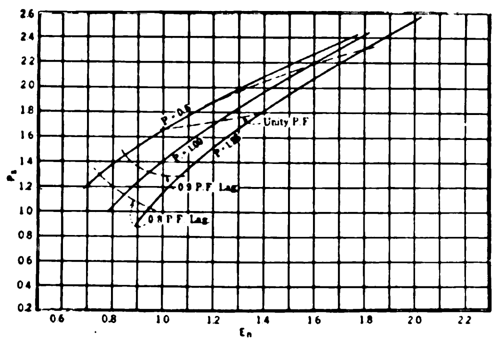

Fig. 5—Curves Showing Synchronizing Power, P_s as Function of the Nominal Voltage, E

machine. In higher speed motors this difference will be still less so that, while P_s is not entirely independent of the nature of the load, it is approximately so, for compressors of the conventional types and speeds.

Effect of Resistance on P_s.

The effect of the resistance on the value of P_s may be determined by calculating P_s from equation (**20**), given in appendix, which gives

$$P_s = 1.81 \quad (54)$$

This represents an increase of only 2½ per cent in the value of P_s obtained by neglecting resistance. It should also be noted that 6 per cent resistance is unusually high and hence it may be concluded that for practical work the effect of the resistance may be disregarded.

Effect of Excitation on P_s.

Fig. 5 shows a family of three curves which give P_s as function of the excitation E_n, for 1¼ load, full load, and half load.[9] It may be seen at a glance that the relationship is practically linear for a given load, except at the lower end where the curves droop as the motor approaches the breakdown point. At no load the function would theoretically be a straight line.

The dotted lines are constant power-factor curves and show roughly the power factor which will be obtained for various values of excitation and load.

The half-load line is of particular interest. There

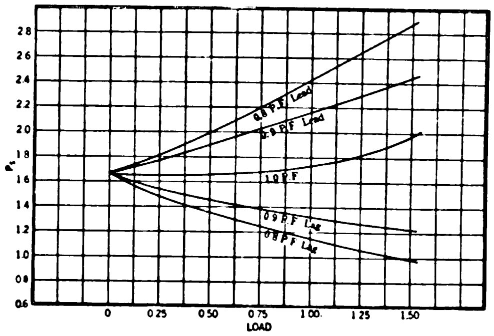

Fig. 6—Curves Showing Effect of Changes in Load on the Value of the Synchronizing Power, P_s

is very little tendency for the curve to droop even at the lower extremity. This shows that the motor may be operated at half load at a power factor as poor as 0.7 lagging or even less without danger of the motor falling out of step. In fact it would be possible to reduce P_s to a value as low as 1.1 at half load by reducing the excitation sufficiently.

This fact is made use of in connection with the unloading of two-cylinder, double-acting compressors by removing one connecting rod. Ordinarily the flywheel is so designed that the natural frequency corresponds

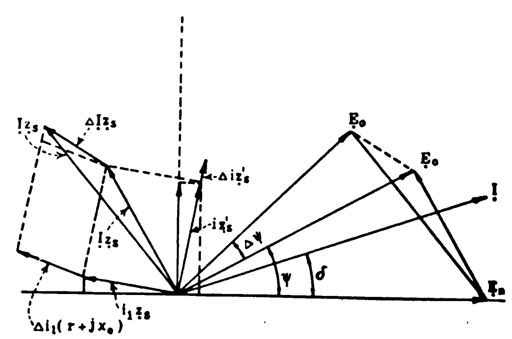

Fig. 7—Vector Diagram of Synchronous Motor Showing Effect of Sudden Increase in Load. (Resistance Taken Into Account)

to about twice the revolutions. This is all right for two-cylinder, double-acting compressors since there is no second harmonic in the torque curve. But if the machine is unloaded there is a large second harmonic and, if severe hunting is to be prevented, the natural frequency must be brought below it. This can be done by reducing P_s and running the motor at a poor lagging power factor. While such operating is not to be recommended as standard practise, it is valuable to know that it may be resorted to in emergency cases.

Effect of Load on P_s.

Fig. 6 shows another family of curves which give P_s

9. The values used in plotting the curves in Figs. 5 and 7 were obtained by substituting (**51**) in equations (**13**), (**15**), and (**36**).

as function of load for various power factors. At a slightly lagging power factor P_s is almost unaffected by the load, while at 0.8 leading power factor there is a decided increase in P_s with load. At 0.8 lagging power factor there is a decided decrease to half load after which the value remains practically the same.

Range of P_s.

In calculating the value of P_s for a number of engine-type, slow-speed synchronous motors, the writer has found that the value is practically always between 1.6 and 2.2 at full load unity power factor. In general, P_s is low in motors of large size and very slow speed, but higher in motors of smaller size and higher speed. Its value depends largely on the real reactance of the machine and on the ratio of the no-load excitation to the full-load armature reaction. A large reactance and low ratio tend to make a low value of P_s.

Appendix

The Transient P_s of the Synchronous Motor Taking Resistance into Account.

It has been shown in Equations (**16**) and (**17**) that under ordinary steady conditions

$$I = i + j\, i_1$$

where

$$i = \frac{r\,(E_0 \cos\psi - E_n) + x_s\, E_0 \sin\psi}{r^2 + x_s\, x_s'} \tag{1}$$

and

$$i_1 = \frac{r\, E_0 \sin\psi - x_s'\,(E_0\cos\psi - E_n)}{r^2 + x_s\, x_s'} \tag{2}$$

Now suppose ψ is suddenly increased to $(\psi + \Delta\,\psi)$. Just as before, there is an increase in the $I\, z_s$ drop as shown in Fig. 7 which is

$$\Delta\, I\, z_s' = E_0\,\{-[\cos\psi - \cos(\psi + \Delta\,\psi)] + j\,[\sin(\psi + \Delta\,\psi) - \sin\psi]\,\} \tag{3}$$

This increase in $I\, z_s$ is made up of two $i\, z$ drops. One is due to the real component of I, which is

$$\Delta\, i\,(r + j\, x_s') \tag{4}$$

since it is assumed that the cross armature reaction flux has time to function. The other $i\, z$ drop is due to the wattless component of current i_1, and is

$$j\,\Delta\, i_1\,(r + j\, x_e) \tag{5}$$

where x_e is the effective reactance.

Hence, from the above statement and equations (**4**) and (**5**),

$$\Delta\, I\, z_s = \Delta\, i\, r - \Delta\, i_1\, x_s + j\,(\Delta\, i\, x_s' + \Delta\, i_1\, r) \tag{6}$$

Equating real and imaginary parts of equations (**3**) and (**6**),

$$\Delta\, i\, r - \Delta\, i_1\, x_s = E_0\,[\cos(\psi + \Delta\,\psi) - \cos\psi] \tag{7}$$

$$\Delta\, i\, x_s' + \Delta\, i_1\, r = E_0\,[\sin(\psi + \Delta\,\psi) - \sin\psi] \tag{8}$$

Therefore

$$\Delta\, i = \frac{E_0}{r^2 + x_s'\, x_s}\,\{x_e\,[\sin(\psi + \Delta\,\psi) - \sin\psi + r\,[\cos(\psi + \Delta\,\psi) - \cos\psi]\,\} \tag{9}$$

and

$$\Delta\, i_1 = \frac{E_0}{r^2 + x_s'\, x_e}\,\{x_s'\,[\cos\psi - \cos(\psi + \Delta\,\psi)] + r\,[\sin(\psi + \Delta\,\psi) - \sin\psi]\,\} \tag{10}$$

By adding $\Delta\, i$ and $\Delta\, i_1$ to the original components of current, the new components are obtained.

$$i = \frac{E_0}{r^2 + x_s\, x_s'}\left\{ r\left(\cos\psi - \frac{E_n}{E_0}\right) + x_s \sin\psi \right\} + \frac{E_0}{r^2 + x_s'\, x_e}\,\{x_e\,[\sin(\psi + \Delta\,\psi) - \sin\psi] - r\,[\cos\psi - \cos(\psi + \Delta\,\psi)]\,\} \tag{11}$$

and

$$i_1 = \frac{E_0}{r^2 + x_s\, x_s'}\left\{ r\sin\psi - x_s'\left(\cos\psi - \frac{E_n}{E_0}\right) \right\} + \frac{E_0}{r^2 + x_s'\, x_e}\,\{x_s'\,[\cos\psi - \cos(\psi + \Delta\,\psi)] + r\,[\sin(\psi + \Delta\,\psi) - \sin\psi]\,\} \tag{12}$$

The new voltage is:

$$E_0\,\{\cos(\psi + \Delta\,\psi) + j\sin(\psi + \Delta\,\psi)\,\} \tag{13}$$

Telescoping the current and voltage, the power is obtained.

$$\begin{aligned} P = {} & E_0^2 \cos(\psi + \Delta\,\psi)\left[\frac{r\left(\cos\psi - \dfrac{E_n}{E_0}\right) + x_s \sin\psi}{r^2 + x_s\, x_s'} + \frac{x_e\{\sin(\psi+\Delta\,\psi) - \sin\psi\} - r\{\cos\psi - \cos(\psi + \Delta\,\psi)\}}{r^2 + x_s'\, x_e}\right] \\ & + E_0^2 \sin(\psi + \Delta\,\psi)\left[\frac{r\sin\psi - x_s'\left(\cos\psi - \dfrac{E_n}{E_0}\right)}{r^2 + x_s\, x_s'} + \frac{x_s'\{\cos\psi - \cos(\psi+\Delta\,\psi)\} + r\{\sin(\psi + \Delta\,\psi) - \sin\psi\}}{r^2 + x_s'\, x_e}\right] \end{aligned} \tag{14}$$

In the above equation let

$$\left.\begin{aligned} r^2 + x_s'\, x_e &= z_e^2 \\ \text{and} \quad r^2 + x_s'\, x_s &= z_0^2 \end{aligned}\right\} \tag{15}$$

Substituting (**15**) in (**14**) and reducing,

$$\begin{aligned} P = {} & E_0^2 \cos(\psi + \Delta\,\psi)\left[\frac{-r\,(x_s - x_e)}{z_0^2\, z_e^2}\,\{-r\sin\psi + x_s'\cos\psi\,\} + \frac{1}{z_e^2}\{x_e \sin(\psi + \Delta\,\psi) + r\cos(\psi + \Delta\,\psi)\,\} - \frac{r\, E_n}{z_0^2\, E_0}\right] \\ & + E_0^2 \sin(\psi + \Delta\,\psi)\left[\frac{x_s'(x_s - x_e)}{z_0^2\, z_e^2}\,\{x_s'\cos\psi - r\sin\psi\}\right. \end{aligned}$$

$$+ \frac{1}{z_e^2} \{ r \sin (\psi + \Delta \psi) - x_s' \cos (\psi + \Delta \psi) \}$$

$$+ \frac{x_s'}{z_0^2} \frac{E_n}{E_o} \Big] \qquad (16)$$

In Equation (**16**), let

$$C = \frac{(x_s - x_e)}{z_0^2 \, z_e^2} \{ x_s' \cos \psi - r \sin \psi \} \qquad (17)$$

Substituting (**17**) in (**16**),

$$P = E_0^2 \cos (\psi + \Delta \psi) \Big[- r\, C + \frac{1}{z_e^2}$$

$$\{ x_e \sin (\psi + \Delta \psi) + r \cos (\psi + \Delta \psi) \} - \frac{r\, E_n}{z_0^2\, E_0} \Big]$$

$$+ E_0^2 \sin (\psi + \Delta \psi) \Big[x_s' \, C + \frac{1}{z_e^2}$$

$$\{ r \sin (\psi + \Delta \psi) - x_s' \cos (\psi + \Delta \psi) \} + \frac{x_s' \, E_n}{z_0^2 \, E_0} \Big] \qquad (18)$$

Differentiating P with respect to $\Delta \psi$ to get P_s,

$$P_s = E_0^2 \left\{ \left(C + \frac{E_n}{z_0^2\, E_0} \right) [x_s' \cos (\psi + \Delta \psi) \right.$$

$$\left. + r \sin (\psi + \Delta \psi) + \frac{x_e - x_s'}{z_e^2} \cos 2 (\psi + \Delta \psi) \right\} \qquad (19)$$

At displacement ψ, (**19**) becomes

$$P_0 = E_0^2 \left\{ \left(C + \frac{E_n}{z_0^2 \, E_0} \right) [x_s' \cos \psi + r \sin \psi] \right.$$

$$\left. + \frac{x_s - x_s'}{z_e^2} \cos 2 \psi \right\} \qquad (20)$$

which is the required value of P_s, taking resistance into account. In this formula, c is given by equation (**17**), and z_e and z_0 by equation (**15**).

If the resistance terms are disregarded,

$$C = \frac{(x_s - x_e)}{x_s \, x_s' \, x_e} \cos \psi \qquad (21)$$

Substituting (**21**) in equation (**20**) and neglecting r, equation (**20**) degenerates into

$$P_s = E_0^2 \left\{ \left(\frac{1}{x_e} - \frac{1}{x_s} \right) \cos^2 \psi \right.$$

$$\left. + \left(\frac{1}{x_s'} - \frac{1}{x_e} \right) \cos 2 \psi + \frac{E_n}{E_0 \, x_s} \cos \psi \right\} \qquad (22)$$

which is the expression obtained previously for the case of no resistance, Eq. (**36**).

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WILL HE SEE AND HEAR ACROSS U. S. IN 1929?

"I expect to see and hear by electricity the presidential inauguration in 1929 even though I may be thousands of miles away from Washington," declares Dr. Gerald Wendt, director of the division of industrial research, Pennsylvania State College. He is foreseeing electrical advances that are sure to be made in the next few years by industrial research. "Single pictures are already being sent across the sea," he points out. "When a more sensitive photoelectric cell is developed, a picture will be transmitted as rapidly as the movie can flash it on the screen. In Washington during the ceremony, the microphone will have a 'microscope' alongside it and I shall be sitting in my own living room seeing and hearing the entire performance as if I were on the spot. Then we shall have radio movies for every home."

WIND MAKES POWER LINES "HEAVY ON THEIR FEET"

Power lines have to be built to support wind as well as wire. Where a new high-tension line crosses the Sacramento River with a span four-fifths of a mile long, the tallest power-line tower in the world rears its top 459 feet in air. The weight of wire suspended in a long arc from this tower to another 410 feet high on the opposite side of the stream is 69,000 pounds but wind pressure against the wires may add as much as 14,400 lb. to the load. The tallest steel structure itself weighs 405,000 lb. but is built to resist a wind pressure of 108,000 lb. It stands on a foundation of piles driven 80 ft. into the ground under a concrete base weighing a million pounds. Sixty-six per cent of this piling and concrete is required for wind load only.

Abridgment of

The Circle Diagram of a Transmission Network

BY FREDERICK EMMONS TERMAN[1]

Associate, A. I. E. E.

Synopsis.—*The first circle diagrams of the character herein described were published almost simultaneously by Thielemans in Europe and Evans and Sels in this country. The diagram of Evans and Sels is not nearly as complete as Thielemans's, but is more easily constructed because of the mathematical methods employed to determine the circle centers and radii. The present paper is an elaboration of the work done by these two investigators. It coordinates the graphical and mathematical methods of construction and extends their application.*

The principal contributions of this article are incorporated in Tables I and II and in the paragraphs concerning geometrical checks that may be applied to the circle diagram. Tables I and II include formulas for determining the coefficients of a large number of circular loci which have not been heretofore constructed by mathematical methods. Other formulas given in Tables I and II are to be found elsewhere, but generally in a somewhat more complicated, although equivalent, form. The graphical checks that result from the geometrical properties of the circle diagram, as first investigated by Thielemans, have not heretofore been applied to diagrams derived by mathematical computations. By establishing the identity of the Thielemans and Evans and Sels diagrams, it has been possible to utilize the numerous geometrical properties of the diagram that Thielemans has worked out, as well as to make use of other graphical properties. With the aid of the information incorporated in the following paragraphs it is possible to construct a circle diagram on which may be drawn circles representing almost any conceivable locus. This construction is carried out with the aid of computations made from the relatively simple formulas incorporated in Tables I and II. Any errors in the mathematical or graphical work that lead to an incorrect diagram can be simply and quickly uncovered by applying the numerous geometrical checks that are given in the paper. The result is a diagram easy to obtain, almost error proof, and of extreme usefulness.

* * * * *

INTRODUCTION

In the last few years there has been considerable development in methods for the graphical solution of transmission systems. The principal results of this work have been the conception of network constants developed by Evans and Sels,[2] and the work that has been done on the circle diagram by Thielmans[3], Evans and Sels[2], and others.

At the present time the information available on the circle diagram consists of more or less incomplete and unrelated fragments that have been developed by these different writers. It is the purpose of the present paper first, to coordinate, consolidate and expand the work that has been done on the circle diagram; second, to develop simpler methods of constructing the diagram; and finally, to determine new loci.

Any electrical network to which power is supplied at two terminals and this power transmitted by the network to another pair of terminals can always have its characteristics represented by either of the following pairs of equations in which the subscripts s and r denote sending-end and receiving-end quantities, respectively:

$$E_s = A\,E_r + B\,I_r \qquad \textbf{(1a)}$$

$$I_s = C\,E_r + D\,I_r \qquad \textbf{(1b)}$$

$$E_r = D\,E_s - B\,I_s \qquad \textbf{(2a)}$$

$$I_r = A\,I_s - C\,E_s \qquad \textbf{(2b)}$$

These two pairs of equations are equivalent to each other but it is often convenient to utilize all four equations. The frequency of transmission and the character of the electrical network being used for transmission are taken into account by the four complex quantity coefficients A, B, C, and D. A set of such constants, commonly referred to as the *network constants,* can always be determined from a knowledge of the network elements and the frequency. Only three of the four constants are independent, for it can be shown that in any network the relation $A\,D = 1 + B\,C$ must hold true. Also, in the special case of a network which is symmetrical about the center it can be shown that $A = D$.

RECEIVING-END CIRCLE DIAGRAM

Construction of the Diagram. Let us first lay out a coordinate system in which the X and Y axes represent received power P_r and received reactive power Q_r, respectively, with *leading values of Q_r considered as positive.* With the aid of equations (1) and (2) it is possible to compute values of P_r and Q_r which will give a constant generator voltage E_s. When these results are plotted on the $P_r - Q_r$ coordinate system, the result is found to be a circle no matter what constant value of E_s is being investigated *when the receiver voltage E_r is constant.* The only effect of the value of E_s is to vary the radius, so that the locus of points on the $P_r - Q_r$ coordinates which represent constant values of E_s is a family of concentric circles, as shown in Fig. 1. If the investigation is continued, it is found that the loci of points in Fig. 1 which represent constant generator power factor, constant efficiency of transmission, constant sending-end power, etc., are also circles, *provided only that the receiver voltage is kept constant.* A $P_r - Q_r$ coordinate system upon which such circular

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2. Evans and Sels, *Electric Journal,* 1921.

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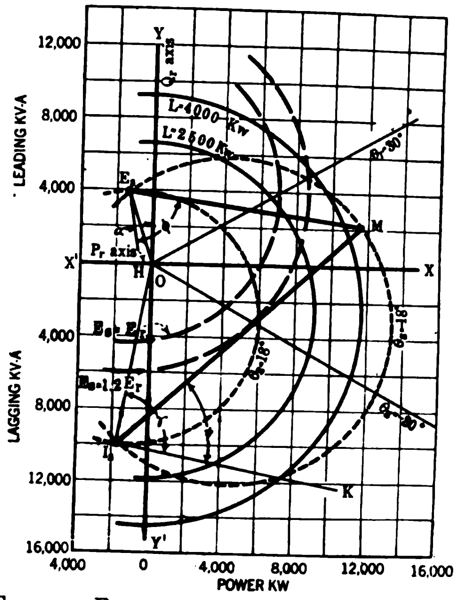

FIG. 1—TYPICAL RECEIVING-END CIRCLE DIAGRAM

Showing loss circles, sending-voltage circles, and sending-end power-factor circles

loci have been placed is called the *receiving-end circle diagram* of the transmission network.

In order that the circle diagram may be of practical use, it is necessary to find some satisfactory way of drawing the various circular loci that may be put on the coordinates in Fig. 1. To draw a circle, one must know the coordinates of the center and the value of the radius measured in terms of the coordinate system. Starting with the equations (1) and (2), it is possible to derive equations that give the relation of P_r, Q_r and E_r to other quantities, such as generator voltage, generator end power, etc. These all come out as equations of circles, and from these equations we can determine the P_r and Q_r coordinates of the circle centers and the length of the circle radii. The results of such a series of computations are given in Table I which presents the formulas required to compute the center and radius of any kind of circle that one may desire to draw on the $P_r - Q_r$ coordinates. The method used in obtaining the equations in Table I is indicated in Appendix A. In Appendix C will be found a numerical example which

TABLE I
CIRCLE COEFFICIENTS OF RECEIVING-END DIAGRAM

Kind of circle	P_r coordinate of center	Q_r coordinate of center	Radius	Remarks*
Sending-end voltage...	$-w = -e_r^2 \frac{a}{b} \operatorname{Cos}(\alpha - \beta)$	$-x = -e_r^2 \frac{a}{b} \operatorname{Sin}(\alpha - \beta)$	$\frac{e_r\, e_s}{b}$	Circles are concentric
Power loss in transmission............	$-w + m \cos^2 \beta$	$-x - \frac{m}{2} \sin 2\beta$	$\sqrt{m L - m w + m^2 \cos^2 \beta}$	Circles are concentric
Sending-end power factor................	The sending-end power factor circles can be drawn by a simple geometric construction that is much quicker than the analytic method. See text for graphical method.			
Sending-end current...	$-e_r^2 \frac{c}{d} \operatorname{Cos}(\gamma - \delta)$ $= -w + \frac{e_r^2}{b\,d} \operatorname{Cos}(\beta + \delta)$	$-e_r^2 \frac{c}{d} \operatorname{Sin}(\gamma - \delta)$ $= -x - \frac{e_r^2}{b\,d} \operatorname{Sin}(\beta + \delta)$	$\frac{i_s\, e_r}{d}$	Circles are concentric
Efficiency of transmission...............	$-w + \frac{m}{2}\left[\cos 2\beta + \frac{1}{\eta}\right]$	$-x - \frac{m}{2} \operatorname{Sin} 2\beta$	$\sqrt{\frac{m^2}{4}\left[1 + \frac{1}{\eta^2} + \frac{4}{\eta}\left(\frac{\operatorname{Cos} 2\beta}{2} - \frac{w}{m}\right)\right]}$	Circles are not concentric
Sending-end power....	$-w + m \frac{\cos 2\beta}{2}$	$-x - m \frac{\sin 2\beta}{2}$	$\sqrt{m P_s + \frac{m^2}{4}}$	Center is usually off page
Sending-end reactive volt-amperes........	$-w - \frac{r}{2} \sin 2\beta$	$-x - \frac{r}{2} \cos 2\beta$	$\sqrt{\frac{r^2}{4} + r Q_s}$	Circles are concentric
Reactive volt-amperes consumed by line.. .	$-w - r \frac{\sin 2\beta}{2}$	$-x + r \operatorname{Sin}^2 \beta$	$\sqrt{r V - r x + r^2 \sin^2 \beta}$	Circles are concentric
Receiver current.......	0	0	$i_r\, e_r$	Circles are concentric
Receiver admittance...	0	0	$Y_r\, e_r^2$	Circles are concentric
Sending-end conductance	$-w - k \cos 2\beta$	$-x + k \sin 2\beta$	k	Circles are not concentric
Sending-end susceptance...............	$-w + l \sin 2\beta$	$-x + l \cos 2\beta$	l	Circles are not concentric

Notation

$A = a \angle \alpha$, $B = b \angle \beta$, $C = c \angle \gamma$, $D = d \angle \delta$ } Network constants

P = Power in watts per phase
Q = Reactive volt-amperes per phase
E = Voltage to neutral
I = Current in each wire
G = Conductance to neutral
B_s = Susceptance at sending end
Y = Admittance
$L = P_s - P_r$ = Watts loss in transmission per phase
$\eta = P_r / P_s$ = Efficiency of transmission
$V = Q_s - Q_r$ = Reactive volt-amperes consumed in transmission

$$w = \frac{a}{b}\, e_r^2 \cos(\alpha - \beta); \quad x = \frac{a}{b}\, e_r^2 \sin(\alpha - \beta)$$

$$m = \frac{e_r^2}{b\, d \cos(\delta - \beta)} \qquad r = \frac{e_r^2}{b\, d \sin(\delta - \beta)}$$

$$k = \frac{1}{2}\, \frac{m\, e_r^2}{G_s\, b^2\, m - e_r^2}$$

$$l = \frac{1}{2}\, \frac{r\, e_r^2}{B_s\, b^2\, r - e_r^2}$$

Subscript "*s*" denotes a sending-end quantity.
Subscript "*r*" denotes a receiving-end quantity.
A positive Q or V denotes leading reactive volt-amperes.
In designating vector quantities a capital letter denotes the vector while the small letter denotes the length of this vector.

*These remarks apply only to the case when the receiver-end voltage is constant.

shows in a specific way the method of utilizing Table I in constructing the circle diagram.

After Table I has been used to determine the circular loci, and these have been drawn on the $P_r - Q_r$ coordinates, the values of the sending-end voltage, power, power factor, etc., that go with known receiving-end conditions can be determined by inspection from the diagram. It is necessary merely to observe the various circles that pass through the point on the coordina e system that represents the known receiving-end conditions. This indicates the great usefulness of the circle diagram, for the one set of computations required to draw the diagram gives the solution of the transmitting system for all possible conditions.

It is evident from Table I that a great number of families of circular loci may be drawn on one system of coordinates. Not all of these are ordinarily needed in the solution of any particular problem, however, and in any event it is best to draw no more than three or possibly four sets of circles on one coordinate system. When more loci are required it is preferable to divide them between two or more diagrams.

When deciding which loci to draw on a diagram, it is well to keep in mind the information in Table I under the column entitled "Remarks." When representing the characteristics of a transmission system for ordinary purposes it is usually sufficient to draw three families of circles, which can best be sending-end voltage circles; transmission power-loss circles; and either sending-end power factor circles, or sending-end reactive power circles; drawing each family of circles in colored ink of a distinguishing hue. The data given by these sets of circles will enable other items of importance to be easily determined. Thus the sending-end power can readily be found by adding the power loss to the received power; the efficiency of transmission is the ratio of receiver to sending-end power, etc.

It is worth noting that all of the circle centers and radii can be computed from Table I without involving the network constant C. This is possible because only three of the network constants are independent, so that the constant C can be expressed in terms of A, B, and D.

Procedure to be followed in drawing circle diagram. In drawing the receiving-end circle diagram it is necessary to take the following steps:

1. Lay out a set of $P_r - Q_r$ coordinates to any convenient scale which will cover the range of values to be expected.
2. Decide upon the kinds of loci that will be best suited to give the information that is desired.
3. Compute the centers and radii of the desired circles with the aid of Table I, and draw these circles on the coordinate system that has been laid out. In making these computations it is necessary to exercise care in determining the algebraic signs of the terms involving sines and cosines of angles.
4. Apply as many of the geometrical checks and constructions described below as are desired.

A receiving-end circle diagram can be drawn only for a fixed value of receiving voltage E_r. It is necessary to draw a separate receiving-end diagram for each receiver voltage to be considered. The approximate locations of the various circle centers are shown in Figs. 1, 2, and 3, which represent actual results given by a long transmission line with terminal transformers. The notation of these figures is that of Table I, with the addition that the center of the P_s circles is designated by P_s, the center of the E_s circles by E_s, etc.

The units involved in the diagram need introduce no confusion. The results given in Table I are based on equations (1) and (2); thus the units of the circle diagram are the units of these equations. This will ordinarily mean volts to neutral, current in each wire, watts and volt-amperes per phase, transmission loss in watts per phase, etc., as indicated in Table I.

Geometrical properties of the receiving-end circle diagram. A circle diagram drawn following the formulas in Table I must possess certain geometrical properties. While these properties can be used to draw the circular loci, it is more accurate and much quicker to draw the diagram with the aid of Table I, and to use the geometrical properties as checks to verify the correctness of the construction. The only exception to this is in the case of sending-end power factor circles, which are most satisfactorily drawn by the geometrical construction given below. The more important graphical properties of the receiving-end circle diagram follow:

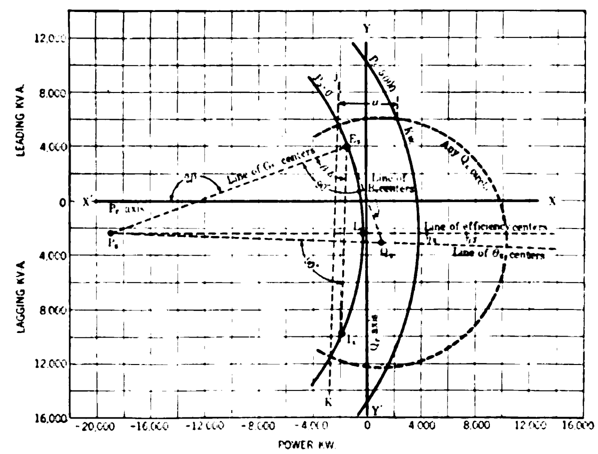

Fig. 2—Receiving-End Circle Diagram

Showing approximate location of centers and some of the diagram's geometrical properties

Location of E_s. The angle $X\,O\,E_s$ (see Fig. 3) must equal $(180° + \alpha - \beta)$ when measured in the conventional manner from $O\,X$.

Location of I_s. The angle $X\,O\,I_s$ (see Fig. 3) must equal $(180° - \gamma + \delta)$ when measured backward from $O\,X$.

Locus of constant receiver power factor. Constant receiver power factor is equivalent to a constant Q_r/P_r, and the locus of this condition is a straight line passing through the origin of the $P_r - Q_r$ coordinates.

The angle between this straight line and the axis $O X$ is the power-factor angle θ_r. Positive values of θ_r indicate that the received current leads the receiver voltage by the angle θ_r. Fig. 1 shows several constant receiver power-factor loci.

Phase of sending-end voltage and sending-end current. The phase of sending-end voltage with reference to the receiver voltage is found by drawing $E_s H$ in Fig. I so that the angle of $O E_s H$ measured backward from $E_s O$ is equal to α. The true phase of E_s referred to E_r for any point M on the diagram is then the phase of $E_s M$ relative to $E_s H$. This is the angle Φ shown in Fig. 1. The phase of sending-end current with reference to the receiver voltage is found by drawing $I_s K$ backward from $O I_s$ by the angle γ. The phase of I_s referred to receiver voltage for any point M on the diagram is then the phase of $I_s M$ relative to $I_s K$. This is the angle ψ shown in Fig. 1.

Sending power-factor circles. If M is some point on the coordinate system in Fig. 1, then the angle $E_s M I_s$

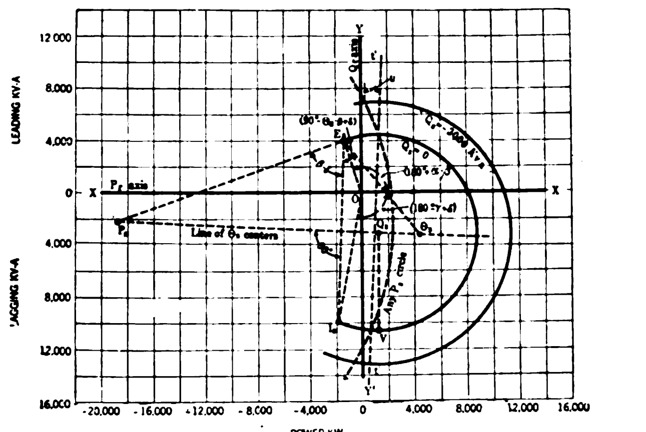

FIG. 3—RECEIVING-END CIRCLE DIAGRAM

Showing approximate locations of centers, and some of the diagram's geometrical properties

equals $(\theta_s + \beta - \delta)$, where θ_s is the angle by which I_s leads E_s, and therefore is a *positive angle for leading power factors*. The locus of points for constant θ_s is accordingly a circle passing through E_s and I_s, and with its center on the perpendicular bisector of $E_s I_s$. The location of the center on this perpendicular bisector depends upon the power factor being represented, and can be found by laying off the angle $I_s E_s \theta_s$ in Fig. 3 equal to $(90° - \theta_s - \beta + \delta)$ measured in the positive direction from $E_s I_s$. The intersection of $E_s \theta_s$ with the perpendicular bisector is the center desired, and the radius can be readily determined by the fact that the circle must pass through E_s. This geometrical construction offers the only satisfactory method of determining the θ_s circles, for the corresponding formula that might be put in Table I is most cumbersome and awkward in application.

Sending-end power circles. The center of these circles, P_s, is the point where the line $P_s E_s$ intersects the perpendicular bisector of $E_s I_s$, as shown in Fig. 2. The line $P_s E_s$ is determined by laying off the angle $P_s E_s I_s$ equal to $(\beta - \delta)$. This construction is shown in Fig. 2.

The sending-end power represented by any circle with P_s as a center can also be determined by a graphical construction. Draw any convenient circle representing sending-end reactive power (a Q_s circle). This circle must be large enough to intersect the P_s circle that passes through E_s. Draw a line through the two points of intersection (line $j\,k$ in Fig. 2). This line will be parallel to $E_s I_s$. The sending-end power represented by any P_s circle can then be found by noting where this circle intersects the Q_s circle mentioned above. The perpendicular distance from this intersection to $j\,k$ is proportional to the value of P_s being represented. Let this distance be u when measured in terms of the coordinate system. Then in the notation of Table I, the value of P_s that corresponds to u is

$$P_s = \frac{u}{\sin(\beta - \delta)}$$

Transmission loss circles. The center of the loss circles is point L. This is the point where the line parallel to $X X'$ and passing through P_s intersects the circle that has P_s as its center and passes through E_s. See Fig. 2. This sending power circle that passes through E_s is the circle for which $P_s = O$. The intersection of this circle with a loss circle must occur at a value of P_r that is the negative of the loss represented by the loss circle forming the intersection. This determines the radii of the loss circles.

Efficiency circles. The centers of the efficiency circles lie on the parallel to $X X'$ which passes through P_s. The distance from the efficiency center to P_s is in inverse proportion to the efficiency being represented, so that referring to Fig. 2,

$$\frac{\text{Length } P_s\,\eta_y}{\text{Length } P_s\,\eta_x} = \frac{\text{Efficiency } \eta_x}{\text{Efficiency } \eta_y}$$

This property can be used to locate quickly a large number of efficiency centers after one center has been computed from Table I.

Q_s circles. The point Q_s which is the center of the sending-end reactive power circles is also the center of the sending-end power-factor circle for which $\theta_s = O$. The Q_s circle representing the condition $Q_s = O$ passes through E_s, and of course coincides with the power-factor circle for $\theta_s = O$. The sending-end reactive power represented by any Q_s circle can also be determined geometrically. Select a convenient sending-end power circle that intersects the circle for $Q_s = O$ and the other Q_s circles to be investigated. Draw the line $t\,t'$ which joins the points where the circle $Q_s = O$ intersects this P_s circle (see Fig. 3). The value of Q_s represented by any reactive sending-end power circle can be found by noting where this circle intersects the P_s circle being used in the determination. The perpendicular

distance from this intersection to the line $t\,t'$ is proportional to the value of Q_s at the intersection. If this distance is u' (see Fig. 3) when measured in terms of the coordinate system, the value of the Q_s circle that gives this distance is

$$Q_s = \frac{u'}{\cos(\beta - \delta)}$$

The notation used is that given in Table I. Intersections to the right of $t\,t'$ are caused by leading or positive values of Q_s, and intersections to the left of $t\,t'$ represent lagging or negative values of Q_s.

V circles. The center of these circles, the point V in Fig. 3, is where the parallel to $Y\,Y'$ that passes through the point Q_s intersects the sending-end reactive

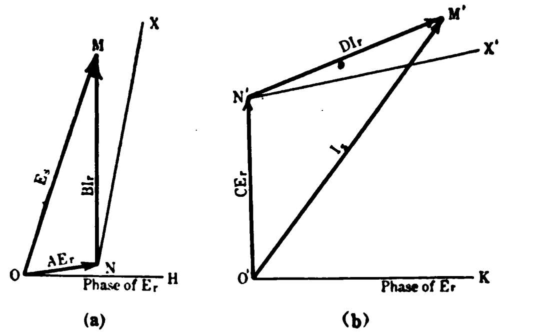

FIG. 4A-B—VECTOR DIAGRAM REPRESENTING EQUATIONS (1A) AND (1B) IN VECTOR FORM

power circle representing $Q_s = O$. This is shown in Fig. 3. These circles must have radii of such values that the V circles intersect the circle $Q_s = O$ at a value of Q_r which is the negative of the value of V at the intersection.

G_s circles. Circles respresenting different values of sending-end conductance have their centers lying on the line $E_s\,P_s$. See Figs. 2 and 3.

B_s circles. Circles representing different values of sending-end susceptance have their centers lying on the line $E_s\,Q_s$, as shown in Figs. 2 and 3.

In addition to these geometrical properties, the receiving-end diagram must satisfy certain other relations. Thus the P_s circles must intersect the loss circles at a value of P_r such that the received power plus the loss equals the sending power. Similarly, the point of intersection of the P_s circles with the efficiency circles must be a value of P_r equal to the sending power multiplied by the efficiency. Certain angular relations must also exist between construction lines. These are shown in Fig. 2, and are as follows:

Angle $P_s\,E_s\,Q_s = 90$ deg.
Angle $P_s\,E_s\,I_s = \beta - \delta$
Angle between $E_s\,P_s$ and axis $X\,X' = 180° - 2\,\beta$

Geometrical basis of the receiving-end diagram. Since the receiving-end diagram is determined by the mathematical properties of equations (1) and (2), it is possible to plot these equations in vector form and obtain the receiving-end diagram without the use of Table I. This has been done by Thielemans, and gives an alternative method of construction.

Using the received voltage as the axis of reference, equations (**1a**) and (**1b**) give the vector diagrams shown in Figs. 4**a** and 4**b**. The parts $N\,M$ of Fig. 4**a** and $N'\,M'$ of Fig. 4**b** are both determined by the phase and magnitude of the received current. By suitably choosing the voltage scale in Fig. 4**a** with reference to the sending-end current scale in Fig. 4**b**, it is possible to make $N\,M$ and $N'\,M'$ represent received current to the same scale. It is then possible to superimpose $N\,M$ on $N'\,M'$, with the result shown in Fig. 5. This is a compound diagram, for the part $O\,N\,M$ is a sending-end voltage diagram in which $O\,H$ represents the phase of E_r, while $O'\,N\,M$ is a sending-end current diagram in which $O'\,K$ represents the phase of E_r. These two triangles are related by the common link $N\,M$ which simultaneously represents a component of sending voltage, a component of sending-end current, and the received current vector. The phase of the received current is determined by $N\,X$, the position of $N\,M$ when the receiver current is in phase with the receiver voltage. The scales in the different parts of Fig. 5 are not the same, but are related to one another by the common part $N\,M$.

Let us consider Fig. 5 for a constant value of receiver voltage E_r. In this case, points O, O', and N, in Fig. 5, are fixed, and the position of point M, which is deter-

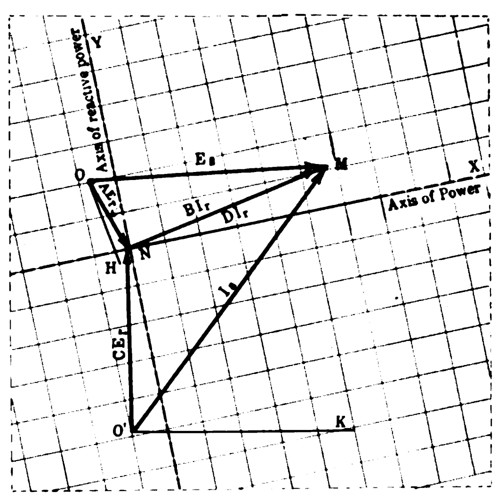

FIG. 5—COMPOUND DIAGRAM RESULTING FROM THE SUPERPOSITION OF FIGS. 4A–B

mined by the received current, is the only variable point on the diagram. Since the receiver voltage is constant, it is possible to make $N\,X$ and $N\,Y$ the P_r and Q_r axes of a system of power-reactive power coordinates. This is because the received real and reactive power are proportional to the in-phase and quadrature components of received current, respectively, when the receiver voltage is constant, and it is obvious that these current components are the projections of $N\,M$ on $N\,X$ and $N\,Y$.

Now compare Fig. 5 with Fig. 1. It is evident that these two diagrams are the same, as far as they represent the same things. The points O, O', N, and M in Fig. 5 correspond exactly to E_s, I_s, O, and M in Fig. 1, and the power coordinate systems are identical in the two cases. Thielemans has investigated the geometrical properties of Fig. 5, and his results form the basis of many of the geometrical checks given above for use in verifying the accuracy of the diagram construction.

It is helpful to keep in mind the relation between Figs. 1 and 5. The principal difference is that in Fig. 1 the important points of the diagram are located by plotting on the $P_r - Q_r$ coordinate system, while in Fig. 5 these same points are found to be ends of important vectors in the representation of equations (**1a**) and (**1b**). With Fig. 5 in mind it is easy to see why some of the loci are circles. Thus the sending-voltage vector in this diagram is represented by $O\,M$, and obviously a constant sending voltage must be for positions of M that lie on a circle having 0 as the center. It is the identity of Figs. 1 and 5 that makes it desirable to plot leading quantities as positive, as explained in Appendix B.

SENDING-END CIRCLE DIAGRAM

Construction of the diagram. Instead of using a system of $P_r - Q_r$ coordinates, as in the receiving-end circle diagram, it is possible to use a set of $P_s - Q_s$ coordinates. When results computed from equations (1) and (2) on the basis of a *constant generator voltage* E_s are plotted upon this system of coordinates, properties similar to those of the receiving-end diagram are found. Thus the loci of points on the $P_s - Q_s$ coordinate system which represent constant receiver voltage, constant receiver power factor, constant efficiency of transmission, constant receiver power, etc., are all circles, *provided the sending voltage is constant.* Such a diagram is known as the *sending-end circle diagram* of the trans-

TABLE II
CIRCLE COEFFICIENTS OF SENDING-END DIAGRAM

Kind of circle	P_s coordinate of center	Q_s coordinate of center	Radius	Remarks*
Receiver voltage	$y = \frac{d}{b} e_s^2 \cos(\delta - \beta)$	$z = \frac{d}{b} e_s^2 \sin(\delta - \beta)$	$\frac{e_s e_r}{b}$	Circles are concentric
Power loss in transmission	$y - n \cos^2 \beta$	$z + \frac{n}{2}(\sin 2\beta)$	$\sqrt{L n - y n + n^2 \cos^2 \beta}$	Circles are concentric
Receiver power factor	The receiving-end power factor circles can be drawn by a simple geometric construction that is much quicker than the analytic method. See text for graphical method.			
Receiver current	$e_s^2 \frac{c}{a} \cos(\gamma - \alpha)$ $= y - \frac{e_s^2}{a b} \cos(\beta + \alpha)$	$e_s^2 \frac{c}{a} \sin(\gamma - \alpha)$ $= z + \frac{e_s^2}{a b} \sin(\beta + \alpha)$	$\frac{e_s i_r}{a}$	Circles are concentric
Efficiency of transmission	$y - \frac{n}{2}(\cos 2\beta + \eta)$	$z + \frac{n}{2} \sin 2\beta$	$\sqrt{\frac{n^2}{4}\left[1 + \eta^2 + 4\eta\left(\frac{\cos 2\beta}{2} - \frac{y}{n}\right)\right]}$	Circles are not concentric
Receiver power	$y - \frac{n \cos 2\beta}{2}$	$z + \frac{n \sin 2\beta}{2}$	$\sqrt{\frac{n^2}{4} - n P_r}$	Center is usually off page
Receiver reactive volt-amperes	$+y + \frac{s}{2} \sin 2\beta$	$+z + \frac{s}{2} \cos 2\beta$	$\sqrt{\frac{s^2}{4} - s Q_r}$	Circles are concentric
Reactive volt-amperes consumed by line	$y + \frac{s}{2} \sin 2\beta$	$z - s \sin^2 \beta$	$\sqrt{s V - s z + s^2 \sin^2 \beta}$	Circles are concentric
Sending-end current	0	0	$e_s i_s$	Circles are concentric
Sending-end admittance	0	0	$Y_s e_s^2$	Circles are concentric
Receiver-end conductance	$y - t \cos 2\beta$	$z + t \sin 2\beta$	t	Circles are not concentric
Receiver-end susceptance	$y + u \sin 2\beta$	$z + u \cos 2\beta$	u	Circles are not concentric

Notation

$A = a \,/\underline{\alpha}$, $B = b \,/\underline{\beta}$, $C = c \,/\underline{\gamma}$, $D = d \,/\underline{\delta}$ } Network constants

P = Power in watts per phase

Q = Reactive volt-amperes per phase

E = Voltage to neutral

I = Current in each wire

G = Conductance to neutral

B_r = Susceptance at receiving end

Y = Admittance

$L = P_s - P_r$ = Watts loss in transmission per phase

$\eta = P_r / P_s$ = Efficiency of transmission

$V = Q_s - Q_r$ = Reactive volt-amperes consumed in transmission

$$y = \frac{d}{b} e_s^2 \cos(\delta - \beta); \qquad z = -\frac{d}{b} e_s^2 \sin(\delta - \beta)$$

$$n = \frac{e_s^2}{a\, b \cos(\alpha - \beta)}; \; s = \frac{e_s^2}{a\, b \sin(\alpha - \beta)}$$

$$t = \frac{1}{2} \; \frac{n\, e_s^2}{G_r\, b^2\, n + e_s^2}$$

$$u = \frac{1}{2} \; \frac{s\, e_s^2}{B_r\, b^2 s + e_s^2}$$

Subscript "s" denotes a sending-end quantity.
Subscript "r" denotes a receiving-end quantity.
A positive Q or V denotes leading reactive volt-amperes.
In designating vector quantities, a capital letter denotes the vector while the small letter denotes the length of this vector.

*These remarks apply only to the case when the sending-end voltage is constant.

mission network. It is found that for every property possessed by the receiving-end diagram there is a corresponding property of the sending-end diagram.

The construction of the sending-end diagram is carried out in a manner exactly similar to that used in obtaining the receiving-end diagram. The only difference is in the formulas used in determining the centers and radii of the circles. The coordinates of the circle centers and the length of the radii can be derived from equations (1) and (2) in the manner indicated in Appendix A. The results of such derivations are given in Table II, which is used in exactly the same number as is Table I.

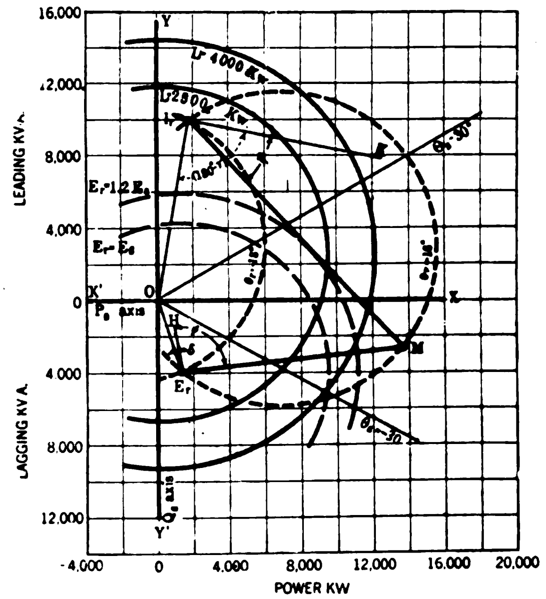

FIG. 6—TYPICAL SENDING-END CIRCLE DIAGRAM

Showing loss circles, receiving-end, power-factor circles, and receiver-voltage circles

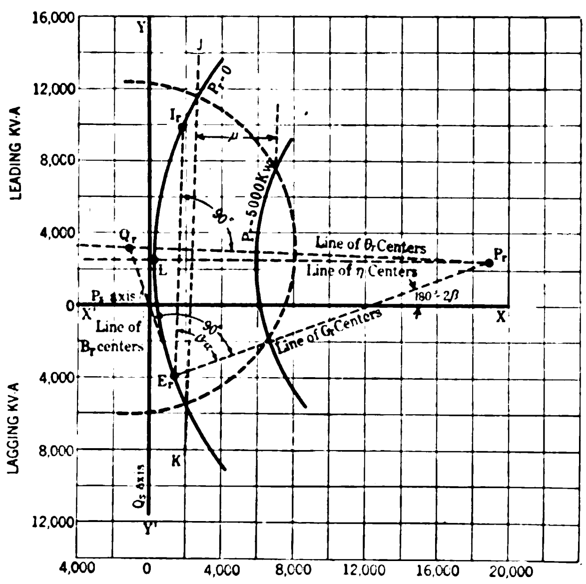

FIG. 7—SENDING-END CIRCLE DIAGRAM

Showing approximate location of centers and some of the diagram's geometrical properties

The difference between the sending-end and receiving-end diagrams is in the coordinate system and in the quantities that are represented by the circular loci. The receiving-end diagram must always be drawn for a constant receiver voltage, and similarly, the sending-end diagram can be drawn only for a constant sending-end voltage. If the sending voltage is changed, it is necessary to draw a new diagram.

Procedure to be followed in drawing the sending-end circle diagram. This procedure is exactly the same as that given under the heading of Receiving-End Circle Diagram, with the exception that the circles are determined with the aid of Table II instead of Table I and that the geometrical properties of the sending-end diagram are somewhat different. The approximate locations of the circle centers are shown in Figs. 6, 7, and 8 which have been drawn to represent a long trans-

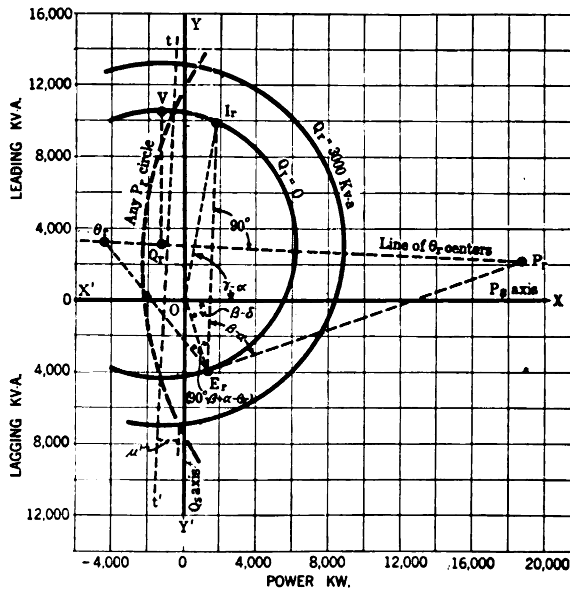

FIG. 8—SENDING-END CIRCLE DIAGRAM

Showing approximate location of centers and some of the diagram's geometrical properties

mission line with terminal transformers. The notation of these figures is that of Table II with the addition that the center of the P_r circles is labeled P_r, the center of the E_r circles is labeled E_r, etc. As with the receiving-end diagram, care must be taken in using Table II to ensure the correct algebraic signs of terms involving sines and cosines.

Geometrical properties of the sending-end circle diagram. The circle diagram drawn with the aid of the formulas in Table II possesses certain geometrical properties. These properties are analogous to those of the receiving-end circle diagram and have the same practical usefulness. These geometrical properties are indicated in Figs. 6, 7, and 8. A complete description of them is given in the unabridged paper.

The receiving-end power factor circles which, as indi-

cated in Table II, are most satisfactorily drawn graphically can be obtained by the following construction.

Receiving power-factor circles. The locus of points on the sending-end diagram which represents constant receiving-end power factor is a circle passing through E_r and I_r and having its center on the perpendicular bisector of the line $E_r I_r$. The location of this center depends upon the power factor being represented and is at the intersection of the perpendicular bisector with a line passing through E_r in such a way that the angle $\theta_r E_r I_r$ is equal to (90 deg. $- \theta_r - \beta + \alpha$) measured in the conventional direction from $E_r I_r$. This construction is shown in Fig. 8.

Geometrical basis of the sending-end diagram. Since the sending-end diagram is determined by the mathematical properties of equations (**1**) and (**2**), it is possible to plot these equations in vector form and obtain the sending-end diagram without the use of Table II, just as it was possible to derive the receiving-end diagram by means of a vector construction.

Miscellaneous Topics

Relations between sending-end and receiving-end diagrams. When the receiver end of the transmission network is supplying power to the network, the received power P_r is negative and the operating point is somewhere to the left of the axis $Y\ Y'$ in Fig. 1. It is possible in this way to extend the circle diagram to cover generator action at the receiver, and since generator action at the receiver is equivalent to making the receiver a sending-end of the diagram, it is evident that the negative part of the receiver diagram is closely related to the positive part of the sending-end diagram, and vice versa.

The reduced circle diagram. The receiving-end circle diagram must be drawn for a constant E_r, and the sending-end diagram must be constructed for a constant E_s. When neither terminal voltage is constant, it is necessary to use the circle diagram indirectly by drawing the diagram for a certain voltage and then multiplying results obtained from this diagram by appropriate factors to convert the results to those for the voltage desired.

The basis for determining this multiplying factor is that all power and reactive power quantities are proportional to the voltage squared and all current quantities are proportional to the voltage. In this way it is possible to draw a sending-end or receiving-end diagram for a terminal voltage of one volt and from this diagram determine the network solution for any terminal voltage.

Use of current and admittance coordinate systems. Instead of calibrating the axes of the coordinate system in watts and reactive volt-amperes, these can be calibrated in terms of reactive and in-phase components of the terminal current, or in terms of terminal conductance and susceptance. This is possible since when the terminal voltage is constant a definite terminal power is equivalent to a certain in-phase current and a certain conductance. When the coordinate system is in terms of current components all centers and radii computed with the aid of Tables I and II must be divided by the constant terminal voltage before plotting on the current coordinates. When the coordinate system is in terms of admittance components, all centers and radii computed from these two tables must be divided by the square of the terminal voltage before plotting.

The geometrical properties of the sending-end and receiving-end diagrams are the same whatever the kind of calibrations that are put on the coordinate axes.

ELECTRIC POWER FOR SICILY'S SULPHUR MINES

Sulphur is one of the few minerals that Italy possesses and exports in large quantities, but since her practical monopoly in this ore ceased in 1905, when America began working the deposits of Louisiana and Texas, the conditions under which this branch of the Italian mining industry has labored have been very difficult and at one time disastrous. Since 1923, when an agreement as to output and sales was signed with America, there has been an improvement, but the export figures for 1925 again showed a decline.

Sulphur mines occupy nearly one-fifth of the area of Sicily and afford employment to some 18,000 persons. They are therefore of great economic importance to the Island, but hitherto they have labored under the disadvantage of antiquated equipment and working organization. While the wages paid to labor have been notoriously low, the cost of production has been high. It has long been felt that the electrification of the mines was the essential to their economic recovery and now at last comes a decisive step in this direction.

On the 11th May, 1926 the corporation for the technical and economic development of the sulphur industry of Sicily signed a contract for the electrification of all the services connected with the Sicilian sulphur mines, the power to be produced by a central thermal electric station at Catania and transmitted to all the sulphur mining districts over a main line at 40,000 volts running between Catania, Caltanisetta and Campo-Franco, with a subsidiary line at 10,000 volts for the Caltanisetta-Sommatino district. The agreement requires that the whole installation be completed in three years' time, but it is believed that the work will be finished much sooner.

The cost of the installation is estimated at from 34 to 35 million lire of which the corporation for the technical and economic development of the Sicilian sulphur mines will contribute eight million.

The total length of the lines to be installed is not less than 500 km. Expert opinion pronounces the scheme adopted a sound one, both technically and economically. Modern mining industry cannot prosper unless it can avail itself of an adequate power supply which can be transmitted and subdivided readily, and is available at a low cost. These are the expediencies of electric power.

Abridgment of

Lightning

A Study of Lightning Rods and Cages, With Special Reference to the Protection of Oil Tanks

By F. W. PEEK, JR.[1]

Fellow, A. I. E. E.

Synopsis.—*Former papers have discussed the voltage and nature of lightning, lightning voltages on transmission lines, and means of protecting against them, the effect of lightning voltages on insulations, etc. This paper is a further report on this investigation which has been in progress a number of years. Special attention is given here to additional work on the chance of objects being struck; the area protected from direct strokes, by a rod or number of rods, overhead wires, grids, nets, etc.; the effect of nets and cages in reducing induced voltages, etc. This work is particularly applicable to the protection of oil tanks, buildings, magazines, etc.*

Oil Tanks and Reservoirs

Oil is frequently stored in very large quantities. This storage is often so great, in fact, that, economically, metal tanks are said not to be feasible. The tanks or reservoirs, which are usually made of reenforced concrete, are frequently 500 ft. in diameter, but sometimes in oval form as large as 600 by 1200 ft. and 30 ft. deep. Occasionally some of the smaller tanks are of metal. The capacity ranges from seven hundred thousand to three million barrels. A group of tanks makes up a farm.

The tops of the tanks are covered with wood or wood covered with felt or other materials to keep out the sun and to prevent evaporation. Between the roof and the surface of the oil there is an air space which may contain oil vapors. The mixture of air and oil gases may be in the right proportions to be explosive and ignited by a very small spark. Sparks can occur between metal parts on the roof or between wet parts by induction, or by direct strokes, and cause fires or explosions. It is probable that induced voltages can cause fires only when inflammable or explosive gases are present. Direct strokes can set fire to either oil or wood.

Various principles found in the general study of lightning, as well as specific investigations for transmission lines, etc., can be applied to oil tank and reservoir protection.[2] Work already reported[3] will be outlined here for convenience. Additional work done, specifically on model oil tanks, will be given in greater detail. Although work on models and theoretical work cannot always exactly simulate or anticipate all practical conditions, it should be of great help in solving the problems of protection.

How Sparks Occur

Sparks can occur in oil tanks by a *direct stroke, electrostatic induction* or by *electromagnetic induction.* A direct stroke can take place when the storm center is over the oil tank and set fire to wooden roofs, ignite oil directly or indirectly, or melt thin, metal plates. Sparks can form between conducting parts by electrostatic induction from storms overhead or at a considerable distance. As already noted, induced sparks can generally cause fires only by the ignition of gases. Electromagnetic induction could cause sparks as a result of heavy currents caused by a direct stroke in the vicinity of the tank.

Direct strokes are by far the most dangerous, but voltages by direct strokes are much less likely to occur than by induction. Induced sparks can occur only between isolated conducting parts or conducting parts in poor contact. These conducting parts could be of metal or water, etc. Trouble by electromagnetic induction is probably the least likely to occur.

Induced Voltages

A brief description may be of interest as to how electrostatic induction occurs. Assume the cloud in Fig. 1 to be negatively charged. A well insulated wire along an equipotential surface takes the potential of the space in which it is located and becomes (+) on the side nearest the cloud and (−) on the side farthest from the cloud (Fig. 1A). When the cloud discharges, the two charges on the wire go together and the potential of the wire becomes zero. In this case, it is possible for a spark to occur between the insulated wire and some other wire near it but differently located in space, even though the cloud does not discharge. What is usually known as electrostatic induction, however, occurs as follows: Assume the wire in Fig. 1B to be poorly insulated, or grounded;

1. Consulting Engineer, General Electric Co., Pittsfield, Mass.

2. F. W. Peek, Jr.—*The Effect of Transient Voltages on Dielectrics*, Transactions, A. I. E. E., 1915, Vol. 34, page 1857; 1919, Vol. 38, p. 1137; 1923, Vol. 42, p. 940.

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Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

the negative charge leaks away. The wire becomes positively charged, while its potential becomes zero. When the cloud discharges, the bound charge on the wire is released, which causes it to take a potential above ground with a sign opposite to that of the cloud. The wire generally reaches its maximum potential at the instant the cloud reaches zero. The potential that the wire assumes is approximately equal to its height above ground times the voltage gradient or volts per foot, measured vertically. The voltage gradient depends upon the position of the cloud with reference to the wire. The maximum voltage that a

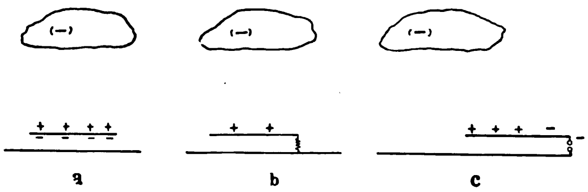


FIG. 1—VOLTAGE INDUCED BY LIGHTNING

wire can assume is equal to 100,000 times its height in feet above ground. This is practically a direct stroke. In general, this voltage is,

$$V = g\,\alpha\,h = G\,h$$

where g is the gradient in volts per foot and h is the height in feet. As shown in Fig. 2, g depends upon the distance of the cloud from the wire. For short wires, α is unity. In the case of long transmission lines, α would be less than unity, its exact value depending upon the rate at which the cloud discharges. This would follow because in slowly discharging clouds the charge would be dispersed over the line for a considerable distance before the cloud became completely discharged. Measured values of $g\ \alpha$, or apparent gradients, G, as high as 50,000 kv/ft., have been obtained on transmission lines. Sparks may occur between wires or other conductors on tanks, due to these induced voltages. Grounded wires near and parallel to the line wire reduce induced voltages; a cage around the wire still further reduces them, while a complete metal cover eliminates them. Ground wires are considered effective on transmission lines if induced voltages are cut in half; this would not be the case of conductors in oil tanks because even 500 volts could cause a tiny spark between metal parts almost in contact. The work on models has shown that tiny sparks can occur between conductors inside of cages even when the mesh is comparatively small. No sparks could be obtained in complete metal tanks. (See Table VII). Sparks can occur in metal tanks, however, between plates making poor contact or from wires or pipes brought in from the outside and not making good contact with the tank.

Electromagnetic induction resulting from heavy currents flowing in the vicinity of the tank may cause sparks. In experiments, it was not possible to obtain sparks in the complete metal tank or in the tank with open sides. Sparks were obtained only in the extreme case shown.

DIRECT STROKES

While the most severe lightning effects are produced by direct strokes, in order to have a direct stroke at a given spot, it is necessary for the cloud to be over that spot at the instant it is charged to sufficient voltage to cause a discharge. Voltages by direct stroke are thus much less likely to occur than voltages by induction since induced voltages can be produced by any storm within a radius of several miles. Sparks by induced voltages cannot occur unless there are conducting parts almost in contact or making poor contact; as wire, nails or wet spots on a wooden roof, etc.

Although the chances of direct strokes are usually small, the effects are so severe that an exhaustive study of protection against them seemed worth while. The general methods followed were similar to those used in previous work. Models were built to scale and subjected to voltage from the lightning generator as well as all other types of voltages. The same general results were obtained from all types of clouds, points, spheres and planes. The hits were recorded by placing paper targets under the tank or other object under study. A hole in the paper recorded the spot struck. It was found that either the rod was struck or the ground approximately four or more rod lengths away. There was an area immediately around the rod that was not struck. It can be seen that a model building or tank properly located with reference to the rod inside of

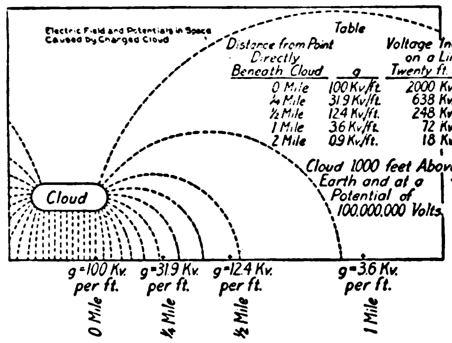


FIG. 2—ELECTRIC FIELD AND POTENTIAL IN SPACE CAUSED BY CHARGED CLOUDS

the protected area would not be struck. It has been found that this same principle applies to a number of rods. For instance, if four rods are arranged at equidistant points around a circle in such a way that their protected areas overlap, a spark never strikes inside of the circle. Thus, a building or tank placed within the circle would be protected from direct hits. It is desirable to place the rods a rod-length away from the tank. Fig. 6 illustrates how this can be applied to an oval tank.

There are other methods of protection which have

been investigated and which will be described below. An umbrella frame of conductors, placed over the tank, can be made to take direct hits. Parallel wires strung over the tank would prevent direct hits to the tank provided the wires were not separated more than four times their height above the tank. Other types of meshes or cages could be used. The disadvantage of such arrangements is that it is generally not practicable to place the conductors high enough above the tank to prevent side flashes to the roof. The lightning flash is also brought directly over the tank with the possibility of dropping hot metal, magnetic induction, etc.

Practical Protection

From the investigation it seems that a metal tank offers the only complete protection in oil storage against both direct strokes and induced lightning voltages. The thickness of the metal is not important from the standpoint of induction but from the standpoint of direct strokes must be great enough to prevent melting through. The cover and all other metal parts must be in good electrical contact. This applies especially to parts near together. When explosive or inflammable gases can be eliminated the problem is greatly simplified since it is reduced to the protection of the tank against direct hits. It appears that this can be done by placing pointed rods around the tank. A round tank can be protected by three rods. The method is shown in Fig. 23. No part of the protected area must be a greater distance from some rod than approximately four times the height of the rod. To secure a greater factor of safety it may sometime be advisable to use a ratio of less than four as indicated in Fig. 19. It is desirable to locate the rods about a rod's length away from the tank although it is possible that this distance may be as small as half a rod length without trouble. The object of placing the rods in this way is to cause the hits to occur at some distance from the tank and to prevent side flashes. The rods should be grounded to damp earth immediately below. Where the ground resistance is high or uncertain it is probably best to connect the rod to the tank ground as well as to its own ground. Figs. 10 and 11 show tests on protected and unprotected tanks. If guys are used, it is desirable to make them as short as practicable and to attach them to the rod as near the ground as practicable. When there are projections above ground, the height of the rods is increased an amount equal to the height of the highest projection.

When inflammable gases are present it is important to reduce or eliminate induced voltages. This can be done by means of a thin metal or conducting roof grounded and preferably extending over the sides. A less degree of protection can be obtained by nets or wires placed on the roof in the same way. When nets are used, the closer the mesh the greater the protection. Less protection would be given by wires or nets in practise than indicated by tests on model.s This follows because the inductance of long wires would not permit them to go instantly to zero potential.

The high degree of protection given by an all metal tank is probably most nearly approached by a combination of rods to take direct hits and a thin metal or conducting roof and sides to protect against induced voltages. Wires or mesh on or above the roof instead of metal sheets would reduce induced voltages to a less extent. In tests with a uniform field, a considerable variation of the distance of the net above the roof did not materially change its protective value. While there may be theoretical reasons for placing a net a distance above depending upon the size of the mesh, it would appear less expensive and, by tests, as effective to put it directly upon the roof. All metal parts close to the net should be connected to it. If this is difficult or

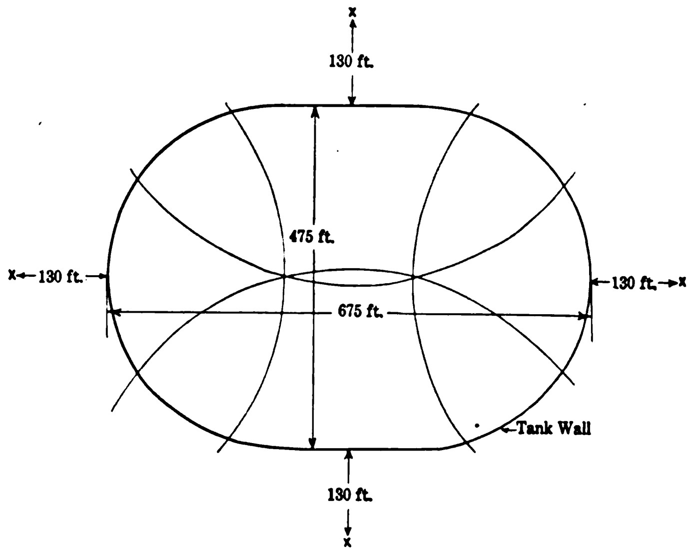


Fig. 6—Diagram Showing Protection of Oil Tank from Direct-Lightning Stroke

Height of roof peak—35 ft.
Crosses denote four 130-ft. poles, 130 ft. from tank wall
Arcs indicate area within the tank wall, protected by each grounded pole

uncertain, it may generally be desirable to raise the net on slats or otherwise to bring it away from such objects. With quarter-inch mesh, the supporting slats need not be more than several inches high. (See induced voltages in Table VII). In working out the protection for any tank, such details are important.

The above may be summarized as follows:

1—An all metal tank offers the most complete *protection against both induction and direct strokes.* Such a tank does not seem to be always economically feasible.

2—When explosive or inflammable gases are not present, it is not necessary generally to provide for protection against induced voltages. *Rods can then be used to protect against direct hits.* Rods do not protect appreciably against induced voltages.

3—When inflammable gases are present protection against induced voltages and direct strokes are necessary. When an all-metal tank is not practicable from

the standpoint of cost, the next best thing would be thoroughly bonded and grounded metal roof and sides to protect against induced strokes combined with rods to take direct hits. The roof could be of thin metal, since direct hits would go to the rods.

4—For the same purpose as the metal roof in (3), but

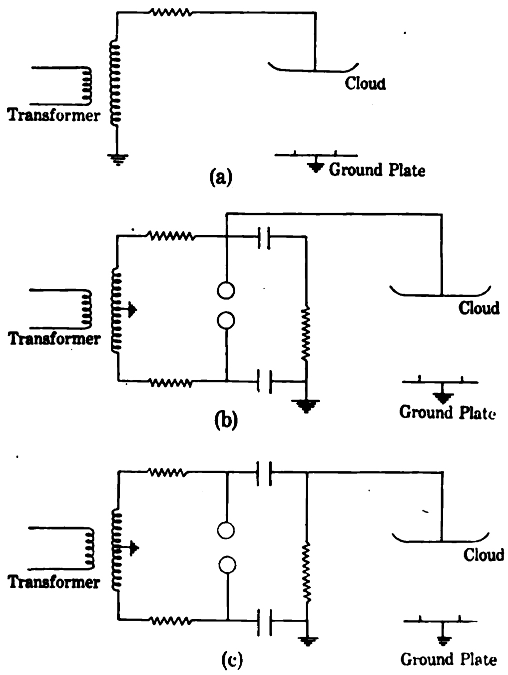


FIG. 7—LIGHTNING GENERATOR CIRCUIT USED IN TESTS

less effective, would be the substitution of a wire net. The smaller the mesh the more effective the net. Details are important in placing the net. Other methods of protection can be worked out from the test data

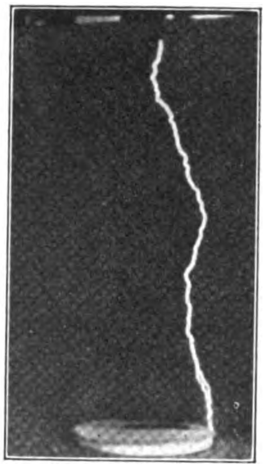


FIG. 10—LIGHTNING STRIKING UNPROTECTED OIL TANK WITH COVER (TANK FILLED WITH OIL)

given below. The above methods were discussed in detail as an example, because they seemed among the most practicable.

An actual test was made on a model of the tank shown in Fig. 6. All of the hits went to the rods with clouds no higher than ten times the height of the rod. Fig. 12 shows a section of a tank farm protected by rods. In tests on the model, with the storm center at various positions as indicated, the tanks were never hit.

3. EXPERIMENTAL INVESTIGATION

The arrangements used for studying lightning discharges as well as the lightning generator have been described in former papers[4]. The results obtained in these papers also have a bearing upon the present study. The circuits are shown in a, b and c, Fig. 7. Fig. 7A gives a 60-cycle spark. In Fig. 7B a dielectric field is established over the tank or wires under test. When the sphere-gap discharges, this dielectric field collapses, voltage is induced, and the effect of a cloud discharging in the distance is simulated. When still higher voltages are used, a direct stroke is made to take place to the object under test. How well this arrangement simulates a natural lightning discharge is illustrated in

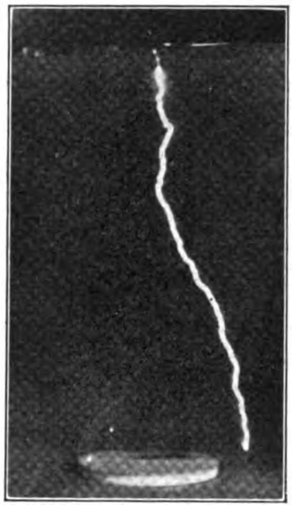


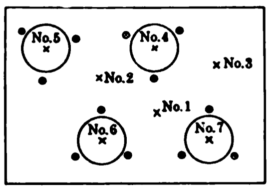
FIG. 11—LIGHTNING STRIKING RODS PROTECTING OIL TANK WITH COVER (TANK FILLED WITH OIL)

Fisg. 10 and 11, which show zig-zag discharges, split strokes, side flashes and branches. The branches which show quite plainly in the photographic negative are partly lost in reproduction. Both unidirectional and oscillatory discharges may be obtained with this circuit. The tests were made in such a way that the cloud was about half the time negative and half the time positive. The circuit in Fig. 7C gives an impulsive discharge. The cloud is "dead" until the discharge takes place. It would simulate one cloud discharging to another and then to ground. Tests have been made also up to 350 kv. d-c., with clouds both + and –.

In studying any condition, from fifty to several hundred discharges were usually made. Voltages up to 2,250,000 r. m. s. effective, 60-cycle, 2,000,000 lightning and oscillatory were used.

4. F. W. Peek, Jr., "High Voltage Phenomena", *Journal* of Franklin Institute, Jan. 1924. "Lightning", *Journal* of Franklin Institute, February, 1925.

The cloud shown diagrammatically in Fig. 7 was a horizontal plate 5 ft. x 7½ ft. (152 cm. x 229 cm.) with rounded edges. The height above ground was usually about 43½ in. (110 cm.). Other types of "clouds" such as spheres, and points were used. A short pointed rod was usually suspended from the plane to represent the storm center.



Scale: 1 in. = 850 ft.
• Denote positions of Grounded Towers
x Denote positions of Storm Center over Farm

FIG. 12—SHOWING PROTECTION OF OIL TANK FARM FROM DIRECT-LIGHTNING STROKES

Position of storm center	Hits to rods in per cent of total from cloud	Hits to ground in per cent of total from cloud	Location of hits to ground
No. 1	80%	20%	All hit directly beneath storm center, some distance from tanks
No. 2	30%	70%	All hit directly beneath storm center, some distance from tanks
No. 3	90%	10%	All hit directly beneath storm center, some distance from tanks
Nos. 4, 5, 6, 7	100%	0%	All strokes were to rods, with none to tanks or ground

Height of rods = 1.24 in. (equivalent to 105 ft.)
Height of storm center = 12.4 in. (equivalent to 1050 ft.)
Ratio of cloud height to rod height = 10 : 1
Diameter of tank = 532 ft.
Distance rod to tank = 60 ft.

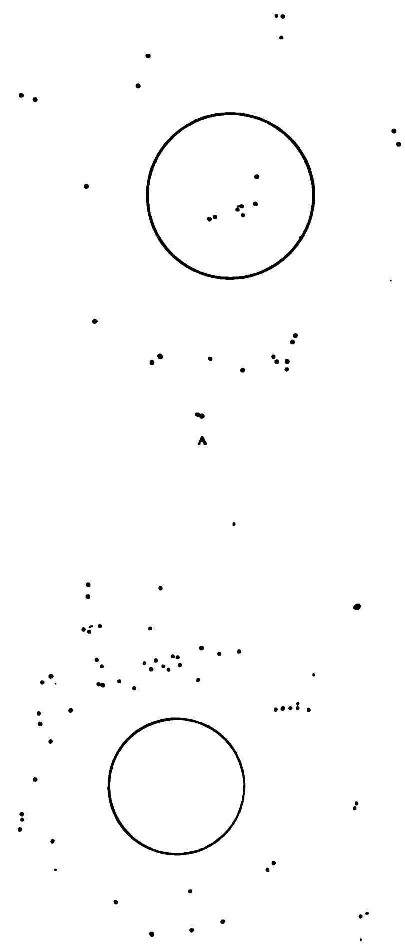
Division of hits around a tank. These tests were made to determine the division of hits between the ground around the tank, the inside of the tank and the edge of the tank. The tank consisted of a circular or elliptical ring, made of a thin metal strip placed on a metal plane. Fig. 14A is a typical target for a circular tank. A number of strokes went inside of the tank, a number to the edge of the tank and a number to the ground at some distance from the tank. In Fig. 14B the diameter of the tank was reduced while the height was kept the same. In this case, there are no hits inside of the tank. Either the edge of the tank or the ground some distance away was struck. *The tests show that a hit never occurs within a circular tank when the height of the tank is greater than one-tenth the diameter.*

If rods are placed around the tank shown in Fig. 14B, so that a line drawn from the top of a rod to the center of the tank just touches the edge of the tank practically all hits go to the rods.

Area protected from direct hits by wires and nets. Fig. 17 shows a typical target of a wire parallel to and connected to ground. Either the wire is hit or the ground some distance from the wire. *For a single wire, the ground is never hit nearer the projection of the wire than about four times its height above ground.*

A similar test was made on parallel ground wires. It was found that the ground between the wires was never hit when the separation of the wires was not greater than about four times their height. Both of these rules however, are subject to the cloud height as discussed later.

In general, ground wires are not especially efficient. There are also several factors not shown by these tests. Since, for large tanks, the wires must be quite long compared to their height above the tank, side flashes to the tank are thus likely to occur. Wires arranged like



B

FIG. 14—TARGET MADE BY LIGHTNING STROKES FROM CHARGED CLOUD
a. 6¼-in. ciruclar tank, ½-in. high
b. 5-in. circular tank, ½-in. high

an umbrella frame would be somewhat more efficient, but a direct hit would be likely to side flash or follow the central insulating pole to the tank. Heavy currents flowing in such wires could produce internal voltages by electromagnetic induction, while hot metal could drop on the tank.

Area protected by rods. In previous investigations it was found that lightning either struck a rod or the ground some distance from the rod. There was always

a protected area around the rod equal to about four times the height of the rod. This is illustrated in Fig. 5. The protective ratio should, however, vary with the height of the cloud for a given rod. The following relation would be expected theoretically:

$$R_p = \sqrt{2\,R_c - 1}$$

Where

R_p = protective ratio

R_c = cloud height divided by rod height or cloud rod ratio.

Actually, however, a ratio much greater than four would not be expected in practise because irregularities

FIG. 17—TARGET MADE BY LIGHTNING STROKES FROM CHARGED CLOUD ONE HORIZONTAL GROUND WIRE, ¼-IN. ABOVE GROUND

would overcome the slight increased distance effect. This is well illustrated in Fig. 19 where the theoretical and measured curves are plotted together.[5]

It was found that a given area could be protected by placing a number of single rods so that their protective circles or areas over-lapped. For example, with a cloud about fifty times the height of a rod the protective ratio should be about five. Four rods were arranged symmetrically about a circle. It was found that no hits took place within the circle when no rod was at a greater distance from the center than five times its height

Complete data on the area protected by three or more rods with different cloud heights and different types of clouds are given in Tables IV and V.

It may be concluded from these tests that a given area can be protected by arranging a number of rods about it so that no point on the area is at a greater distance from a rod than the protective ratio times the rod height. The protective ratio varies with the cloud-rod ratio or the ratio of the height of the cloud to the height of the rod. The practical protective ratio will usually vary between three and four.

The results in Table VI show the effect of projections within the protected area. It will be noted that, for the given ellipses, complete protection is obtained for a flat plane with the protective ratio of 3.47. This area is still protected when a roof as high as one-third of the rod height is used. The effect of varying the position of the cloud is also illustrated. In this case a protective ratio of four does not give complete protection for all positions of the cloud. The height of the cloud, however, was taken unusually low.

It is desirable to protect a tank from all directions of approach of a storm. For this reason it is not well to use less than three rods.

It is desirable to place the rods one rod length away from the tank to prevent side flashes.

Chance of non-metallic objects being struck. It is important to know if non-metallic but partly conducting objects such as green trees, wet wood, wet wooden roofs, etc., affect the electrostatic field sufficiently to determine the direction of a stroke as metallic rods do. Tests were made by placing dry wooden poles, wet wooden poles, dry and green branches to simulate trees, etc., under the model cloud. It was found that the green trees or the wooden poles completely wet to ground determined the direction of the stroke in the

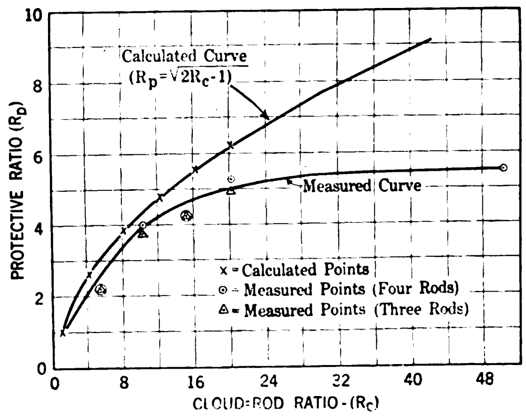


FIG. 19—PROTECTION OF AREAS FROM DIRECT-LIGHTNING STROKES

Curves showing relation between $R\,p$ (Ratio of radius to rod height) or protective ratio, and $R\,c$ (Ratio of cloud height to rod height)

same way that metal rods did. However, when the trees or wet wooden pieces were struck they were badly shattered and side flashes took place. The dry pieces had practically no effect. Thus a tall dry "building" was not struck but a nearby green tree of less height was. A green tree was generally struck at the top without appreciable effect but with great explosive damage at exit part way down under the branches. An examination of the tree without knowledge of what had really happened would give the impression that the hit took place under the branches.

Since wet wood has the same effect in determining the

5. When steady direct current is used, the measured curve Fig. 19 is followed with cloud (—). With cloud (+) the protective ratio for a given cloud-rod ratio is less. Theory indicates a cloud is likely to be (—). Steady direct current does not represent the usual lightning condition.

direction of a stroke as metal it would appear that a metal cover on a wooden roof would not greatly increase the hazard of the tank being struck.

Electrostatic induction. In previous investigations, it was found impossible to obtain sparks in all-metal tanks unless there were metal parts extending in from the outside and making poor contact with the tank.

Table VII gives the results of an investigation to determine the reduction of voltage due to over-head grounded nets or cages. It will be seen that a cage of ¼-in. mesh reduced the induced voltages between a model tank and ground practically to zero, while cage of 2-in. mesh reduced induced voltage to 8 per cent of the values without a cage.

A net of 2-in. mesh over the tank only reduced the

TABLE III

LIGHTNING PROTECTION BY PARALLEL GROUND WIRES

Cloud height = 30 in. (at storm center)
Wire " = 3 in.

Distance between ground wires	Cloud Height / wire height ratio	Ratio of ½ distance between wires to wire height	Percentage division of strokes: to ground (inside wires) per cent	Percentage division of strokes: to wires per cent	Distance to nearest ground hit-in.	Ratio of distance to hit to wire height
24.0"	10:1	4.00:1	50	50	7.88	2.63
18.0"	"	3.00:1	10	90	7.75	2.58
16.5"	"	2.75:1	5	95	8.38	2.79
15.0"	"	2.50:1	5	95	7.00	2.33
13.5"	"	2.25:1	0	100	..	..
Cloud height = 30 in. (at storm center) Wire " = 1.5 in.						
15.0"	20:1	5.00:1	40	60	4.00	2.67
13.5"	"	4.50:1	10	90	5.62	3.74
12.7"	"	4.25:1	10	90	6.00	4.0
12.0"	"	4.00:1	0	100	..	..

TABLE IV

EFFECT OF CLOUD HEIGHT—ROD-HEIGHT RATIO ON AREA PROTECTED BY RODS SYMMETRICALLY ARRANGED AROUND A CIRCLE ON A CONDUCTING PLATE . . . .

Test arrangement	Cloud height (At storm center) in.	Rod height in.	Cloud-rod ratio	* Radius-rod ratio	Percentage Division of strokes: To ground (inside rods)	Percentage Division of strokes: To rods
Three rods	30.0	6.0	5:1	2.5:1	10	90
" "	"	"	"	2.0:1	0	100
" "	"	3.0	10:1	4.0:1	5	95
" "	"	"	"	3.5:1	0	100
" "	"	2.0	15:1	5.0:1	50	50
" "	"	"	"	4.5:1	10	90
" "	"	"	"	4.0:1	0	100
" "	"	1.5	20:1	5.5:1	20	80
" "	"	"	"	5.0:1	0	100
Four "	"	6.0	5:1	3.0:1	30	70
" "	"	"	"	2.5:1	15	85
" "	"	"	"	2.0:1	0	100
" "	"	3.0	10:1	5.0:1	80	20
" "	"	"	"	4.5:1	10	90
" "	"	"	"	4.0:1	0	100
" "	"	2.0	15:1	5.0:1	50	50
" "	"	"	"	4.5:1	10	90
" "	"	"	"	4.0:1	0	100
" "	"	1.5	20:1	6.0:1	30	70
" "	"	"	"	5.5:1	10	90
" "	"	"	"	5.0:1	0	100
Special tests using 25 cm. sphere as cloud. (No needle on sphere).						
Four rods-sphere over center	30.0	3.0	10:1	4.0:1	25	75
Sphere over center	30.0	3.0	10:1	3.5:1	0	100
Four rods— Sphere offset ⅓ from center	30.0	3.0	10:1	4.0:1	0	100
Four rods— Sphere offset ¼ from center	30.0	3.0	10:1	4.0:1	5	95
Four rods sphere offset ⅙ from center	30.0	3.0	10:1	4.0:1	0	100

*Radius of circle divided by rod height.

TABLE V

VARIATION OF PROTECTIVE RATIO OR RADIUS—ROD RATIO, WITH CLOUD-HEIGHT ROD-HEIGHT RATIO . . . .

Rods used	Cloud height Rod height Ratio	Ratio of Maximum Radius to Rod Height For complete protection
Four symmetrical rods	50:1	5.00:1
" " "	20:1	5.25:1
" " "	15:1	4.25:1
" " "	10:1	4.00:1
" " "	5:1	2.25:1
Three symmetrical rods	20:1	5.00:1
" " "	15:1	4.25:1
" " "	10:1	3.75:1
" " "	5:1	2.25:1

TABLE VI

AREA PROTECTED BY RODS ARRANGED ON THE AXIS OF AN ELLIPSE

Cloud height = 30 in. (at storm center)
Rod height = 3 in.

Test arrangement	Cloud-rod Ratio	Radius-rod Ratio *	Percentage division of strokes: To ground (Inside rods)	Percentage division of strokes: To rods
Four rods arranged on metal plate at ends of axes of 7 x 4 ellipse. Storm center over center of ellipse.	10:1	4.60:1	5	95
Same conditions as above		4.05:1	0	100
Same as above except storm center moved ⅓ of distance along major axis	"	"	20	80
Same as previous conditions	"	3.47:1	0	100
Same as previous conditions except metal piece 1/7 height of rods placed along major axis to simulate roof	"	"	0	100
Same as previous test except metal piece made ⅓ of rod height.	"	"	0	100
Same as previous test except metal piece made ⅞ of rod height.	"	"	90 (To roof)	10
Same as previous test except metal piece ⅓ of rod height used. Rod spacing also increased.	"	4.05:1	25 (To roof)	75

*This "Radius-Rod Ratio" is the ratio of (the minimum radius of those arcs drawn from each rod position for the given arrangement which will just cover the entire area within the rods) to —(the height of the rods used

TABLE VII

REDUCTION OF INDUCED VOLTAGES ON MODEL TANKS BY MEANS OF OVERHEAD NETS OR CAGES

Size of mesh used—in.	Clearance to tank—in.	Position of mesh	Induced voltage on tank	Actual induced voltage in per cent of voltage induced of unprotected tank
Cage or net 21 inches square				
..	..	No protection	41.4	100
¼	1.0	Over top and around sides	0(+)	0(−)
2	"	Over top and around sides	3.2	8
2	"	Around sides only	20.7	50
2	"	Over top only	6.1	14.8
2	"	"	5.5	13.3
2	2.0	"	5.1	12.3
2	4.0	"	5.9	14.3
2	8.0	"	7.4	17.9
Net, 36 in. square over top only				
2	1.0	..	2.4	5.8

Diameter of tank:—17 in. Cloud height:—44.5 in.
Height of tank:— 6 in. Cloud voltage:—372 kv.

TABLE VIII

LIGHTNING PROTECTION OF OBLONG TANKS

Special tests with arrangement simulating a 1170-ft. x 583-ft. tank, placed on 50 ft. of sand and protected by 140-ft. rods, 110-ft. from edge of tank

Cloud height = 30 in. (at storm center)
Rod height = 3 in.

Test Arrangement	Cloud rod ratio	Radius rod Ratio *	Percentage Division of strokes: To ground (Inside rods)	Percentage Division of strokes: To rods	Remarks
25.0 in. x 12.5 in. lead foil on 1 in. of sand, protected by four 3 in. rods, 2.36 in. from foil edges. Lead foil *ungrounded*, storm center over middle of tank	10:1	3.32:1	0	100	..
Same as previous test, except lead foil *grounded*	"	"	0	100	..
Same as previous test, except storm center *offset* 1/3 along major axis	"	"	0	100	..
Same as previous test, except *rods* on top of sand were *ungrounded*	"	"	0	100	Strokes to rods were afterwards found to have fused sand beneath *ungrounded* rods
Same as previous test, except lead foil, as well as rods was ungrounded	"	"	0	100	Strokes to rods were afterwards found to have fused sand beneath *ungrounded* rods
Same as previous test, except rods and foil were placed on top of grounded metal plate set on sand	"	"	0	100	..

*This "Radius-Rod Ratio" is the ratio of (the minimum radius of those arcs drawn from each rod position for the given arrangement which will just cover the entire area within the rods) to (the height of the rods used.)

voltages to about 15 per cent. The reduction was practically the same whether the net was very near the top of the tank or a considerable distance above. In the last test a large 2-in. mesh net corresponding more nearly to the size of the cloud was used. Since the edge effect on the tank was removed in this way and the field was practically uniform, some idea of the reduction due to a similar net on a large tank should be given. The voltages were reduced to about 6 per cent of voltages in an unprotected tank. Thus nets do not eliminate induced voltages, but very materially reduce them. It is probable that the hazard is reduced in a greater proportion than the reduction of voltage.

A roof of high-resistance or partly conducting material could take as great a bound charge as a roof of conducting material. Upon release of the charge, however, the high resistance roof could not discharge instantly. High local voltages would result and such a roof would appear to be a hazard.

TABLE IX

PROTECTION OF ROUND OIL TANK FROM DIRECT LIGHTNING STROKES, BOTH FILLED AND EMPTY, AND WITH VARIOUS TANK COVERINGS AND GROUNDS

Diameter of pan used to simulate tank: 10 in.
Height of pan used to simulate tank : ¼ in.
Height of cloud needle : 30 in. (storm center)
Number of rods used : 3
Height of rods used : 2 in.
Distance of rods to edge of pan : 2 in.
Note: All tests were made with both 60 cycle and oscillatory lightning generator circuits—(see *A* and *B* on Fig. 7. See Figs. 8, 9, 10 and 11.

Conditions	Results
Test No. 1—*With empty pan*	
No rods—no roofing	All strokes were to edge of pan
3 rods—no roofing	All strokes were to rods
3 rods—dry cardboard roof	All strokes were to rods
3 rods—wet cardboard roof	All strokes were to rods
3 rods—wet cardboard roof (pan insulated)	All strokes were to rods
Test No. 2—*With pan filled with oil*	
No rods—no roofing	All strokes were to edge of pan
3 rods—no roofing	All strokes were to rods
3 rods—dry cardboard roof	All strokes were to rods
3 rods—wet cardboard roof	All strokes were to rods
3 rods—wet cardboard roof (pan insulated)	All strokes were to rods

Tests on Model Tanks and Practical Applications. A number of tests were made on model tanks. A very complete example is illustrated in Figs. 10 and 11, while the results are tabulated in Table IX. In this test a study was made of the effect, with and without oil, in an open and covered tank with both wet and dry roof.

Further tests were made on models to scale of single tanks, groups of tanks and a large farm. A few of the arrangements are illustrated in Table X. Table VIII gives results on the effect of ground resistance.

In applying rods to the protection of tanks one of the factors that must be decided upon is the protective ratio to use. By referring to Fig. 19 it will be noted that this ratio depends upon the height of the rod and the cloud. If it is assumed that the minimum thunder cloud height is 1500 ft., the cloud rod ratio is ten for a 150 ft. tower and the protective ratio, four. Weather

TABLE X
ACTUAL LIGHTNING PROTECTIVE ARRANGEMENTS FOR OIL TANKS

Object being protected	Tank size	Actual ht. of tower ft.	Ht. of tower minus roof ht. ft.	Distance of tower to nearest tank wall-ft.	Actual radius-rod ratio (Using actual tower ht.)	Effective-radius-rod ratio (Using tower ht. minus roof ht.)
Single oblong oil tank	675 x 475 Fig. 6	130	95	130	2.92	4.0
Oil tank	583 x 1177	140	119	110	3.4	4.0
Three tank farm	One oval two round	150	107	100	2.85	4.0
Four tank farm	Round and oval	150	107	150	2.85	4.0
Section of tank farm (four tanks)	Fig. 12	105	85	60	3.24	3.83
Large tank farm (thirty tanks)	520 ft. and 430 ft.	150	120	150	3.4	4.0

authorities usually give the cloud heights considerably greater than the above value.

A number of layouts were made of single oval and round tanks as well as of tank farms. (See Table X). A height of rod was used that covered the tank with a protective ratio of four. The height of the tallest part of the roof above ground was then aded to the rod height. The method is illustrated in Fig. 6 for a single oval tank. Fig. 23 gives the general method. The rods were always placed at least one-half of the rod length away from the tank. All directions of approach were guarded against by using at least three rods per tank. In the tests of these models a cloud rod ratio of ten was used. The layout gave complete protection on the models in call cases. By referring to Table X it will be seen that the actual protective ratio used in making the layout, neglecting the effect of the roof, was considerably less than four and, in fact, varied from 2.85 to 3.4. As shown in Table V, however, the effect of the roof is not so great as the allowance made for it in the layouts. In any event, the actual rod height attained seems about right for the condition assumed. In the above, it is assumed that the top of the rod is brought to a point.

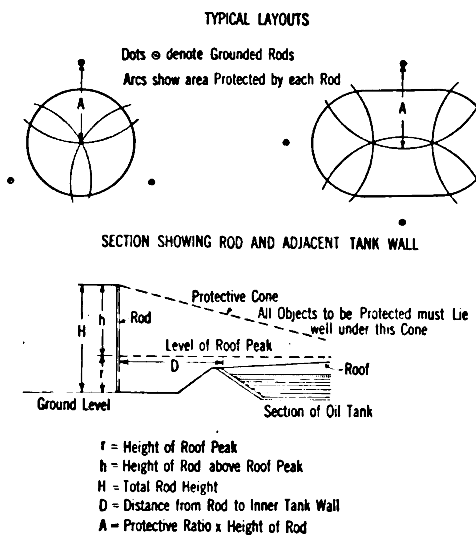


FIG. 23—DIAGRAMMATIC LAYOUT SHOWING PROTECTION AGAINST DIRECT STROKES

Perhaps a more direct method would be to use a actual protective ratio of 3 to 3.5, depending upon the rod height, neglecting the effect of the roof when it is less than one-quarter of the rod height.

4. MISCELLANEOUS FACTORS

It might not be out of place to mention here several factors outside of the scope of this paper.

Any leakage of inflammable gases should be prevented or means taken to prevent flames starting on the outside from going back into the tank. This would apply to vents or to other possible leakage.

It is quite evident that the hazard is increased as the amount of oil stored at a given place is increased. It would thus seem desirable to reduce storage or separate places of storage when practicable.

ELECTRICITY TRAPS IRON OUT OF SMOKE

About 75,000 tons of iron is wasted into the air annually in the Birmingham, Ala., iron district along with the flue gases escaping from blast furnaces, according to the U. S. Bureau of Mines. This loss could be prevented by passing an electric charge through the furnace stacks, a Bureau report says. This process of reclaiming solid matter out of industrial flue gases is a common one and is used in many cities by electric power companies to reduce the amount of smoke from coal-burning power stations.

In the case of the blast furnaces, the particles of escaping iron would be attracted to a plate and allowed to fall into a hopper. By present practise the iron particles go out into the atmosphere along with the approximate 300,000 tons of other flue dust. This dust is about 25 per cent iron and the 75,000 tons of iron dust equals about 3 per cent of the whole yearly iron output of the Birmingham district.

Construction of the 110-Kv. Transmission Line of the Washington Water Power Company

BY LESTER R. GAMBLE[1]
Associate, A. I. E. E.

Synopsis.—*This paper describes some of the features of design and construction of the 110-kv. transmission lines of The Washington Water Power Compnay.*

A brief outline is given of the loads served and existing interconnections, with other electric utilities.

The general design of single- and double-pole circuits, covering the alinement, the profile, and the structure types, is taken up in detail. Special reference is made to certain long span construction and to the construction required in heavy frost-loading areas.

The materials used are fully described and several important construction details are discussed. Illustrations are included, showing the form of sag tension curves used for stringing and sagging conductors.

A new type of 110-kv. fuse used in conjunction with an induction type relay is described, the new type of fuse being used on 110-kv. substations of relatively low capacity.

The paper is concluded with a full description of a new method of pole preservation known as the "Cold Treater Dust Method."

General

The territory served by The Washington Water Power Company extends 200 miles in an easterly and westerly direction from the Montana State line through northern Idaho into the State of Washington as far west as the Cascade Mountains and 150 miles in a northerly and southerly direction from the Canadian Border almost to the south boundary line of Washington.

The industrial and agricultural development in the area described has been very marked during the past few years. In the northern and western parts of the area, large sections of land have been utilized in the growing of orchards. These orchards are irrigated in most cases by electric pumping. In the west and south is a large wheat growing section. Most of this land is non-irrigated but the large annual production of grain has been effective in developing a number of thriving communities. To the east is the Coeur d'Alene Mining District of northern Idaho, where large quantities of both base and precious metals are produced. To the north and south of the mining districts are some of the large lumber producing areas of the Pacific Northwest.

The power supply to the section above described is about centrally located, so that it requires the transmission of large blocks of power over distances of 100 miles or more.

In the year 1917, the first 110-kv. transmission line was built from the Long Lake generating station, southwesterly to Taunton. This line is 113 miles long and was built to serve the Chicago, Milwaukee and St. Paul Railway when their line through the Cascade Mountains to the Coast was electrified. After the building of this line, the 110-kv. transmission facilities were rapidly extended, until now they carry power into every section of the area served. The single line diagram shown in Fig. 1 is the existing 110-kv. transmission system. This diagram indicates the industries served, their power requirements and the distances of transmission.

Interconnection with Other Power Companies

The interconnection which exists with the Puget Sound Power & Light Company on the west and the Montana Power Company on the east is shown also in Fig. 1. The connection on the west is made with the Snoqualmie plant through the Chicago, Milwaukee and St. Paul Railway 110-kv. bus. This connection is maintained continuously and successful operation is accomplished. The connection on the east is made, at the present time, through 100 miles of 60-kv.

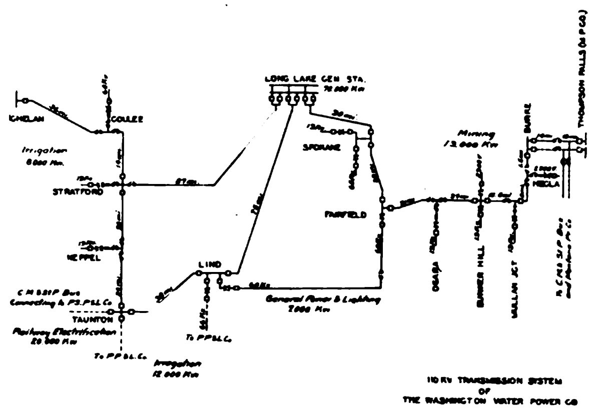


Fig. 1—Plan of 110-Kv. Transmission System of Washington Water Power Co.

transmission line and a 15,000-kv-a. bank of from 110,000- to 60,000-volt transformers. Continuous parallel operation has not been possible with this connection because the transformer bank has not sufficient capacity to take care of the large swings in power transfer.

With the new 110-kv. line now practically completed into the Coeur d'Alene Mining territory, a direct connection with the Montana Power Company will be made, as shown in Fig. 1. A study has been made of this proposed tie and it is found that a maximum of 30,000 kw. can be transmitted. The interconnection

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Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, September 6-9, 1926.

of the three power companies will represent an electrically connected system, 550 miles in length, reaching across the entire states of Washington, Idaho, and half way into the state of Montana.

Design Features

Voltage regulation and power loss. The voltage regulation and power loss for various kinds and sizes of conductors are determined by means of the Perrine-Baum chart, and the economical size of conductor calculated with due regard to corona limitations. Where stability is a factor, it is also evaluated. All factors established, the kind and size of conductor which will give the most desirable and economical line is chosen. On account of corona loss in the usual altitudes encountered, the minimum size of conductor used is one having a diameter equivalent to seven strands of No. 8 copper. For altitudes above 2800 ft., a diameter equivalent to seven strands of No. 7 copper is specified.

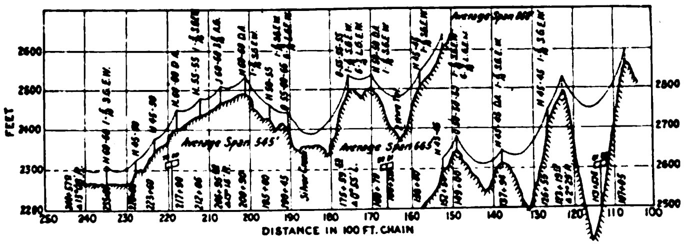


Fig. 2—Profile of 110-Kv. Transmission Line
Horizontal Configuration; 7-Strand, No. 7 Copper Conductors

Alinement and profile. The data furnished by the survey of a line is sufficient for the drawing up of a plan and profile. (Profile shown in Fig. 2.) The plan is drawn to a scale of 400 ft. to the inch and the profile to a vertical scale of 40 feet to the inch. The sheets are of such size as to cover about two miles of line. The structures are located by means of celluloid sag templates made through the application of the "Melvin-Wynne Sag Tension Charts." The templates represent to scale the approximate catenary which the conductors will take at 100 deg. fahr. and −30 deg. fahr. The 100-deg. template represents the wires in extremely hot weather, when they are sagged to a maximum amount, and is used to determine the location and heights of poles to maintain the specified ground clearances. The 30-deg. template represents the conductors in cold weather when they are sagged to a minimum

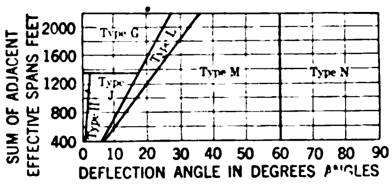


Fig. 3—Angle and Guy Chart for 7-Strand, No. 7 Copper Conductors

Structure type	Normal span	Max. actual span	Max. sum of effective spans	Angles from	Angles to	Side guys 5/16"S.M.	Side guys 7/16"S.M.	Line guys 5/16"S.M.	Line guys 7/16"S.M.	Remarks
				0	4°	1 E. W.			4 E. W.	
G	850	1350	2200	4°	30°	1			4 E. W.	Dead end each way
H (*S. A.*)	450	850	1350	0	2°	1				Angle guy
						1 E. W.				Above 650' spans
H (*D. A.*)	850	1350	2200					2		Next to crossing str.
J (*S. A.*)	450	850	1350	0	6°	1				
				6°	12°	2				
J (*D. A.*)	850	1350	2200	12°	18°	3				
K	850	1350	2200			1 E. W.			4 E. W.	
				6°	12°	2				
				12°	18°	3				
L	450	1350	2200	18°	24°	4				
				24°	31°		3			
				7°	12°	2				
				12°	18°	3				
M	450	1350	2200	18°	24°	4				
				24°	37°		3			
				37°	48°		4			
				48°	60°		5			
N	450	1350	2200			3			3 E. W.	See guy plan dwg. B-1665
O		1800				1 E. W.			6 E. W.	To be used only when approved by engr. office

Assumptions: Guys.
24" clearance of conductor to structure with 60 mi. wind and no ice.
Guying to withstand tension in all conductors.

amount. This curve is used to check up strain on any of the poles as located.

The height and type of structure at each location is determined by the length of span, the effective spans, the loading conditions, the conflict with other lines and other classes of utilities, and the degree of angle through

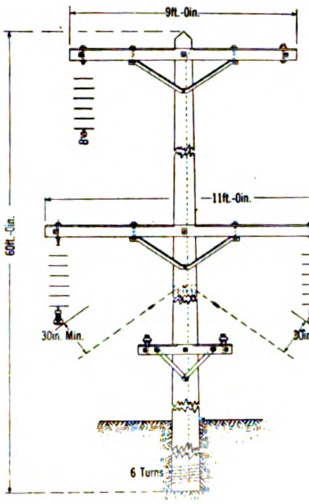


Fig. 4—Type "A" Suspension, Single-Hole Structure

which the line is turned. Referring to Fig. 2, a notation on the profile *H*-50-55 indicates an *H* type structure, having one pole 50 ft. long and another 55 ft. long; *D A* refers to a double arm; $4\frac{7}{16}$ *L. G. E. W.* indicates four $\frac{7}{16}$-in. guy wires each way in the line; and $1\frac{5}{16}$ *S. G. E. W.* indicates one $\frac{5}{16}$-in. side guy each way.

The proper guying for all structures is obtained from

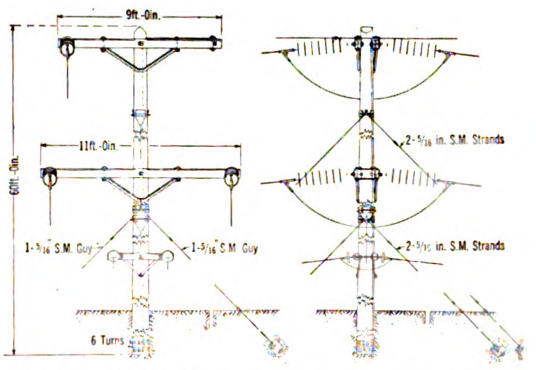


Fig. 5—Type "CT" Dead-End, Single-Pole Structure

a chart such as shown in Fig. 3. The chart shown is made for seven strands of No. 7 copper. The maximum actual span as referred to in the chart is that one which is limited because of pole strength, conductor spacing and wind pressure. The sum of the effective spans is that span which is limited by crossarm strength. The chart is based on guys being placed at 45 deg. with the structure. Where the angle is decreased, the number of guys is correspondingly increased.

Structure Types. In the development of the 110-kv. transmission structures, the wood pole has been universally used. Two forms of conductor arrangement are provided. One is known as the *L* type configuration, which is used on single-pole lines and the

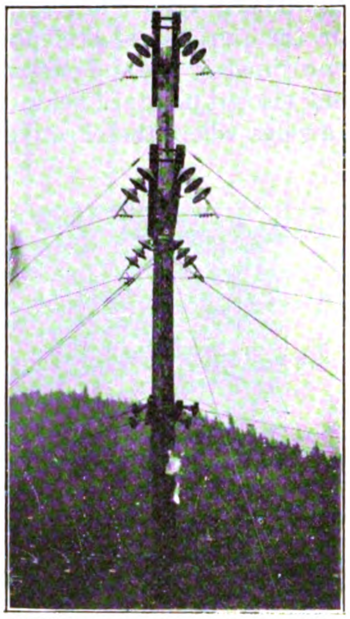


Fig. 6—Type "E" Semi-Tension, Single-Pole Structure

other is the horizontal type of configuration used on double-pole lines. The single-pole structures have their application on the less important lines where

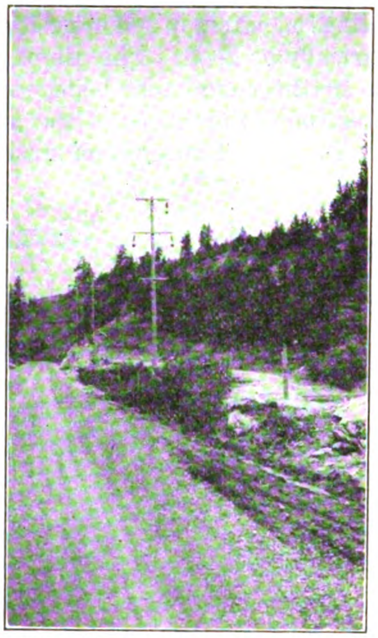


Fig. 7—Type "A" Suspension, Single-Pole Structure, Showing Application of Conductor Weights

conductors are relatively small and where short spans can be maintained.

There are seven types of such structures; the type *A* for normal tangent suspension, the type *B* for very slight angle points, the type *C* and *C T* for semi-

tension and dead-ends, and the types *D*, *E* and *F* for large angle points.

Fig. 4 illustrates the *A* type of structure, Fig. 5, the *C T* type of structure, and Figs. 6 and 7 show the actual structures, Fig. 6, being one of the semi-tension type. The semi-tension type of structure is used quite extensively for the purpose of stiffening the line at intervals of approximately one and one-half to two miles in long tangents; also, at points of heavy strain, such as at the top of a ridge where the effective spans are excessive for the suspension structures. This structure is also used in many instances at railroad and telephone crossings. The primary reason for using the semi-tension construction in place of the actual dead-end is to avoid placing insulators in strain position where they are not electrically as good. The use of this structure also permits of the conductors being strung through and facilitates the maintenance of the insulators.

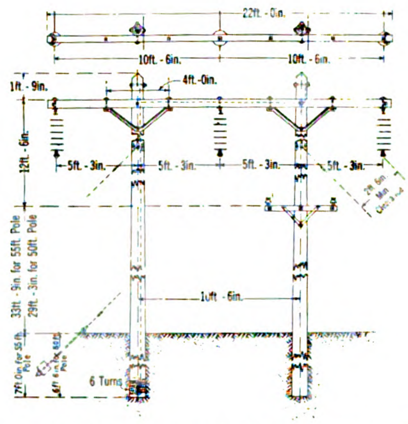


FIG. 8—TYPE "H" SUSPENSION, DOUBLE-POLE STRUCTURE

Fig. 7 shows a type *A* suspension structure, demonstrating the use of conductor weights. These weights are used where up-strain occurs in the conductor and where the sum of the negative effective spans is less than 500 ft. Where the sum of the negative effective spans is more than 500 ft., however, a standard, dead-end structure is used. As a general rule, these weights are not used, as the intention is to place structures so that up-strain does not occur. In the few cases in which they are used, they have been necessary because of a slight error in the profile which is discovered when the conductor is installed.

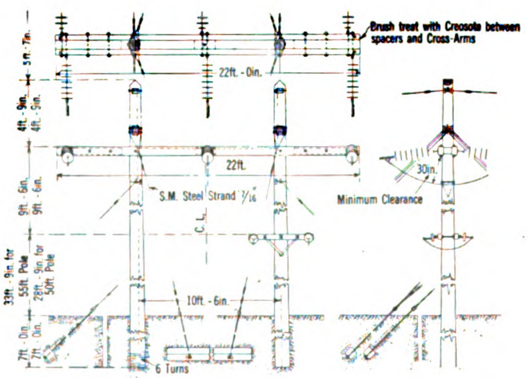


FIG. 9—TYPE "G", DOUBLE-END, DOUBLE-POLE STRUCTURE

The double-pole structures are used on all lines of any considerable importance and where the size of copper is No. 00 or larger, also where the profile is rough and long, actual, or effective spans are necessary. Such structures are also used on lines where heavy ice-loading conditions are encountered. There are eight distinct types of these structures. The *H* type is used for tangent suspension structures; the *G* type for dead-end structures; the *J* type for slight angle structures; the *K* type for semi-tension structures; the *L*, *M* and *N* types are three-pole, angle structures; and the *O* type is for especially long spans and is used also in places where the effective spans are excessive. There is one additional structure which has no letter of designation and is known as the *transportation structure.*

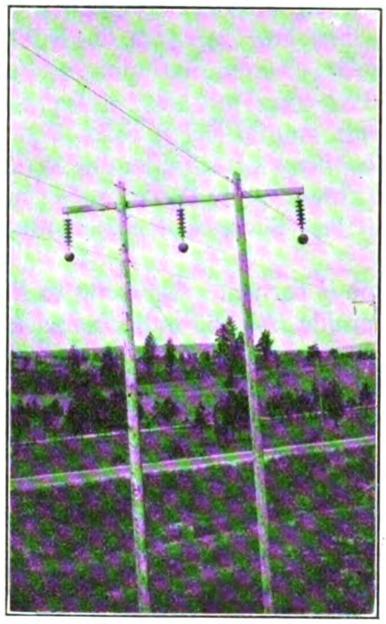
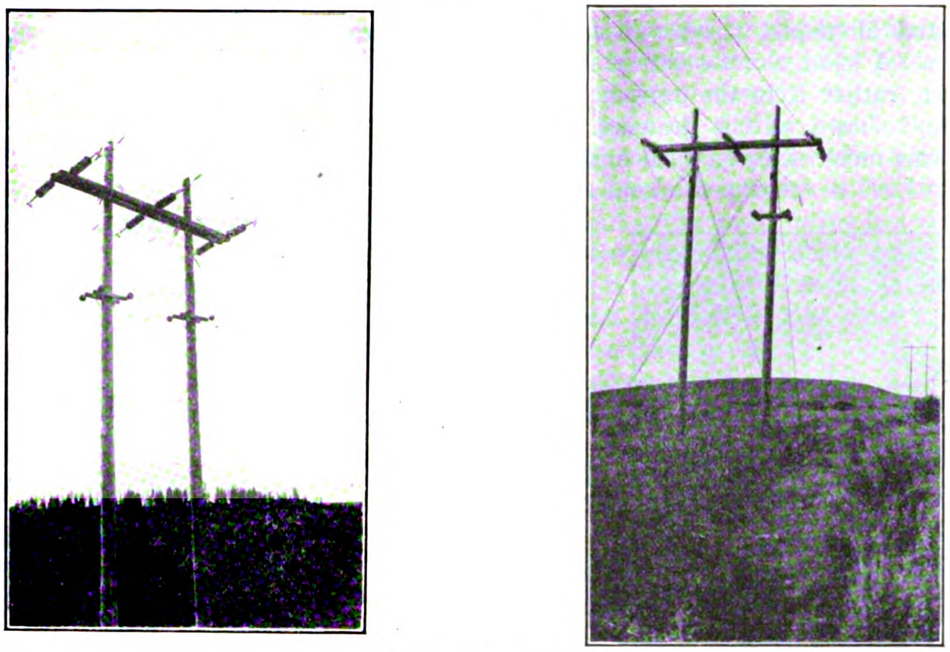


FIG. 10—TYPE "H" SUSPENSION, DOUBLE-POLE STRUCTURE SHOWING APPLICATION OF CONDUCTOR WEIGHTS

Fig. 8 is an illustration of the type *H* suspension structure. Fig. 9 represents the type *G* dead-end structure. Fig. 10 is from a photograph of an *H* structure; a slight error in profile required the installation of the weights as shown. Figs. 11 and 12 are taken from photographic reproductions of the type *G* or dead-end structure, and Figs. 13 and 14 show the three-pole structures used in long span construction. The structure shown in Fig. 14 is supporting a span 2640 ft. in length. In the construction of this span it was necessary to place the telephone on a separate structure. The telephone circuit insulation was equal to that used in the power conductors so that the telephone conductor could be used as a power wire in case of power-wire failure. The bus arrangement between the two structures facilitates connections in case of emergency.



Figs. 11-12—Type "G" Dead-End, Double-Pole Structures

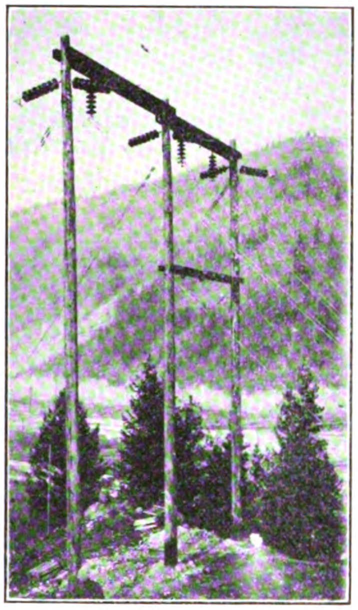


Fig. 13—Type "O", Three-Pole Structure

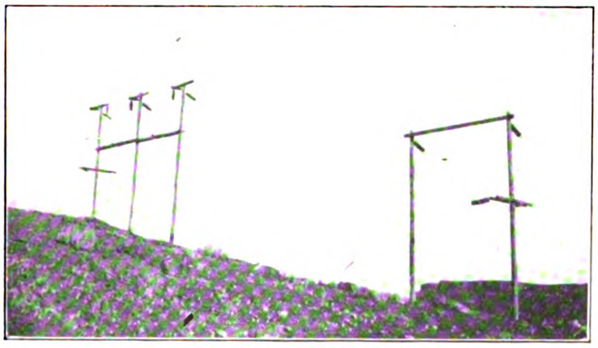


Fig. 14—Type "O", Three-Pole Structure For Extra Long Spans

Fig. 15 shows the three-pole structure where excessively high poles were required. This span crosses the Columbia River where a 50-ft. clearance over the water was required.

Figs. 16 and 17 show angle structures, types *N* and *M*, respectively.

On a very recently constructed line into the Coeur

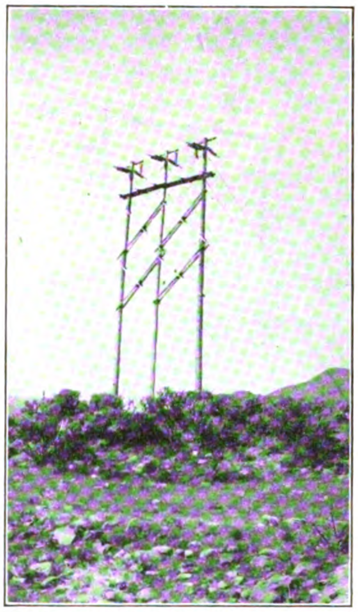


Fig. 15—Type "O", Three-Pole Structure For Long Poles

d'Alene Mining territory, it was necessary to cross the lower end of Coeur d'Alene Lake for a distance of approximately half a mile. The crossing was made through shallow water and the structures placed on piling. Three structures were required in the construction of this crossing. Fig. 18 illustrates the structure

used. Figs. 19 and 20 depict the structures in the process of erection. A ½-in. chain was used in lashing the piling together, rather than the 5/16-in. Siemens Martin steel strand shown on the drawing. It was found the chain was more easily applied and did not

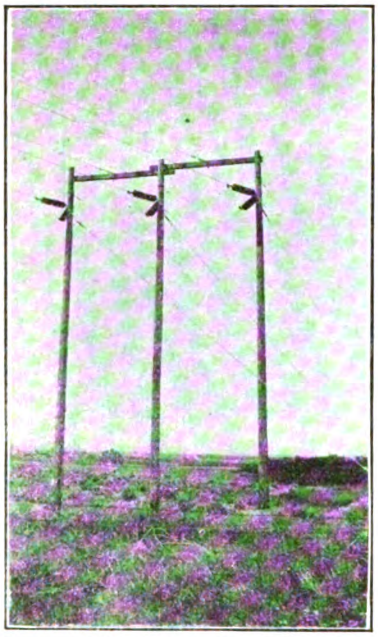


FIG. 16—TYPE "N", THREE-POLE ANGLE STRUCTURE

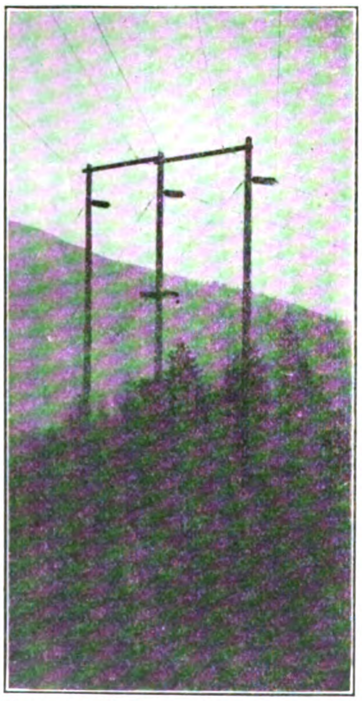


FIG. 17—TYPE "M", THREE-POLE ANGLE STRUCTURE

mutilate the piling when being pulled snug. Two complete wraps were made and the chain fastened to the piling by means of drift pins. The bottom of the lake at the point of crossing was extremely soft, and pilings 65 ft. in length were required.

Heavy Loading Districts. In a number of localities, the lines are subjected to an extremely heavy frost loading. Frost measuring 8 in. in diameter and weighing 2.33 lb. to the foot has been recorded. Lines constructed through these frost belts are built with short spans and double-pole structures. The conductor is sagged excessively. Fig. 21 shows a line in a heavy

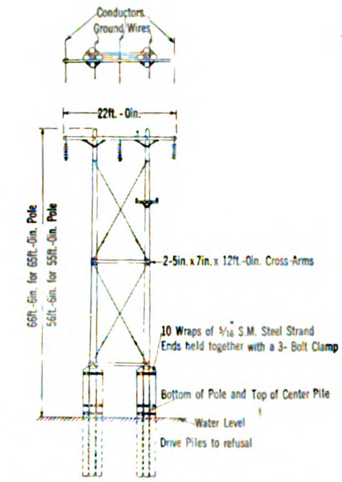


FIG. 18—PILE FOOTINGS FOR STRUCTURES PLACED IN MARSHY OR BOGGY GROUND

loading area. The conductor in this line is of No. 000 copper and sagged 18 ft. at 60 deg. The span length is 350 ft. and the sag given is sufficient to prevent the

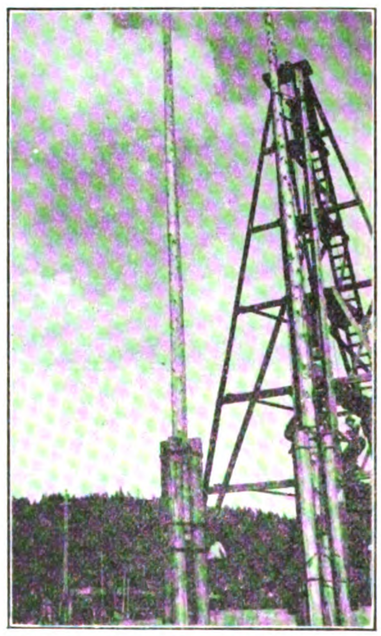


FIG. 19—ERECTION OF STRUCTURE ON PILE FOOTING

conductor from being over-stressed with a loading of 2½ lb. per foot of frost, and a wind load of one pound per foot.

Clearances. The ground clearances provided are as follows: Over ordinary ground, spans 700 ft. or less—27 ft.; over ordinary ground, spans more than 700 ft.—

29 ft. Over cultivated fields—29 ft. Inside the corporate limits of cities—29 ft. Clearances to guys must be not less than 30 in. The clearances over railroads, telephone circuits and other power lines are such as to be within the requirements of State Law.

Telephone Circuits. A telephone circuit is placed on practically all lines, the primary use of such a circuit being for patrol purposes. Such circuits however, are used also for the transaction of other business. The insulation is of the 13,000-volt class and the conductors are transposed at practically every half mile. Where balance points occur at convenient locations, sectionalizing switches are provided in the telephone circuit. Also the placing of telephone booths at certain advantageous points is arranged.

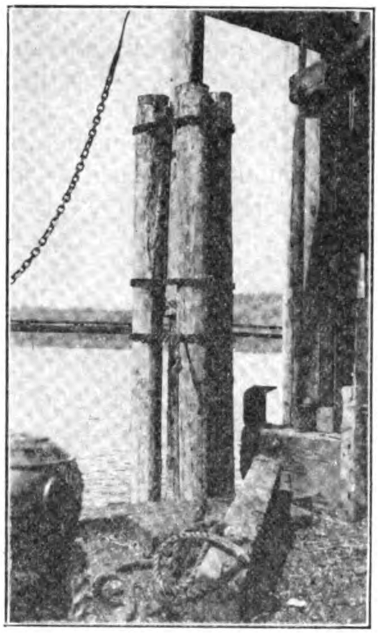


Fig. 20—Pile Footing Showing Chain Lashings

Power Line Transpositions. Transpositions are not placed in the power conductors unless necessary because of interference with foreign telephone or telegraph lines.

Static Wires. Overhead ground wires are installed on practically all lines to insure the service against lightning discharges. The ground wire is also used to give a certain degree of mechanical stability to the line.

One ground wire is installed on single-pole lines at the outer end of the upper crossarm. This wire is grounded at every structure. On two-pole construction, two ground wires are installed, one attached to each pole; these wires are grounded, one on each alternate structure. None of the pole-line hardware is bonded or grounded.

Materials and Construction

Poles. Class *B*, 8-in. top, Western red cedar poles are used for all lines. The pole butts are penetrated and butt-treated by the open-tank, *B* process. Poles treated in this manner have been used almost exclusively until very recently.

The poles on a new line just constructed in the Coeur d'Alene Country were not creosoted but were given a special treatment at the time of setting. This treatment is discussed in the last section of this paper.

In view of inability to dig holes to an exact depth, making it very hard to properly line up the structure, the poles in double-pole structures are not framed until after they are set.

Crossarms. The crossarms used on the single-pole structures are 4¾ in. by 5¾ in. by 9 ft. and 4¾ in. by 5¾ in. by 11 ft. The crossarms for the double-pole structures are 5 in. by 7 in. by 22 ft. The telephone cross arms are 3¼ in. by 4¼ in. by 4 ft. 8 in. All power conductor crossarms are provided with 48-in. angle iron braces; the telephone crossarm, with a 28-in. flat brace. To prevent the arms from splitting a ½-in. machine bolt is placed five inches from each end of all crossarms.

Insulators. Insulators of various types consisting of the cap-and-pin, the Jeffery DeWitt and the Hewlett are used. For the suspension strings, six cap-and-pin type, six Hewlett type or five Jeffery DeWitt type, are used. For the strain positions, seven cap-and-pin type, seven Hewlett type, or six Jeffery DeWitt type, are used. As a general rule only the Hewlett type insulator is used in strain.

Wires and Cables. The conductors used are stranded medium hard-drawn copper; aluminum, steel reinforced cable or extra high strength copper-clad cable. The overhead ground wires are 5/16-in., Siemens Martin, seven-strand, galvanized cable. The telephone wires usually consist of No. 6, high-strength, copper-clad wire. The guy wire consists of 5/16-in., and 7/16-in., Siemens Martin, seven-strand, galvanized cable. The power conductors are spliced with two copper splicing sleeves, having two and one-half complete turns each. The ground wire is spliced with one steel sleeve, having three and one-half turns. The telephone wires are spliced with two sleeves, each sleeve having three turns. At the points of attachment to the pole the guy wires

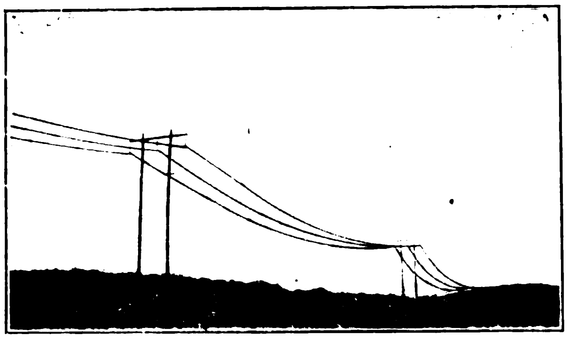


Fig. 21—Line Construction in Extra Heavy Loading Districts. (Note Excessive Amount of Sag in Conductors)

are provided with 4-in. by 8-in. strain plates and guy hooks; standard three-bolt clamps are used, one clamp for 5/16-in. cable and two clamps for the 7/16-in. cable.

Guys. Pressure treated, creosoted ties 7 in. by 8 in. by 4 ft. are used for anchors. The galvanized guy rods are ¾ in. by 8 ft., equipped with one 4-in. by 4-in. square washer and two nuts. Only one ¾-in. rod is

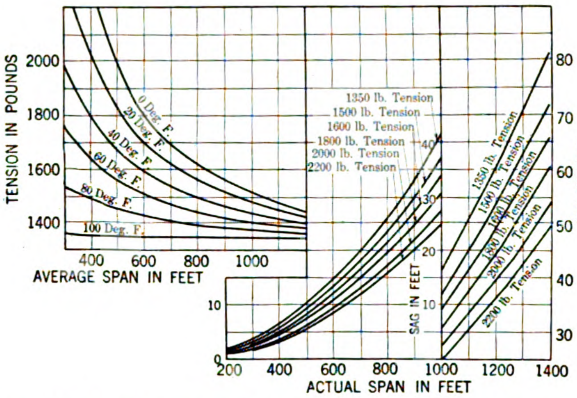


FIG. 22—SAG-TENSION CHART FOR 7-STRAND, NO. 7 COPPER CABLE

Maximum Stress in 7-Strand, No. 7 B & S Cable, 25,000 lb. per sq. in., (2850 lb.) at 15 deg. fahr. with N. E. S. C. medium loading. Modulus of elasticity, 16,000,000; coefficient of expansion, 0.0000096 (Melvin-Wynne Sag-Tension Chart)

used to an anchor. The maximum number of guys in the rod is two 7/16-in. steel cable. A 1-in. thimble is used to take the two 7/16-in. guy wires. In certain locations, where it is impossible to install side guys, the poles are cross-guyed, as shown in Fig. 18. All

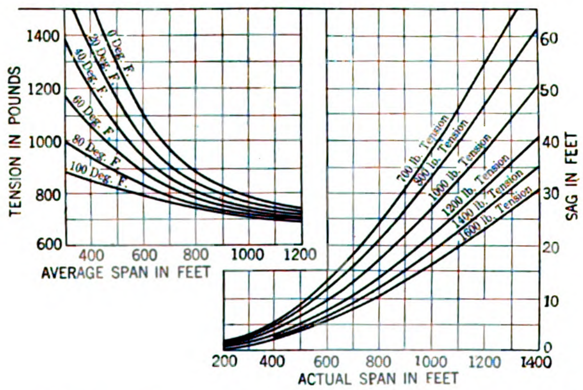


FIG. 23—SAG-TENSION CHART FOR 5/16-IN. SIEMENS MARTIN CABLE

Maximum stress, 40,000 lb. per sq. in., (2430 lb.) at 15 deg. fahr. with N. E. S. C. medium loading. Modulus of elasticity, 29,000,000; coefficient of expansion, 0.0000064 (Thomas Sag-Tension Chart)

guy wires are protected by means of a wooden guy guard.

Stringing and Sagging. The conductors, which are supported by suspension insulators, are strung through snatch blocks suspended from each insulator support. The snatch blocks have hardwood sheaves and are designed so as to prevent injury to the conductors. No metal grips are used in pulling the conductors, but a 1½-in. rope snub is provided for this purpose. The conductor is entwined through the strands of this rope snub for a distance of four or five feet. A pull on the end of the snub causes the rope strands to firmly grip the wire and makes it possible to pull it into position without injury. This rope snub is commonly termed the "grapevine grip" and is very quickly applied to the conductor.

Dynamometers are used in all cases, but they are used, primarily, for the purpose of giving the conductor the initial pull, which is designated as twice the stringing tension at 100 deg. fahr. The conductor is held at this tension for three minutes and then slacked back to the stringing tension. However, due to the various inaccuracies which may occur in the dynamometer

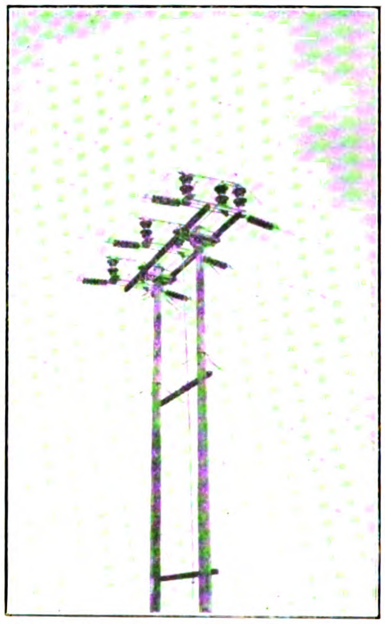


FIG. 24—TWO-POLE STRUCTURE FOR SECTIONALIZING SWITCH

reading the conductor is never sagged by reading the dynamometer. The proper sag is always obtained by measurement in some convenient span in the section pulled. By the use of thermometers and the sag-tension charts shown in Figs. 22 and 23, the construction forces are able to sag the conductors with a considerable degree of accuracy. Fig. 22 is a chart for seven-strand, No. 7 copper and Fig. 23, a chart for 5/16-in., Siemens Martin steel strand.

Having given the average span in the section of line being pulled, the actual span where the sag measurement is to be made and the temperature at the time of pulling the wire, the procedure in the use of the sag-tension charts is as follows:

Determine the tension from the curves on the left-hand side of the chart; refer this tension to the tension curves on the right-hand side of the chart and read the sag for the actual span in which the sag is to be measured.

The ground wires are never sagged parallel to the power wires but in accordance with the curves for the material used. In sagging the ground wires, a special dolly, consisting of an iron frame supporting a $\frac{3}{4}$-in. pipe roller and fitted to the top of the crossarm, is used. The device permits the wire to run freely when being pulled in and also avoids injury to the crossarm.

The telephone wires are always sagged parallel to the power conductors.

Switches and Substations

For the purpose of sectionalizing the transmission lines at certain convenient and advantageous points, a three-phase air break switch is usually installed. The type of structures used in mounting such switches are shown in Figs. 24 and 25. A typical 110-kv. substation is shown in Fig. 26.

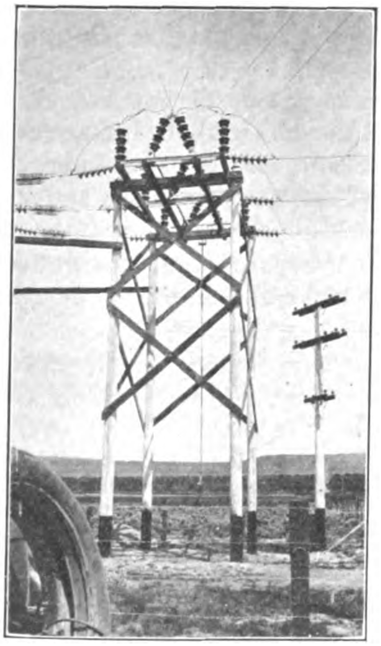


Fig. 25—Four-Pole Structure for Mounting Heavy Type Sectionalizing Switch

At the smaller substations, oil circuit breakers are not installed on the 110-kv. side of the transformer bank but fuses are used.

For the 1000- and 1500-kv-a. substations, a satisfactory medium priced 110-kv. fuse which will operate effectively with the relay operation of the balance of the network is not available. The desire has been to have a fuse which will give some selectivity. Such a fuse has been developed recently but as yet it has not been placed in actual service. It is expected that this fuse will be placed at one of the substations where a bank of three 400-kv-a., 110,000- to 13,000-volt transformers will be installed. These transformers are single-bushing transformers with neutral of the Y solidly grounded. The fuse will be of the ordinary open type, designed to give protection from both short circuit and overload, and, at the same time, provide a fuse wire of sufficient size to prevent deterioration due to corona. The fuse is mounted on two stacks of six Jeffery DeWitt post-type insulators. On one post is mounted a small sheet metal cabinet, containing an induction type relay and a suitable clip, into which one end of a micarta tube is secured. A fuse wire of not less than 30-ampere capacity is placed in the tube and secured at the opposite insulator post by a binding screw. At the clip end, a small heating coil, having the same impedance as the relay circuit, is slipped over the lead fuse wire. This heating coil is connected to the tripping circuit of the relay. Under normal operation the main line current passes through the fuse and relay coils to the load. Overload protection is secured by the proper setting of the relay which, when called upon to function, closes its contacts, shunting part of the load current through the heat coil and melting the fuse, thereby opening the 110-kv. circuit. The fuse is equipped with horns so that the arc established is readily extinguished.

Cold Treater Dust Method of Pole Preservation

The poles which have been used in transmission line construction during the past year have been treated by the "Cold Treater Dust Method." The dust consists of several chemical compounds, obtained in the process of smelting ores. These compounds have varying degrees of solubility, some being highly soluble while others are soluble to a much lesser degree.

The treatment is not applied to the pole before it is set, but always at the time of setting. It may also be applied around poles which have been in the ground for any length of time. The effectiveness of the dust was established after a series of tests covering a period of several years. The tests disclosed the following facts:

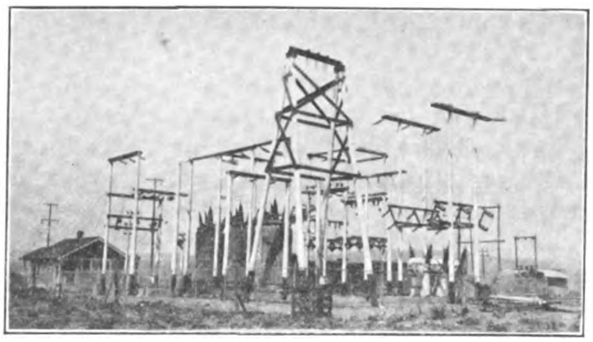


Fig. 26—6000-Kv-a. Substation, 110 Kv. to 60 Kv.

1. That the dust absorbs moisture from the surrounding earth and becomes a putty-like mass.
2. That, in all soils except rock, the dust does not readily leach out in the earth.
3. That the highly soluble compounds are soon dissolved and carried up through the outer fibers of the wood by capillary action, and thus immediately head off any decay.
4. That the less soluble compounds act as a storage reservoir, keeping up the supply to the pole in sufficient quantity to prevent decay.

5. That very little or none of the compound is evident in the wood below its point of application.
6. That those portions of wood impregnated with the compound are hard and tough.
7. That the dust must be placed in actual contact with the pole to be effective—any dust out in the earth around the pole is practically useless.
8. That the dust, to be effective, must be placed far enough below the ground surface to get below that point where decay will start.
9. That any rot on the pole at the time of application acts as a cushion or barrier and does not allow the compound to reach the good wood of the pole and thereby stop further rot.
10. That in marshy ground the treater dust is soon dissolved and carried away by the water.
11. That in certain lines built three years ago, in which every alternate pole was treated, there is at this time no evidence of decay and that those poles in the same line which were left untreated show one-fourth to one-half inch of rot.

The following specifications are used in applying the dust:

Seven pounds of treater dust are used at each pole butt. The first application is made by placing one pound of the dust in the bottom of the hole before the pole is set. This is for the purpose of insuring against any heart rot which may develop.

The second application consisting of two pounds of the dust is put around the pole after the hole has been backfilled to approximately midway between the bottom of the hole and a point two feet below the ground line. A narrow groove about ¾-in. wide and one inch deep is made in the earth around the pole with a special tamping bar and this groove is filled with the dust. This application is made as a security against any decay below the two foot level. It is found that in some territory decay will take place as far down as six feet. The hole is then backfilled to within two feet of the ground surface.

The third and last application is then made at this point (two feet below the ground surface) by tamping a groove around the pole with the same tamping bar as previously used but with groove made two inches deep so as to take four pounds of the dust. The hole is then backfilled and the dirt banked solidly up around the pole.

In marshy ground the dust is not used.

In rock holes the dust is applied in the usual manner but dirt is mixed with the rock used in backfilling so as to fill all crevices between the rocks and thus prevent the sifting away of the dust.

All deadmen for guys are treated with five pounds of the dust placed under and on top of the deadmen.

The cost of the dust ranges from three to five cents a pound. The labor of making the application is relatively small, although the pole setting crew will be forced to lose a little time. Taking everything into consideration the treatment will possibly cost in the neighborhood of $1.00 per pole.

Electricity and Coal Mining

BY DANIEL HARRINGTON[1]

Non-Member

WHILE the far western states (Arizona, California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Washington, and Wyoming) are known much more for metal mining than for coal, their ultimate natural wealth in coal nevertheless far exceeds that of all combined metallic resources. Government estimates place the combined coal tonnage in the above mentioned states as only a trifle less than 50 per cent of the total coal tonnage of the entire United States, yet these states now produce less than five per cent of the annual output of the United States. Utah alone is credited with having within its boundaries nearly 200,000,000,000 tons of coal and to date has mined less than 100,000,000 tons or about 5/100 of one per cent, annual tonnage mined being around 5,000,000. From the above it will be seen that coal constitutes a vital part of the resources of the West and while water-generated electricity is a strong competitor of coal, yet much of the coal mined goes to generate electricity and on the other hand electricity enters very actively into the mining of coal. Consequently the subject of electricity and coal mining is of decided interest to the West as well as to all of the rest of the United States, but as it is a very broad subject, this paper will be confined chiefly to influence of electricity at the mines rather than including the broader subject of influence on markets.

The major underground operations in coal mining are cutting of the coal, lighting, blasting, haulage, drainage, and ventilation, and those on the surface are sizing, cleaning, and loading the product. Twenty-five years ago electricity was being utilized only in a comparatively minor way in the coal mines of the United States, while up-to-date installations at the present time are going largely if not almost entirely to electricity for practically every one of the above mentioned operations.

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Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, Sept. 6-9, 1926.

Hand or pick mining is almost a thing of the past; compressed air mining machines are rapidly disappearing and even where used, the compressed air is usually of electrical compression; the old hard-boiled solid shooting methods are confined to "back-woods" properties; and some form of electrically operated cutting equipment (undercutters, over-cutters, shearers) is now relied upon for up-to-date mining or preliminary loosening of coal.

The recent extensive experimentations in mechanizing of coal-handling at or around coal-mine faces, involving various kinds of loaders, conveyors and scrapers, as well as combinations of them with or without cutting machines, practically all depend upon electricity for their motive power. Even where hydraulic principles are applied or where compressed air is used in these underground mechanical coal handling contrivances, the pumps or compressors are almost invariably driven by electric motors.

Most of our up-to-date coal mines use incandescent electric lighting on main haulage roads or at hoist or pump stations or other underground places where there is much concentrated activity; occasionally one finds face regions wired for electric lighting and it seems probable that the new intensive systems of mining now being tried out as above mentioned will greatly increase the wiring of face regions for lighting purposes. At least one-third of the 750,000 coal miners of the United States use storage battery electric lights which are both safer and more efficient than the open flame lights which have caused loss of hundreds of lives and millions of dollars worth of property in the mines of the United States. Utah leads in that she alone of the coal producing states has eliminated the dangerous, inefficient open lights from coal mines and now requires that the coal miner's light shall be from the safe, sane, efficient permissible electric safety lamp.

The old-time steam or compressed air hoists and locomotives have largely given way to electrical equipment, though steam-operated main hoisting plants still give good service where located on the surface close to steam boilers. Steam pumps underground are a rarity except in some very old installations; compressed air pumps are in use to some extent but here again the tendency is strongly towards electrical equipment, except that at some very gaseous mine faces compressed air pumps are used, but ordinarily the air compressor is electrically driven.

Many main fans for coal mines are steam driven and while steam driven fans are generally preferred because of dependability and general safety, still electrically operated fans are coming very much into use, in fact are rapidly displacing steam driven units. There is also a decided tendency toward use of small electrically driven "booster" fans underground, a policy which appears unsafe and unnecessary.

Blasting by electricity is by no means as nearly universal in coal mines as it should be, as it is much safer and more efficient than the older methods using squibs or fuse. Here again the state of Utah points the way to all other coal producing states in the Union in that nothing but electrical blasting is allowed in her large coal mines. Moreover, Utah has more than half of its coal produced by mines in which all blasting is done by electricity when all persons, including the *shot firers*, are out of the mine; this system is by all odds the safest in the world when it is accompanied by exclusion of all explosives from the mine when the working shift is in the mine and having all explosives brought into the mine by shot firers after the regular working shift.

In addition to these major underground activities most of which are being handled electrically in up-to-date coal mines, there are numerous minor operations in which electricity takes or appears about to take the leading role; among them are signaling systems, telephones, rock dusting machines, heaters, drilling machines, as well as a host of others.

Up-to-date surface tipples or breakers which do the coal sizing, cleaning and loading are almost wholly driven by electricity and it is by no means unusual to have 20 or more electric motors on an up-to-date coal screening plant. Box car loaders, elevators, conveyors, car dumps, car hauls, car retarders, machine shop equipment, in fact nearly every mechanical activity around the modern tipple or coal mining plant, is electrically driven where 25 years ago practically all of this type of work was done by steam or hand power.

The coal mining town or camp which is not electric lighted in offices, residences and streets is decidedly behind the times and electric washing machines, electric irons and other similar household electrical conveniences are more generally found through coal mining camps than in the general run of homes of the middle class in our larger cities.

Coal mining men of the United States who have in recent years visited foreign coal mines, especially those of Europe, state that we are far in advance of any foreign country in the adaptation of electricity to coal mining; in fact, many of the every-day uses to which we put electricity in our coal mines are prohibited by law in some foreign countries. A commission of labor men from Great Britain's coal mines recently made a study of our coal mining conditions chiefly to ascertain why we are able to pay peak wages to our coal miners, yet produce coal at comparatively low cost; among the most important of their conclusions was that our superiority in coal mine working conditions, at least as to high wages, was due chiefly to the fact that our coal mining companies do not hesitate to "scrap" out-of-date equipment and substitute for it up-to-date equipment even though the first cost of doing so may be comparatively high. Boiled down, this means essentially that much of the good position our coal miners occupy as against foreign coal miners is due largely to the fact that our coal mines have been quick to adopt and to

adapt new, more flexible, more efficient electrical machinery and to discard older, less efficient, even if not completely worn out, compressed-air or steam equipment; and curiously enough many of these changes are made with active opposition of the miners who have thus been benefited.

While progress in the electrification of our coal mines has been especially rapid during the past 15 years, there remain a large number of older mines in which electrification is only partial or has scarcely begun. Stress of competition in these days of immense overproduction will soon force modernization (which essentially means electrification), or these out-of-date properties must close. Many of the mines electrified 10 to 15 years ago are now pretty much out of date, and with the extra competition due to concentrated mining, these one-time model mines will also be forced to discard old equipment or methods such as the d-c. installations for the newer more efficient, more flexible alternating current now coming so much into use. Hence it appears that notwithstanding the "slump" in coal mining, there will be heavy purchases in the more or less immediate future of large quantities of electrical equipment for the coal mines of the United States.

Whether or not this extensive electrification of our coal mines continues uninterruptedly depends largely upon electrical men themselves; unless electrical men and manufacturers of coal mining machinery which needs electrical equipment, acquire a type of conscience which many of them now lack, there is likely to be a sharp reaction against use of electricity in mines which may result in drastic state regulations against electrification especially at or near working faces. With the increased use of electricity in coal mines, there is absolutely no question that there is also an increased hazard as to explosions as well as to contact electrocutions. In the period from 1910 to 1924, out of 200 explosions in the coal mines of the United States, 15 explosions or 7½ per cent were charged against electricity as the igniting agent; in 1924, the last year included in the above list, of 200 explosions, 10 explosions were listed and of these 5 or 50 per cent were of electrical origin; in 1925, out of 10 known coal mine disasters, 6 or 60 per cent were attributed to electricity as the starter. Hence, while only 7½ per cent of our coal mine explosions during the 15-year period from 1910 to 1924 were of electrical origin, the percentage of explosions of electrical origin jumped to 50 in 1924 and to 60 in 1925.

Electrical men usually resent publication of figures of this description; they say they are overdrawn, are inconclusive because of being fragmentary, are "harrowing," and so on; and the amount of "buck passing" encountered by the coal mine safety engineer in calling attention to dangers of electricity is remarkable in the extreme. A manufacturer of small booster fans, when confronted with dangers of these small fans near coal mine faces, especially when electrically driven, shrugged his shoulders and said, "I sell fans; I should worry how they are driven." The machinery manufacturer who purchases from other companies the electric motors which operate his equipment only too frequently washes his hands as to the degree of safety with which the purchased electric motor may be used underground; in other words, "he should worry" also. The manufacturer of electric motors, or of almost any electrical equipment, seldom inquires into the safety side of the use of the equipment in the proposed sale and leaves that to the mine management. In general the mine management has a purchasing agent who seldom if ever sees the inside of the mine and who wouldn't be able to interpret conditions if he did see the mine workings, and his prime conception of his official duties is to purchase at minimum cost, with possibly some attention to probable efficiency but with seldom a thought as to safety; in fact, if the safety situation enters into the matter and there is any substantial increase in price for the safety feature, the purchasing agent usually rejects it because of the price increase; and the salesman fearing loss of sale seldom if ever presses the safety element in his higher priced product, this being the case especially if he has also some lower priced, less safe substitute. The man at the mine usually gives his order in general terms, relying upon the salesman to supply the correct kind of material or equipment.

This "vicious circle" is in itself sufficient to explain much of the increased percentage of coal mine disasters due to electricity, but there are also other important contributing factors:—state laws and regulations as to electricity in coal mines are usually much out of date, loosely worded and are now and always were entirely inadequate; in the few instances where state laws are even fairly sensible as to use of electricity in coal mines, they are not enforced, as there are very few (probably not any) state coal mine inspectors who have anything like a sufficient knowledge of electricity to enable them to interpret the safety of underground electrical conditions as a prior requisite to enforcement of adequate electrical regulations; company mine safety inspectors seldom if ever are sufficiently well grounded in electricity to give competent advice as to safe underground practise in electricity and very seldom is a competent electrical man employed to make periodical underground inspections as to *safety* in electrical installations or safe use of electrical equipment; "white collared" electrical engineers frequently map out elaborate underground electrical systems but seldom if ever go underground to aid in correct or safe installations, or to "look things over" during operations to see that the system is operated as designed.

In view of the fact that much electricity is being used and will be used increasingly in coal mines, it appears that the electrical people (engineers, manufacturers, and others) owe it to themselves to take the lead in directing thought towards its *safe* use rather

than trailing along as obliging followers of mine officials whose knowledge of safety with electricity is frequently nil; unless intelligent direction is given towards safety in installation and use of electricity in the coal mines of the United States, there is very likely to be a series of disasters charged to electricity with consequent definite barricade placed against further extensions.

In view of the fact that almost any kind of electric arc may ignite either coal dust or explosive gas and start a disaster in almost any kind of coal mine, it would appear that all electrical appliances or equipment used in coal mines should, in so far as feasible, be arc proof; hence there should not be allowed to go into any coal mine any electric motor, switch, etc., of the non-permissible type. This appears drastic but in the final analysis, it is logical and in time will be the rule; hence electrical manufacturers should now be bending their efforts towards construction of nothing but permissible equipment or appliances for use in coal mines; and electrical salesmen should advocate the use of nothing but permissible equipment for all coal mines whether gaseous or so-called non-gaseous.

Electrical men (engineers, manufacturers, salesmen) should initiate and forward a movement looking to the establishment of sensible safe electrical standards not only of electrical materials, appliances, equipment, etc., but also of sane, safe practises and installations in mines in the use of these electrical materials and appliances. These standards should be specific rather than generalized as is so frequently found in attempted standards, generalizations usually meaning little or nothing and getting nobody anywhere at any time.

In view of the fact that alternating current now is used successfully for nearly every operation in or around coal mines with the one exception that it has not been adapted to haulage locomotives, it would appear that our electrical friends should "get busy" and produce a practicable a-c. locomotive and thereby eliminate the necessity for having both alternative and direct current in nearly all of our coal mines. Possibly the ultimate solution will be the use of storage batteries for all underground purposes including main haulage, thus eliminating practically all underground wiring which would be real progress since underground power wires are dangerous, expensive and decidedly undesirable. There is said to be at least one coal mine in the United States using storage batteries for practically all underground power operations and some interesting and extensive experimental work has been done by the Phelps Dodge Corporation of Dawson, New Mexico in the utilization of storage batteries for main haulage as well as for mining machines, pumps, etc.

There appears to be much lack of authentic information as to what kind of electrical current (alternating or direct) is the safer, voltage for voltage, amperage for amperage; also which is the more likely to ignite methane or coal dust in a mine. One English professor a few years ago published a paper stating that alternating current was the safer both as to contact accidents and as to ignitions of gas or coal dust, and the writer has seen these statements denied yet has been unable to secure accurate definite information. It would appear that these matters should be cleared by publication of experimental evidence by electrical men.

In conclusion, it seems that our coal mines are almost certain to become much more thoroughly electrified than they now are, and that the electrical men owe it to themselves as well as to their customers in the coal business to take the lead in pointing out the advisability, in fact, the necessity, of practically complete electrification; on the other hand, the electrical men are morally obligated to make certain that the more intensive electrification of our coal mines will be accompanied by greater rather than less safety for the mines and the employees of the mines.

NEW TYPE SINGLE SLEEVE VALVE ENGINE

The first public announcement of what is considered an important advance in automotive engineering was made November 15 at the monthly meeting of the Metropolitan Section of the Society of Automotive Engineers. At this meeting was described a single sleeve valve engine which has been in course of development for nearly two years.

Such parts as the crankshaft, connecting rods, piston, and spark plugs are of the design used in the conventional poppet valve engine, but the cam shaft and valve gear are replaced by a single valve of tubular form in the new design. Ports are cut at the upper end of this sleeve and in the cylinder, the sleeve being moved up and down and partly turned at the same time so that exhaust and intake manifolds are properly connected to the cylinder.

Lubrication for the sleeve valve engine is made possible by the characteristic twisting movement of the sleeve valve which causes the oil to be rolled evenly over the entire sleeve surface.

Operating efficiency, good power output and silence in operation were given as the chief advantages of a single sleeve valve engine. A test was made on a six-cylinder engine of this type, run for 1000 hours at full load. At the end, the gears ran as quietly as at the start and on dismantling the engine the maximum wear on the piston skirt was only one-thousandth of an inch, while the wear on the outside diameter of the sleeve was undiscernible. The power output was gradually built up during the first 100 hours until it reached 44 b. h. p., after which it remained constant until the test was completed. Silence in operation is achieved by avoiding the hammer and anvil blows of the poppet valve, and it is partly due to the fact that the valve actuating mechanism does not extend outside of the engine body. About 50 lb. weight can be saved by substituting a single sleeve valve engine of average bore with an aluminum casing for a poppet valve engine with a conventional cast iron construction.

Controlling Insulation Difficulties in the Vicinity of Great Salt Lake

BY B. F. HOWARD[1]

Member, A. I. E. E.

Synopsis.—*The difficulties encountered in maintaining a sufficiently high degree of line insulation on long communication circuits in the vicinity of Great Salt Lake, Utah, are dealt with in this paper and a review of the study and solution of the problem of controlling the insulation is made.*

Leading up to this is a description of observations on about 40 mi. of line over a part of the Great Salt Lake Desert known as the mud flats west of the Lake. The description also covers observations on other lines north of the Lake.

The object of these studies was to ascertain the variations in the line insulation caused by different weather and temperature conditions in each of these routes. It was necessary also to determine which route would be better for constructing the central transcontinental communication circuits which were about to be built at that time for extending service to provide telephone connection between points on the Atlantic and Pacific coasts.

IN 1913, when it had been decided to construct a transcontinental telephone line in order to connect Atlantic and Pacific coast points, a warning was given by other wire-using companies of difficulties which would be encountered in the Great Salt Lake Desert, owing to very low insulation of the lines under certain weather conditions. These companies were in the communication business and possessed lines which passed through the section.

At certain times, they had experienced complete failure of telegraph lines in that vicinity, due to this low insulation, particularly when heavy fogs prevailed. It was very important to the success of the transcontinental telephone lines that the insulation should be controlled and prevented from falling below a certain minimum. This was particularly true because at that time the most practical way of giving very long distance service was by means of "loaded" circuits. This required high insulation at all times, for if it fell below a certain limit, the qualities of the line for conveying speech would be even worse than had it not been loaded at all.

For a long time these insulation conditions had existed on lines which had been strung over the mud flats west of Salt Lake. There was evidence that there were stretches of line on the route north of the Lake (one of the two routes under consideration) which showed insulation conditions similar to those on the lines situated upon the mud flats. These stretches on the northern route, however, could be avoided by building the lines around them, whereas, in the case of the southern route, it was impossible to avoid crossing the mud flats and salt beds.

It may be well to give here a description of the mud flats and salt beds which have been known for some time as the Great Salt Lake desert. This desert is comprised of an old lake bed probably many hundreds of feet deep consisting of a deep valley filled with mud. It is known with certainty to be over 400 ft., for a chemical company put a drill down at a place where the surface is covered by a large bed of salt and passed through eight ft. of this, 200 ft. of mud, 30 ft. of solid salt, and another 200 ft. of mud. Drilling was stopped at this point, and it is not definitely known what is below.

The salt-bed surface is about eight mi. wide and 20 mi. long, and varies from a few inches to eight ft. in thickness. The mud flats, as they are called, are covered with a salty crust which, in the dry season, is capable of carrying the weight of a horse and has even carried a tractor; but when a hole is broken through this crust, it will rapidly fill with salt water. The mud becomes softer with the depth; where the surface was wet the author has pushed a broom handle down into the mud with ease. The melting snow and rains from the mountains run into these flats, and the surface water, which varies from one in. to several inches in depth, is blown for miles by the wind. Frequently an area that has been covered with water one day will be dry the next for miles, owing to the removal of the water by the wind to a distance of several miles during the night. To say the surface is dry is hardly correct, since except at that time of the year when a salty crust forms it is impossible to walk upon the surface without splashing the mud in all directions.

After storms, salt is sometimes found upon the windows of houses 15 mi. from the Lake in Salt Lake City, where salt-laden moisture has been deposited upon the glass. Telephone leads in the vicinity of Salt Lake City have had their insulation considerably lowered on account of salt and alkali dust being blown upon them.

The track of the Western Pacific Railroad and the lines of two telegraph companies and at the present time the transcontinental telephone lines all pass across this desert. It is understood that the railroad company when building their road laid a floor of planks on the mud and put a gravel bed upon this. In some places, it is necessary to protect this roadway from the action of the drifting water by filling it in with rock.

Investigations made showed that the salt is blown upon the insulators during storms and splashed by the

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Presented at the Pacific Coast Convention of the A. I. E. E., Salt Lake City, Utah, September, 6-9, 1926.

action of rain. This salt forms a crust on the surface, and when this takes place on the interior of the insulators, the insulation of the lines is materially reduced. During fogs which are very prevalent at certain seasons of the year this salt becomes wet and the insulation resistance falls rapidly to a very low value. At such times it has been observed to fall to values as low as 0.09 megohms per mi.

The effect of freezing is interesting. During the tests which were made for the purpose of investigating this subject, it was observed that at sunrise, after sufficient time has elapsed for the insulator coating to thaw, the insulation would drop materially; and then, as the warmth of the sun evaporated the moisture, the insulation would rise again. In one case when the insulation fell to 0.5 megohms per mi. between wires and ground the wind in one hour dried it so that the insulation returned to 4600 megohms per mi.

The southern route known as the Western Pacific Route appeared to be the better for these transcontinental telephone lines when all things were considered, provided the insulation difficulties could be overcome. It had several points of advantage over the northern route. For example:

1. It would shorten the mileage considerably.
2. Less cable would be introduced.
3. A considerably less amount of interference from foreign circuits would be felt.
4. In addition, by shortening the route, there would be less cost for construction and maintenance.

There were favorable climatic conditions on this route from a point of construction and maintenance, and also it was along a through-line of railway which was kept open at all times of the year. The Lincoln Highway, which was not built at that time, was under consideration and quite likely to be constructed by the side of the railroad tracks which passed over the mud flats. This highway has since been built as expected.

The experience of one of those who had given warning of the difficulties which had been encountered in maintaining satisfactory insulation of lines had extended over thirty to thirty-five years. It was therefore decided to make a series of tests in order to find out the cause and, if possible, the remedy for the falling insulation. It was known that this trouble was usually noticed during January, February, and March of each year and chiefly during the night hours. Consequently in January 1914 an investigation was launched on an experimental basis. The lines chosen for this were those already existing north of the Lake and others to be specially built over the mud flats west of the Lake. The test stations chosen were Kelton in the first case and Arinosa in the second.

The preliminary tests showed how very important it was to have all glass insulators well washed and cleaned before being put in place on the poles. If this were not done, differences of about fifty per cent were observed between the insulations of one line and another which was of similar character.

The observations made were carried out during January, February, and March of 1914, and a series of observations was made and recorded every three hours throughout the twenty-four hours of each day. These comprised insulation tests between wires and between wires and ground, hygrometric, thermometric and barometric observations; and the dew points were calculated.

The charts, Figs. 1 and 2, show typical values of insulation resistance measured between wires and ground

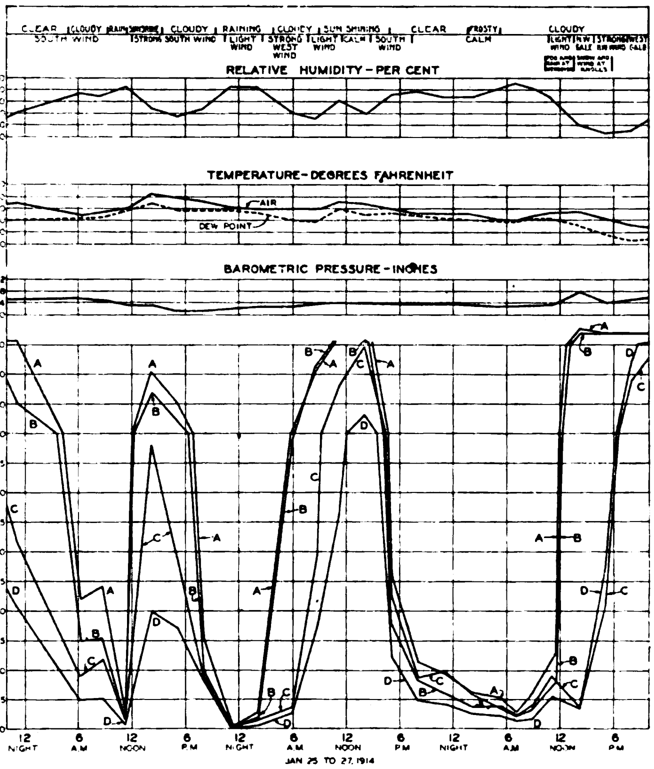

FIG. 1—CHART SHOWING LINE CONDITIONS. AVERAGE INSULATION OF WIRES TO GROUND. KNOLLS—ARIONSA—WENDOVER WIRES THAT HAD BEEN STRUNG UPON INSULATORS FOR SOME TIME AND THEREFORE EXPOSED TO WEATHER

A—Copper circuits—Arinosa to Wendover
B—Iron circuits—Arinosa to Wendover
C—Copper circuits—Arinosa to Knolls
D—Iron circuits—Arinosa to Knolls

upon various circuits under different conditions of temperature and weather. These show clearly the value of having the insulators clean. It was observed that iron-wire lines have a relatively lower insulation than those of copper under ordinary conditions. It is thought that this is due to metallic salts, such as chloride of zinc and iron, or oxides of the latter, being washed onto the arms and the outer surface of the insulators by rain and the action of dripping. The insides of the insulators probably receive these deposits by the action of rain splashing the salts when it strikes the arms around the insulators. These salts when deposited upon the surfaces of the insulators cause leakage which is very marked in damp and foggy

weather. As the inside surface of an insulator plays a very important part in its proper functioning, this seems to teach that these surfaces should be as clean as possible at the time of installation. Careless handling and lack of this precaution will often cause unequal leakage on the two sides of a circuit.

The result of this study brought out the following: That the liability of the insulation of the lines to fall to a dangerously low value was about as great on the route north of the lake as on the southern route west

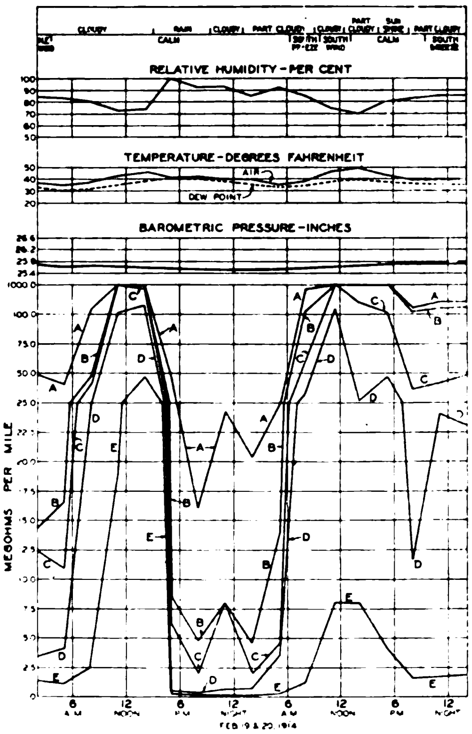

FIG. 2—CHART SHOWING LINE CONDITIONS—ARINOSA TO KNOLLS. AVERAGE INSULATION OF WIRES TO GROUND

A—Experimental circuit—No. 8, B. W. G. Copper wires strung upon clean insulators
B—210-lb. copper wires
C—Iron wire, No. 118
E—Iron wires, No. 19 & No. 1
D—No. 8 B. W. G. Copper wire
} Strung upon insulators that had been in place for some time

of the lake, and that the solution of the problem of preventing these reductions in insulation was to remove the salt from time to time by washing the insulators. It was therefore decided that this would have to be done in the case of either of the routes under consideration.

It was further decided that, all things being considered, the best engineering solution was to build the transcontinental telephone line which passes through Salt Lake City over a route south of Great Salt Lake. This route, after bending in a northwesterly direction, proceeds westward over the mud flats to the Nevada line and so on towards San Francisco. A portion of this line crosses eight mi. of solid salt and 34 mi. of mud flats, besides a stretch immediately south of the lake which is open to receiving a deposit of salt upon the insulators as it is exposed to storms which blow from the lake.

The transcontinental telephone pole line as constructed on the mud flats consists of 20-ft. by 7-in. Western Cedar poles with 176-ft. spans. The guying on this part of the line is done in all four directions every mile with side guying both ways half-way between. The line crosses the Salt Lake Desert between Clive and Wendover. At locations where the loading coils were placed on the poles, cross pieces were fitted to prevent the poles sinking in the mud owing to the extra weight they had to carry.

It may be interesting to note that it has not been found necessary to apply any preservative to the wooden poles which are set in the mud because of impregnation with salt in solution which preserves the wood to a remarkable extent.

The problem of washing the insulators was a somewhat serious one because, if it were necessary to take the insulators down, it would mean interruption to service and damage to the conductors by undoing and retying the tie wires, and this would be a long and expensive process. The author therefore devised a method by which the insulators could be successfully washed from time to time without climbing the poles or untying the wires. This method consists in spraying the insulators with saturated steam or finely divided hot-water spray. Of course the recognized aging action of steam on glass surfaces might make it undesirable to adopt generally such a method for cleaning insulators, but under the unusual conditions prevailing in this case the method described seemed justified.

The steam is applied through a nozzle at the end of a

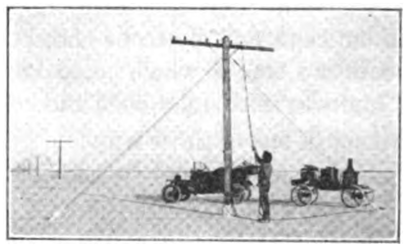

FIG. 3—WASHING INSULATORS WITH STEAM

fishing-rod device which is held under the insulator to be cleaned. The steam is generated in a portable boiler which is heated by an oil fire; see Fig. 3. The temperature is automatically governed so that the steam is kept at about 70- to 90-lb. pressure per sq. in. When an insulator is to be washed, after the nozzle has been placed in position, a valve is opened and the steam forces the water out of the boiler through a pipe leading to the nozzle, and it passes out in the form of a finely divided spray or wet steam. An automatic arrangement of pumps supplies water to the boiler to replace that which is used.

It is advisable to mention that in this location

economy in the use of water is important, as water is a large item in expense; therefore, the time necessary to wash an insulator has been carefully ascertained as 30 sec. All fresh water has to be carried out to the machine from a considerable distance. It is brought by the railroad, distributed at intervals along the line, and then rolled out in barrels across the mud flats.

During the time when an insulator is being washed, no appreciable disturbance has been noticed in the service taking place over the lines. The rapidity with which salt or alkali dust, both of which are of a stubborn nature, is removed by the steam is astonishing.

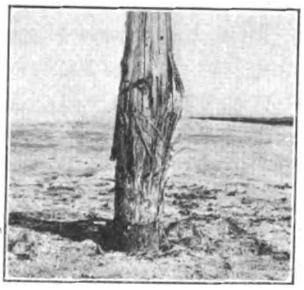

Fig. 4—Pole with Sap Wood Split by Action of Salt

To give an illustration, a broken glass insulator encrusted with salt to the thickness of half an inch was subjected to the spray and in less than a minute after the steam was applied, the glass was completely cleaned.

The steam washing plant is built with wide metal tires and is pulled sometimes by horses and at other times by a Ford car which is also equipped with wide tires. These are fitted on the usual type of demountable rims so that it is easy to change quickly to rubber tires when necessary. Many miles of the mud have been found so soft that it was necessary to lay planks in order to keep the car and the steam-generating plant from sinking. These planks were taken up after the machines had passed over them and relaid in front.

It has been found necessary to wash the insulators at least once every two years but the frequency, of course, is governed by conditions of salt deposit. When the insulation resistance is found to drop to a predetermined amount, it is time to arrange for a washing of the line. While this is in process, the improvement in the insulation of the wires may be observed as the washing proceeds.

The following example of some insulation measurements made in 1923 between a wire and ground shows the effect of washing the insulators.

INSULATION IN MEGOHMS PER MILE

January	March	June	August	October
11.37	32.3	101.6	68.2	637.0

When the insulation had fallen to so low a level in January, when dry, it was decided to wash the insulators as soon as conditions on the mud flats would permit, since in wet weather it would go to about 0.5 megohms per mi. Accordingly they were washed after August. The table shows how the insulation rose from 68.2 megohms per mi. to 637.0 after the washing. Both of these months were comparatively dry months.

The cost of washing the insulators on the mud flats ranges between \$500 and \$700, according to prevailing conditions.

The accompanying illustration, Fig. 4, shows the action of the salt upon the poles above the ground line. This, at first sight, appears to be rather alarming but it has been observed that the rending action of the salt, which takes place as it crystallizes, affects the sapwood only. On poles which are formed by splitting trees into quarters, only the sapwood which exists on one of the three sides seems to be affected in this manner.

Once since the line was built a rather peculiar experience was recorded. This was at a time when rain had fallen in quantity and was upon the surface of the salt solution on the flats. This was followed by a heavy frost and ice formed in thick layers. The wind broke this into floes, which were forced against the poles and did considerable damage by abrasion. Fig. 5 shows a pole damaged in this way.

The telephone line was built at a distance of 1000 ft. from the railroad. The reason for this was because the engines burn oil as fuel, and a deposit from the products of combustion would form upon the insulators if the line were close to the railroad.

The difficulties of constructing this line can be realized from the description which has been given. Mud boats were used to convey material. The insulators were carefully washed close to the railroad and before

Fig. 5—Pole Cut by Action of Ice

they were carried out to be placed in position, each was placed in a paper bag in order to prevent it being splashed with mud while being carried out to the line over the mud flats.

Those in charge of maintenance of lines carrying electric energy, be it either for power or communication purposes, may well consider the advisability of cleaning the insulators from time to time in sections in which

they are exposed to receiving a deposit of such substances as tend to lower the insulating qualities of the lines.

After an experience extending over more than twelve years with these transcontinental lines, it is gratifying to find that that portion which passes over the mud flats of the Great Salt Lake Desert is perhaps more free from disturbance due to weather conditions than any other part of this lead which connects the Atlantic and Pacific Coasts. If, however, the insulation of this portion were not kept at a high standard at all times by periodically washing off the accumulation of salts from the insulators, this would doubtless be the worst section from an insulation viewpoint.

Research Relations Between Colleges and Industry

BY A. A. POTTER[1]

Non-Member

Synopsis.*—The engineering colleges of the U. S. A. are expending about one million dollars per year for research of direct value to industry. The organized research departments or engineering experiment stations of many state supported engineering colleges are cooperating with industry in a variety of projects. In several institutions the amounts appropriated by the cooperating agencies are large, but the total funds expended for engineering research in colleges is less than one-thirtieth of the amount spent by these institutions for undergraduate instruction.*

While the results of cooperative research are directly of value to industry, the by-product of such research relations is a supply of scientifically trained research engineers.

Industry has a clear cut obligation to support engineering research at colleges in order to improve the quality of the college training, to advance basic knowledge in engineering and to increase the supply of trained personnel.

ABOUT forty American engineering colleges are now carrying on organized engineering research. In about nine institutions the funds for this purpose come partly or entirely from state appropriations and these state grants for research have amounted to a total of about $123,000 during the year 1924-25. During the same year about twenty institutions have set aside a total of approximately $451,000 in their engineering college budgets for engineering research. During 1924-25 fifteen engineering colleges received through cooperative relations with industry over $500,000 for research. Thus the total annual expenditure by the engineering colleges for research is about one million dollars, or, roughly speaking, one-thirtieth of the amount spent by these colleges for undergraduate instruction, not including interest on educational plants or depreciation.

The following summary is intended to show the variety of projects which are being carried on in cooperation with industry by engineering colleges which have organized Engineering Experiment Stations or Departments of Engineering Research:

1. The Cornell University Engineering Experiment Station has cooperated with industries for a number of years in research projects of considerable magnitude. No data are available as to details.

2. The Engineering Experiment Station of the University of Illinois has been cooperating with industry in the following projects:

a. The Austin Manufacturing Company contributes $1200 each year for a period of two years from February 1, 1925, to pay the stipend of two research graduate assistants in highway engineering. One assistant is making a study of the maintenance of earth roads; the other assistant is investigating the maintenance of gravel roads.

b. Investigation of the Fatigue Phenomena of Metals is carried on in cooperation with the Engineering Division of the National Research Council, the Engineering Foundation, the General Electric Company, the Allis-Chalmers Manufacturing Company, the Copper and Brass Association, and the Western Electric Company. This investigation has been in progress since November 1919, the amount appropriated each year approximating $15,000.

c. An investigation of the Fatigue of Steel Castings has been carried on in cooperation with the American steel foundries since the spring of 1925. The amount contributed by the American steel foundries is $2000.

d. In cooperation with the National Warm Air Heating and Ventilating Association, an investigation of warm air furnaces and heating systems has been carried on since October 1918. The activities of this investigation were expanded last year by the addition of the Warm Air Heating Residence valued at $22,800. The annual expenses of the investigation average $8000.

e. The Illinois Gas Association furnishes $1200 each year for the maintenance of two research graduate assistants in Gas Engineering. These assistants have been maintained since 1916.

f. An investigation of plumbing is carried on in

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1. Dean of the Schools of Engineering and Director of Engineering Experiment Station, Purdue University, Lafayette, Ind.

Presented at the A. I. E. E. Regional Meeting of District No. 5, Madison, Wis., May 6-7, 1926.

cooperation with the Illinois Master Plumbers Association for which an appropriation of $1800 is made annually. It has been in progress since April 1925.

g. The Department of Railway Engineering cooperates with the Illinois Central Railway in an investigation of railway signaling.

h. The University of Illinois Engineering Experiment Station is also cooperating with a committee which represents six state public utilities in studies of direct value to the utilities of the nation. Appropriation by cooperating agency is $25,000 per year for two years.

i. It has also cooperated with the American Gas Association in a study of the steaming of horizontal gas retorts; with the Illinois Central Railroad in research on railway signal equipment, and with several railway companies in investigations of rail joints and special railway equipment. It is carrying on in cooperation with the American Railway Engineering Association studies of large steel rollers.

j. In May 1925, the University of Illinois Engineering Experiment Station has reported to the New York State and New Jersey Interstate Bridge and Tunnel Commissions on ventilation tests for use in the construction of the Hudson River Vehicular Tunnel. The amount appropriated for this work was between $40,000 and $50,000 and the investigation required about four years for its completion.

k. The University of Illinois Engineering Experiment Station is conducting a cooperative investigation with the United States Bureau of Public Roads to secure data on the factors affecting the design of drainage ditches and the improvement of natural channels to minimize the damage from floods. This investigation was started in 1925 and the U. S. Government furnishes one man on full time.

3. The Engineering Experiment Station of the Iowa State College has carried on investigations dealing with the following subjects:

a. Culvert Pipe. In cooperation with a joint committee of the American Concrete Institute, American Association of State Highway Officials, American Railway Engineering Association, American Society for Testing Materials, American Concrete Pipe Association, and American Society of Civil Engineers. For a number of years about $6000 annually has been spent on this investigation.

b. Strength of Clay Sewer Pipe incased in different thickness of concrete. In cooperation with the Clay Products Association which is paying about $550 for tests of 24-in. pipe.

c. The Iowa State College Engineering Experiment Station has been investigating the strength and loading of highway culverts, tractive resistance and fuel consumption of motor vehicles on various types of highway surfaces, and highway bridge impact. The U. S. Bureau of Public Roads has cooperated in these projects since April 1922 with the following expenditures: 1921-22—$1,571; 1922-23—$8,216; 1923-24—$10,797; 1924-25—$21,462; 1925-26—$7000.

4. The Engineering Experiment Station of the Kansas State Agricultural College has cooperated with industry in the following investigations:

a. Tests of automatic ventilators. (Value of ventilators donated about $400).

b. Tests of oil burners for house heating, in cooperation with manufacturers of burners. (Value of equipment donated for tests about $200).

c. For about four years the Kansas State Agricultural College Engineering Experiment Station has been studying air resistance to movement of motor vehicles. (Contribution by U. S. Bureau of Public Roads to date about $15,000).

5. For a number of years the University of Kansas Engineering Experiment Station has cooperated also with industry in research. These include studies of Kansas coal (in cooperation with the coal producers) and several special projects which are supported by the Chambers of Commerce of the cities of Kansas.

6. The Technology Plan which was put into practise by the Massachusetts Institute of Technology in 1919 is a cooperative arrangement whereby industrial concerns seeking aid in scientific and engineering research may pay the Institute stated sums of money as retainer fees for a period of five years, in return for which they have at their disposal, with certain limitations, the research staff and facilities of M. I. T. The services supplied by M. I. T. in connection with this plan include:

a. Personnel records of M. I. T. alumni available for the purpose of assisting contractors in locating desirable men.

b. The libraries of M. I. T. open to the representatives of contractors.

c. Arrangements made for representatives of contractors to consult with members of M. I. T. staff.

d. Advice given by M. I. T. to contractors for the solving of special problems or the carrying out of tests. (In such cases as call for work in M. I. T. laboratories by members of the staff, the contractor is expected to pay such sums as are mutually agreed between him and the staff. The overhead varies with the nature of the service but the average is about fifty per cent).

The Division of Industrial Cooperation and Research which administers the Technology Plan, acts as a clearing house whereby the questions of the contractors may be discussed, planned for and attacked in a prompt and efficient manner.

Professor Charles L. Norton, the Director of the M. I. T. Division of Industrial Cooperation and Research, states that it is very difficult to make even a rough estimate of the amount of money which has been spent on industrial research at M. I. T. He believes, however, that this has been in excess of $175,000 annually.

7. The Department of Engineering Research of the

University of Michigan reports an expenditure of over $50,000 per year for cooperative engineering research. Among the major projects are included:

a. Natural illumination. (Study is in the third year).

b. Single-phase and fractional horse power motors. (Two years' work have been devoted to these projects).

c. Natural ventilation. (Project is in its third year).

d. Cutting of metals. (This study, in cooperation with Michigan Manufacturers, has been carried on for three years).

e. Admiralty and Muntz metals. (Investigation has continued for two years and involves the properties of these metals at high temperatures).

f. Development of a machine for automatically testing bearings for noise. (This has continued for over two years with results of great value to industry).

g. Boiler feed water treatment.

h. Studies of charcoal iron.

i. Refrigerating media.

8. The Minnesota Engineering Experiment Station reports the following cooperative projects with industries:

a. Transmission of heat through building materials in cooperation with the Flaxlinum Insulating Company. (Contribution by cooperating agency $1750 per year for two years.)

b. Investigation of rotary pumps for viscous oils in cooperation with the Northern Fire Apparatus Company. (Appropriation by cooperating agency $750 per year).

c. Behavior of asphalt under temperature variation in cooperation with McLaughlin and Sons. (Contribution $500).

9. The University of Missouri Engineering Experiment Station is cooperating with industry in the following manner:

a. The National Lime Association has furnished $3000 during a period of eighteen months for a study of the effect of lime products on dirt roads.

b. The Southeastern Missouri Sunflower Growers Association has furnished material for studies of commercial uses of sunflower oils.

c. The Radium Company of Colorado, the U. S. Radium Corporation and the Keystone Metals Reproduction Company have cooperated in an investigation of processes for the extraction of radium from carnotite ores.

10. The Ohio State University Engineering Experiment Station, beside the cooperative investigations with the ceramic industry (which it has practically created) is at present studying:

a. The betterment and the gasification properties of Ohio coals in cooperation with the Southern Ohio Coal Association, Ohio Oil Gas Men's Association, American Gas Association and the Southern Ohio Pig Iron and Coal Association. Contribution by cooperating agencies $10,000 for two years.

11. The University of Cincinnati, Ohio, has been carrying on the following studies:

a. Cooperation for about four years with the Tanner's Council of America in research of a fundamental character and of direct value to the leather manufacturers.

b. Lithographic research of a basic character, started March 1, 1925, in cooperation with the Lithographic Foundation.

c. In cooperation with the Civic Commercial Club and the Union Gas and Electric Company of Cincinnati, studying the sub-surface resources of Cincinnati, Ohio.

12. The North Carolina Engineering Experiment Station reports tests of the strength of poles for the Carolina Light and Power Company. Public Utility is furnishing poles valued at about $3500.

13. The Pennsylvania State College Engineering Experiment Station is studying the following problems:

a. In cooperation with eight Pennsylvania manufacturers, it is attacking problems of cold storage. (Appropriation $800).

b. In cooperation with the Pennsylvania Railroad an investigation is being made of refrigerator cars.

c. In cooperation with the U. S. Navy and with several private parties, a study of internal combustion engines is being carried on. (Contributions in materials and apparatus to date are valued at about $11,000).

d. In cooperation with the American Society of Heating and Ventilating Engineers an investigation is being carried on dealing with heat transmission. (Contribution $500).

e. The Pennsylvania State College Engineering Experiment Station is cooperating with the U. S. Bureau of Mines in investigations of explosiveness of flour mill and elevator dusts.

14. The Engineering Experiment Station of Purdue University is studying:

a. The causes and prevention of discoloration of Indiana limestone; in cooperation with the Indiana Limestone Quarrymen's Association (Appropriation by cooperative agency $4000 per year, plus materials valued at about $500 per year). Project has continued for two years and appropriation was renewed for the third year, effective April 1, 1926.

b. In cooperation with the Automotive Industry investigations of automobile carbureters, manifolds, spark plugs, pistons, piston rings and cylinders; also special problems of steering, detonation, supercharging, fuels, etc. (Contribution by cooperating agencies equipment (mainly), fuel oils, and about $3500 for special assistance.

c. Standardization of Tractors in cooperation with tractor manufacturers and U. S. War Department. Contribution by cooperating agency equipment (mainly), fuel, oil and $1200 for special assistance.

d. Study of insulators for high voltages (up to 600,000 volts) in cooperation with manufacturers of insulators.

e. Tests of brake shoes, pulleys, insulators, materials of construction and a variety of devices for industry.

(Income from such commercial tests has varied from $3000 to $6000 per year for a number of years).

f. Celite as an insulating material in cooperation with the Celite Products Company. (Fellowship $1000 per year for one year).

g. It is cooperating with the mining interests of Indiana in a study of the steaming qualities of Indiana coal and in connection with methods for the improvement of its quality.

h. Investigations in cooperation with the Indiana Sand and Gravel Association.

i. The Purdue University Engineering Experiment Station is cooperating with the American Railway Association in an investigation of power brakes and power-brake appliances. This study was undertaken on March 1, 1925. The amount expended by the cooperating agency from March 1, 1925 to April 1, 1926 has been in excess of $100,000. This investigation will involve an additional expenditure of about half a million dollars before it is completed.

j. The Purdue Engineering Experiment Station is also cooperating with the railroads in studies of brake shoes, rail joints, and special railway equipment.

k. The American Railway Association has contracted to start a cooperative study of draft gears at Purdue University. The machine to be used in these studies will consist of a drop testing machine using a 27,000-lb weight.

l. It is cooperating with the telephone utilities in investigation of buried load cables and with electric light and power utilities in studies of high-voltage insulators, electric meters and in the emergency braking of electric cars.

m. The Purdue University Engineering Experiment Station in cooperation with the U. S. Bureau of Public Roads is studying the effect of moisture on the strength of concrete and on the warping of concrete road slabs, the effect of small amounts of reinforcing in preserving the surface of concrete against cracks, the fatigue of concrete, and a new test for surface hardness of concrete measured by the impression of a standard steel ball. These studies have continued for about four years, the U. S. Bureau of Public Roads furnishing two men on full time.

15. The University of Tennessee Engineering Experiment Station is cooperating with the following units:

a. The American Limestone Company, in an examination of a special grade of limestone as a basis for concrete. (Contribution by cooperating agency $600).

b. The Southern Appalachian Coal Operators Association has contributed $1500 toward a study of the properties of Kentucky and Tennessee coals.

16. The State College of Washington is cooperating with the State Automobile Association in the study of the relation of road surfaces to automobile tire wear.

17. The University of Washington has been cooperating with local industries in studies of centrifugal blowers, heat treatment of cement, intakes for high velocity flumes, flow of water in concrete and vitrified clay sewer pipe, and coal washing problems.

$160,000 has been provided to the University of Washington by outside sources during the past three years for investigations on the K-B propeller.

18. West Virginia University is cooperating with the Gasoline Recovery Corporation in a study of absorption materials for the recovery of gasoline.

19. The Engineering Experiment Station of the University of Wisconsin has the following projects in cooperation with industry:

a. The study of pipe bend losses in cooperation with the Vilter Manufacturing Company and Crane Company who have furnished pipe bends for this study.

b. The electrical standards laboratory renders services to the state somewhat analogous to the services rendered to the nation by the U. S. Bureau of Standards. An established schedule of fees is used for such services.

c. Studies in cooperation with Wisconsin industries of the friction of line shafting, welded joints, steel chain, fatigue of rock drills, riveted and bolted joints. (Appropriation by cooperating agencies $2400 plus special equipment and specimens).

d. At a cost of $1000 per year the Wisconsin Utilities Association has supported two fellowships in electrical engineering at the University of Wisconsin. Since 1917 the Gas Utilities has supported one fellowship by providing $500 per year for this purpose. The Wisconsin River Light and Power Company has contributed $500 for research.

Besides the above investigations under the organized Engineering Research Department the following are of interest:

1. The American Society of Mechanical Engineers is cooperating with Harvard University and the Massachusetts Institute of Technology in steam research and the extension of the steam tables. The total expenditures for this study to date is about $43,000.

2. The National Research Council is (a) indirectly cooperating in connection with the highway investigations in several institutions, and (b) has assigned to the Engineering Experiment Station of the University of Illinois one of its Fellows to make an investigation of the surface tension of the elements. The stipend for this Fellow is $2500 per year. It is also cooperating with Illinois in the investigation of fatigue of metals as mentioned in the earlier part of this paper.

3. The National Electric Light Association is cooperating in the studies of Rural Electrification with seventeen colleges. This cooperative project involves an expenditure of about $250,000 per year, half of which is being contributed by the utilities.

4. The American Society of Civil Engineers is cooperating with the University of Illinois in investigating reinforced concrete arches contributing toward this about $2000 per year.

5. Practically every engineering college is serving individual manufacturers by special tests and investi-

gations on their products. In some cases the results of such commercial tests are published for the benefit of the public, but in the majority of cases they belong exclusively to the manufacturer paying for the investigation.

6. Cooperation between state engineering colleges and state highway departments is quite general. In many states the state engineering colleges have furnished the testing laboratories for the newly created State highway departments. As the State highway departments grew it became desirable that routine tests of road materials be carried on in laboratories outside of the colleges. A number of colleges, however, are constantly assisting their state highway department by special investigations and by studies of road materials in their respective states. The character of the highway projects undertaken in different states shows the value of special state investigations to meet local conditions. Eighteen engineering colleges report very definite projects in cooperation with State highway departments.

7. Cooperation in research is also quite general between engineering colleges and the U. S. Bureau of Public Roads, the United States Bureau of Mines, State Bureaus of Mines, the U. S. and the State Geological Surveys, and with other technical departments of the Federal Government and of the State Governments.

8. The Guggenheim Fund of $2,500,000 for Aeronautics has been announced recently. It is hoped that the trustees of this fund will make a considerable portion of this available for research at engineering colleges

The above summary indicates that the engineering colleges are competent to undertake research projects which vary greatly in scope. While the results of such cooperative investigations are directly of value to industry the by-product of such research relations between the engineering colleges and industry is a supply of scientifically trained research men. Engineering colleges which have good facilities for research attract men of superior mentality desiring to pursue graduate study as a preparation for a research career. Industries and utilities can benefit themselves and stimulate graduate instruction in engineering by sending back to the engineering colleges for advanced study and research, certain of their selected employees.

The industries and utilities have a clear cut obligation to provide the engineering colleges with special equipment and funds for the solution of new problems through research in order to be certain that the engineers of the future have intellectual curiosity and ability to extend the frontiers of engineering knowledge. More liberal support for engineering research at colleges will improve the quality of the engineering college graduate, will advance basic knowledge in engineering and will increase a supply of trained personnel for the research laboratories of industry.

HYDROELECTRIC PROJECTS OF MAJOR IMPORTANCE

In its visualization of a policy of water development, the department has indicated seven great projects of major importance: (1) Mississippi system; (2) Columbia River system; (3) Colorado River; (4) Great Lakes system; (5) the Great Valley of California; (6) intracoastal waterways; (7) other important developments, including the Rio Grande and Hudson Rivers.

Each system must be considered as a whole and organized to the maximum results. We need immediate determination of the broad objective and best development of every river, stream, and lake in our country in order that we do not undertake or permit haphazard development, whether public or private, that will destroy the possibilities of the maximum future returns.

Progress of science and engineering, inventions in construction methods, improvements in water craft, discoveries in transmission of electricity have brought us to the threshold of a new era in utilization of our water resources. We are able to undertake great projects with confidence of successful accomplishment.

During the year, the department has vigorously advocated a policy of water development. Actual inspections have been made on the Great Lakes system, Mississippi River system, Columbia Basin, and in the Great Valley of California. In various addresses, the Secretary of Commerce has directed public attention to the fundamental benefits of the development and indicated its immediate national importance.

The St. Lawrence Commission of the United States, under the chairmanship of Secretary Hoover, has been engaged in consideration of the improvement of the St. Lawrence River from Lake Ontario to Montreal, providing not only canalization for deep-sea navigation to the Lakes but the development of large quantities of electrical power. A joint board of American and Canadian engineers has been actively at work on the engineering aspects and will report later this year. The Department of Commerce has conducted a searching economic study of the effects and benefits of the project for consideration of the commission.

A concurrent study of an alternative route from the Great Lakes across New York State also is in progress. With economic and engineering studies of both routes in hand, sound conclusions can be reached and final recommendations prepared for the consideration of the country.

During the year, at the request of Secretary Hoover, negotiations with Canada were undertaken resulting in the appointment of a joint commission to consider methods for the preservation of the scenic beauty of Niagara Falls. Concentration of water in a V-shaped notch in the Canadian Falls is breaking down the escarpment at a serious rate.—(From the Annual Report of the Secretary of the Dept. of Commerce.)

General Power Application

Annual Report of Committee on General Power Application*

A. M. MacCUTCHEON, Chairman

To the Board of Directors:

Continuing the policy of last year the committee organized its work along the following lines:

1. To secure and present papers covering general power applications not previously on record before the Institute.

2. To study the field of general power application with a view to indicating such parts of the field as are not now adequately served and to point the way toward future developments.

3. To summarize in the Annual Report the progress in General Power Applications during the past year.

4. To present a bibliography which may be referred to by those who desire more complete and detailed information.

The program of the Regional Convention at Cleveland was largely prepared under the direction of this committee. The subject of Sectionalized Electric Drive as applied to paper machines was presented in a series of three papers. Electric refrigeration from the standpoint of the refrigerator manufacturer and the Central Station was discussed in two papers.

The committee has requested the assignment of a session at the 1927 Midwinter Convention and has already arranged for a paper on a-c. elevator motors and a paper on sectionalized group drive applied to the manufacture of steel wool. It is suggested that continued attention in future years be given to this subject of sectionalized group drive where the different motors on the group or train must be synchronized in speed. In the discussion of the committee report it is hoped that other subjects will be suggested, indicating those fields of application in which the members of the Institute will be most interested.

This year the committee can do no more than initiate a consideration of such of the industrial fields as are not now adequately served. Information of this nature must largely come from the user. It is considered that a very real service will be rendered to industry by recording such needs in the proceedings of the Institute. As examples, the manufacturers of refrigerating machines feel that there is a real need for developing a motor for household refrigerators which shall have adequate starting torque and yet be considerably less expensive. This is not a simple problem but deserves the most careful consideration. There is opportunity for rendering a real service to industry in developing a control system for synchronizing the various motors of a group or train drive, which shall have many of the advantages of, and be less expensive than, the extremely accurate control systems developed for paper mill applications. Several suggestions have been received that the Central Stations increase the possibilities of small polyphase motor applications, where such motors might be less expensive, more reliable, and of better operating characteristics than single-phase motors.

It is requested that all members of the Institute record with the General Power Committee the unsatisfied needs of the electrical industry as such needs come to their attention.

The following have been suggested as suitable subjects for papers. Discussion is invited.

"Power Factor Correction" by the Use of Condensers.

"Texrope" Drive for Short Belt Centers.

Induction Motor Control under Starting Conditions by the Use of Resistance Starters.

Double Squirrel-Cage Rotor Induction Motors.

A-C. Elevator Drive.

Experience with Antifriction Bearings Applied to Electric Motors.

Electric Welding of Long Pipe Lines in the Field.

Isolated Small Power Plants for Standby Purposes to Insure Continuity of Service.

Co-operation between Power and Telephone Companies in Eliminating Problems of Inductive Interference.

A summary of the progress in general power applications can never be complete. This report records only those applications which have come to the attention of the committee. The thanks of the committee is extended to Allis-Chalmers Mfg. Co., American Brown Boveri Elec. Corpn., D. H. Braymer Equipment Co., Can. Gen. Elec. Co., Century Elec. Co., Condit Elec. Mfg. Co., Elec. World Pub. Co., Fairbanks, Morse & Co., General Electric Co., Goodyear Tire & Rubber Co., Haughton Elevator & Machine Co., Howell Elec. Motors Co., Lincoln Elec. Co., National Elec. Condenser Co., Ohio Bell Telephone Co., Pittsburgh Elec. Furnace Corpn., Reliance Electric & Engineering Co., Ridgway Dynamo & Engine Co., Westinghouse Elec. & Mfg. Co., who have rendered most valuable aid in the preparation of the report.

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Lumber and Wood Working Machinery

Electric Dogs. The application of electric motor drive to the dogging devices and set works of reversing saw carriages is not only a distinctive forward step from a safety standpoint, but also it makes possible numerous operating economies not obtainable with any form of manual or mechanical operation. For electric dogging and tapering devices, high torque motors can be furnished for either a-c. or d-c. operation, although the former is most generally used. The motors have been thoroughly tried out in this service and proved themselves admirably adapted to the work. Due to the reversing motion of the carriage and operation in other than the horizontal position, the motor bearings are of the waste-packed sleeve type. Each dogging and tapering device is equipped with three motors of the same size and all are interchangeable, which greatly reduces the stock of wearing parts needed.

The control for electric dogs is constructed to withstand the heavy shocks and jars of logs slammed on the carriage by the nigger. The contactors for controlling all motions on the carriage may be housed in a steel cabinet, to protect them against damage and prevent the entrance of dust, and the push button stations mounted on the most convenient locations.

Electric Set Works. Although electrically-driven set works have been available for several years, the motors used on this equipment were formerly belted to the mechanism and ran continuously. For this scheme, a clutch was necessary to apply the motive power for setting or receding the carriage knees. Present practise favors the use of a direct-connected motor which requires less space, eliminates the friction clutch, and operates only during the setting or receding operation. An electrically-operated brake is used in connection with the direct-connected squirrel-cage motor, which acts as a recoil mechanism and makes it unnecessary to use a recoil pawl. The action of the brake is entirely automatic. When the motor is not running, the brake is set but as soon as power is applied to the motor the brake releases.

The control for the direct-connected motor may be either push-button or drum-controller operated, and consists of magnetic reversing contactors designed particularly to function reliably in the rapid operation of the log carriage.

Band Mill Drive. A 9-ft. band mill has been built with the lower wheel shaft direct connected to a 300 h. p. motor through a flexible coupling. This is the first large band mill ever built with a direct-connected motor drive.

Rubber Mills

The synchronous motor has made greater strides in general application in 1925 than probably during any other one year, and in no industry is this more true than that of the rubber industry.

Equipment is now being built for several automatic across-the-line starters with dynamic brake for synchronous motors driving rubber mill lines. These starters are unique in that three-pole, double-throw, oil-immersed, 2200-volt contactors will be used to throw the motors across the line when the contactor is in the upper position. The lower or dynamic braking contacts of the contactor are closed by gravity assisted by spring action. This is the first installation in which a double-throw contactor will be used for both dynamic braking and across-the-line starting.

A synchronous motor has been used to drive a rubber-hog, a machine used to cut up old tires, scrap rubber, etc. We believe this is the first time a synchronous motor has been used on this machine.

Bakeries

For dough mixer drive up to and including 50 h. p., two-speed, squirrel-cage motors have certain desirable characteristics. When starting, the motors are thrown across the line using the slow-speed connection and automatically transferred to the high-speed connection. This reduces the starting current below that of a single-speed motor, and also makes available two running speeds. Magnetic across-the-line starters are used with the proper automatic sequence obtained so that the motors will always start on the low connection.

Petroleum Industry

Two-speed, wound-rotor induction motors of 20-50 h. p. and 25-65 h. p. capacity with suitable controllers have been developed to meet increased requirements of pumping service. Similarly, to meet the demand of shallow light pumping wells particularly in foreign fields, a 10-25 h. p. two-speed motor and complete controller has been developed. There are gaseous oil fields where protected-type electrical equipment must be employed in drilling service, and in some instances protected motors and controllers are desired on pumping wells. This condition, together with the fact that any two pumping motors may be used to form a twin-motor, cable-tool drilling equipment, has resulted in developing enclosing parts for the slip rings of the entire line of pumping motors.

On the protected equipment, the motor slip rings are enclosed in a steel housing on the end of the shaft. The housing is designed to meet the specifications of the Bureau of Mines for explosion-proof apparatus. No parts of the motor subject to sparking are left exposed.

The controllers for the protected pumping motors have been made with all arcing contacts oil immersed. This includes the drum cam contactor-type controller, pole-changing switch, and circuit breaker, which are the only parts presenting a fire hazard due to sparking.

Irrigation

Hollow-shaft, squirrel-cage induction motors are at present being extensively used for driving turbine or centrifugal type pumps used in the irrigation fields

along the Pacific Coast. The pumps are of small diameter so that they can be lowered in the well casing and submerged in the water. As the water level lowers the pump is lowered and the shaft is extended to meet the new conditions.

The motor consists essentially of a standard vertical squirrel-cage motor with a hollow shaft, the inside bore being sufficiently large to accomodate, with clearance the extension of the pump shaft. The motor drives this shaft at the upper end by means of a coupling. The pump half of the coupling is threaded to the pump shaft so that the proper adjustment and alignment of the pump impeller at the other end of the shaft can be made conveniently. The upper ball bearing is sufficiently large to handle the thrust weight due to the motor rotor and the pump impeller and shaft, while the lower ball bearing of the motor acts as a guide bearing for the motor rotor. A cover or hood, which is easily removable for adjusting purposes, encloses the coupling and shaft end and also protects the motor from dripping water without interfering with the ventilation.

The principal demand for these motors is in sizes from five h. p. to 50 h. p. of four and six poles with a tendency to go to higher speeds, that is, two poles and larger horse powers. These motors are so designed that they may be started directly on the line.

Chemical and Electro-Chemical

In this field one large installation consists of a large, geared, turbine-driven, d-c. electrolytic unit, rated at 2800 kw., 136½ volts. This unit, the largest of its kind, is representative of the most efficient type of electrolytic power unit obtainable, where the power plant and electrolytic-cell room are adjacent.

One copper mining company has purchased 11,500 kw. in synchronous motor-generator sets to supply d-c. power for obtaining copper electrolytically from the leached ore.

A new type of drive for centrifugal extractors in chemical and other industries involved the use of a direct-coupled squirrel-cage motor to secure high starting torque with low power consumption and good performance at full speed. This motor has a high resistance section in the rotor winding built in the form of a fan and located at the top of the motor. The heated air developed is thus expelled without passing through the motor proper. Adjustments in acceleration and speed are obtained by use of double busses, one high-voltage and one low-voltage, the accelerating being done on the high-voltage bus, the motor running on the low-voltage bus.

Electric Furnaces

A 15-ton, electric arc furnace requiring 5000 kv-a. electrical equipment has been applied for melting cold scrap, and another 25-ton electric arc furnace requiring 5000 kv-a. electrical equipment, for refining steel.

A 25-ton furnace for duplexing special steels from open hearths for ingot production is of interest. A large industrial plant has installed two 15-ton furnaces for duplexing blast furnace iron direct. In another plant, open hearth to electric furnace duplexing is being carried on with a 1½-ton electric furnace with most satisfactory results, although this size is somewhat smaller than is usually employed.

Continuous melting and the introduction of permanent molding machines has created a necessity for a continuous supply of hot metal. Batch operation is usually unsuitable for these improved molding methods.

A large percentage of recent electric furnaces put into operation have been installed for high-quality, close-grained, strong, electric-furnace, gray irons.

Of particular interest is a recent double electric furnace installation on the duplexing of malleable iron from cupolas on a continuous process. While this installation is unusual on account of the large tonnage handled, the results already obtained indicate that they will have a marked effect on malleable practise generally.

Since its invention, about a decade ago, the high-frequency induction furnace has been exploited on a basis of operation at approximately 12,000 cycles, this frequency being obtained by means of mercury-arc oscillators. In the last year the use of 500-cycle generators in melting copper, brass, nickel-silver, and similar metals has been quite successful. Sets of 2000 cycles also have been supplied.

Arc furnaces, originally supplied with single-voltage equipments, were superseded by two-voltage ones and during the past year three-voltage furnaces were under construction. These latter use the high voltage for breaking down the scrap, an intermediate voltage for completing the melting, and the customary refining potential of approximately 90 volts.

Elevators

The first full-automatic floor-landing elevator equipment for high-speed passenger service was produced and is now in operation. This equipment automatically brings the car to the floor after the operator has initiated the stop by moving the car switch to the "off" position. This constitutes an important improvement over previous elevator operation in that the car stops at the floor, but does not stop before reaching the floor and then creep to it, nor does it overrun the floor and then creep back.

Tunnel Ventilation

While motor application to ventilation problems is not new there is one outstanding instance of such to be found in the furnishing of 90 motors, totaling 6000 h. p., to drive the fans which will ventilate the Holland tunnel, a vehicular passageway under the Hudson River connecting New York and Jersey City. The tunnel has a capacity of 2000 vehicles per hour in each direction, is approximately 8500 feet long and is the largest

tunnel of this type in the world. The motors are standard wound-rotor induction motors and will be installed late in 1926.

Cement Mills, Crushers, Etc.

There is a tendency toward the application of slow-speed, direct-connected motors to grinding mills. Two 900-h. p., 180- rev. per min. clutch-type synchronous motors have been sold to operate 7-ft. by 40-ft. compartment tube mills. These will be among the largest motors for tube-mill drive ever manufactured.

The application of clutch-type synchronous motors has made rapid progress, particularly in the case of grinding and crushing machinery in the cement and copper industries, but installations in flour mills, on pumps, and on other applications have also been made. This motor has been developed for use in applications where the well-known advantages of the synchronous motor are desired and where high starting torque with low starting current is essential. The motor is a combination of a synchronous motor of standard type and a magnetic clutch arrangement to form a compact self-contained unit. The motor rotor can be revolved independently of the load and after synchronous speed is reached the load can be started by exciting the clutch.

Controllers have been developed for this motor ranging from manual control of both motor and clutch to automatic motor starting and automatic clutch engagement. All forms of controllers have both the clutch and motor control built together as a unit.

While the motors above are of the clutch type there have also been applied motors of the same rating (900 h. p. at 180 rev. per min.) of the induction synchronous type for direct connection to compeb mills without the use of a clutch.

High-speed, gyratory crushers driven by vertical direct connected induction motors have been placed on the market by a large manufacturer.

Agriculture

Applications of electricity to agriculture greatly increased during the year. Much attention has been given to this branch both on the continent and in America. Some of these applications include electrical plows, electrical treatment of ensilage, fodder, etc., and general farm and dairy machinery.

Arc Welding

The past year has seen an interesting development in the field of arc welding. While for some years past there have been occasional applications of arc welding in the building industry, the past year has shown several striking applications which no doubt will lead to its adoption, eliminating riveting in many instances. Tests that have been conducted show conclusively that an arc-welded joint made in the fabrication of structural steel is both stronger and cheaper than a riveted joint of the same class of construction. Besides being cheaper and stronger, the elimination of the nerve-racking din of the pneumatic hammer alone will make this process welcome to the inhabitants of the larger cities where building operations are most active.

The introduction of a new and improved automatic arc-welding head for production work is another of the notable advances in the field of arc welding. This head is much simpler than anything yet produced and promises to be a decided advance in this class of work.

The construction and application of automatic welding machines for the commercial production of tanks, range boilers, etc., was continued and a variety of mechanisms adapted to particular classes of work were constructed.

Industrial Heating Progress

Industrial electric heating made marked advancement in 1925, both in increased connected load and in new developments. It is estimated that throughout the country more than 200,000 kw. was added to central station lines not including arc welding.

The use of electric heat is increasing rapidly in such processes as japanning, core baking, drying, heat treating and annealing metals, glass annealing, melting steel, brass, and the soft metals. The application of small units to process machines is increasing the rate of production in many lines and the use of small devices such as glue pots, soldering irons, and immersion units is becoming standard practise.

New developments were carried on in cloth singeing, sheet-metal, tinning, heating mine drills, and in baking bread and other food products.

Paper Mills

A new rotary-contactor regulator for sectional paper-machine drive has been applied to both fourdrinier and cylinder-paper machines and is operating successfully. This regulator is fully described in a paper presented by Mr. S. A. Staege before the Cleveland Section of the A. I. E. E. during the March 1926 meeting. During the coming year a number of paper machines under control of this rotary-contactor regulator will be put into operation. These machines make a variety of papers at maximum speeds varying from 450 to 1400 ft. per min.

A specially-developed d-c. drive for paper cutters has been applied with a resulting appreciable increase in production and uniform quality of product. The motor has a speed range of three or four to one by field control, and the control is designed so as to permit uniform acceleration to a predetermined speed and uniform retardation to the full field speed of the motor. The operation is obtained entirely from the push-button station, and permits the operator to slow down immediately when necessary to remove poor sheets. Also the cutter can be driven at the maximum speed suitable to the product.

An automatic control equipment designed to govern the synchronous motor driving two magazine pulp grinders has been developed. This control, in case of

failure of the power supply to either of the feed motors, continues to function and holds approximately half load on the other stone. It also maintains automatic control on one stone when the other is not in use, and permits of the use of the feed mechanism as a hoist, raising and lowering the magazine when it is necessary to change stones.

In Canada, synchronous motors have been applied with success for direct connection to screens and vacuum pumps of the Nash type. In the past, these have been driven by chain or belt, but, on account of the low-speed, direct-connected induction motors, have not been satisfactory. Higher efficiencies and smaller floor space are the principal advantages.

Printing

The standard drive for printing presses is a two-motor arrangement consisting of a large driving motor and a small motor for threading the paper through the rolls at a very low speed. In a certain installation, a special drive was provided which involved the use of one wound-rotor motor for each press instead of the customary two. The necessary speed variation was secured by means of two synchronous motor-generator sets for supplying current to the driving motors, the generators being of low and high frequency. Full automatic control was provided, and by pressing the proper push button any of the driving motors could be made to run at a threading speed of 1/15 to 1/20 of the normal speed.

Laundry Machinery

An improved control for reversing washing machines in laundries has been developed. The control consists of a drum driven by the machine which is to be reversed. The machine makes a given number of revolutions in one direction, bringing the drum to the point where the connections are changed and the motor reversed. A special motor is used, and the combined design is such that the motor is brought to rest gently and started again in the opposite direction without shock to the machinery, thus combining the advantages of electric control with the cushioned effect of the belt-driven machine.

Steel Mills

A 2500-h. p., 257-rev. per min., synchronous motor has been applied for tube-mill drive. This is apparently the first installation of synchronous motors for this work.

A marked tendency has been evidenced to get back to the use of d-c. motors where variable-speed drive is required.

As regards main-roll drives, the year was one of unprecedented activity in the application of electric motors. One large manufacturer supplied a continuous capacity of 133,000 h. p. in motors for this service.

An unusual equipment was required by the Youngstown Sheet & Tube Company. Instead of driving the several stands of a Morgan Mill from one common line shaft, the stands are combined in several groups, each group driven by a separate adjustable-speed motor. Both a-c. and d-c. adjustable drives are used. The roughing train will be driven by a 3600-h. p., adjustable-speed Kraemer Drive, and the intermediate train by a 7500-h. p. similar drive, while the last three stands will each be driven by a 2000-h.p., d-c. motor. The equipment is unique in that the machines can be regrouped in many combinations, providing high efficiencies even on the lighter loads.

The first application of a decidedly large synchronous motor to main-roll drive is being made by the McKinney Steel Company, where a 9000-h.p., unity-power-factor, 107-rev. per min., 6600-volt, 25-cycle unit is used. The motor will drive a 10-stand, Morgan, continuous sheet bar mill. In addition to being the first large synchronous unit so applied, this motor has a higher continuous rating than any other motor so far applied to industrial purposes in this country and possibly abroad. The complete operation of starting and throwing on the line is entirely automatic and under control of a master switch.

A new and interesting application in the steel industry is the use of individual roll drive on run-out tables, etc. The motors themselves are of a small capacity and of the squirrel-cage induction type, but the installations are interesting in that speed variations of as high as three to one are required in some cases while two to one is very common. The speed variation is accomplished by supplying variable frequency to the motors, this being obtained from a motor-generator set, the motor of which is usually of the adjustable-speed, d-c. type. The alternator voltage follows the frequency changes and the roll motors have the characteristic of constant torque.

Railways

The Ward Leonard system of control was applied for the first time to the operation of a lift and turnover dumper for railroad coal cars. This dumper can handle a 120-ton car and the cradle hoist requires two 450-h. p., d-c. motors supplied with power by two synchronous motor-generator sets. The Barney haul for bringing the car up to the cradle also uses two 450-h. p. motors with similar control. The dumping is entirely automatic.

A number of five-h. p. motors were applied in the operation of car retarders, a service heretofore secured pneumatically. The function of these retarders is to stop railroad cars at the proper place in a classification yard and the retarding action is secured by wedging the car wheels between two sections of rail which are actuated by the five-h. p. motors. Through remote control the car dispatcher has the entire government of the cars.

The application of oil engines in combination with generators and motors for the propulsion of electrically-

driven motor cars has advanced considerably in the past year. New installations have been made by the Canadian National Railway and by the New York Central.

Gas-electric busses, while not new, made large gains in the number of applications.

Mining. A new application of the so called super-synchronous motor is to be found in installations for driving mine ventilating fans. The characteristics of these fans are such that the driving motor must be able to start and bring the fan up to speed under full load.

Tap-Changing Transformers. Considerable publicity has been given to the use of tap-changing transformers arranged for changing ratio under load. This type of transformer has found a special field for electric furnace work and is being manufactured by several companies.

Synchronized Group Drive. Reference is made under Paper Mills to the continued improvement in the highly specialized and accurate systems of control used in paper mill drives.

In the use of the much simpler and less expensive but likewise less accurate "dancer roll" control, experience has shown that it is much easier to keep the various motors in step during the period of acceleration by the use of the Ward Leonard System. As in the paper mill drive, the speed change of the group as a whole is accomplished by changing the line voltage, leaving only the correction in speed of the individual motors to be accomplished by field change.

Several applications of train drive have been made to continuous strip mills where the speed-torque characteristics of the various motors have been so related as to permit the elimination of all corrective rheostatic action. The various motors are held in step by the strip of steel being rolled under tension.

Probably the most novel application of train drive during 1925-26 was in connection with the manufacture of steel wool. Ten motors are kept in synchronism by a novel type of dancer roll which permits the maintenance of an adjustable but uniform tension on the wire which is being cut. This application will be described in detail in a paper to be presented next winter by Crosby Field.

Anti-Friction Bearings. The use of antifriction bearings on motors has increased rapidly. While ball-bearing motors have been supplied for years there is a continued improvement in the method of mounting and provision for disassembly. Standard lines of general purpose motors are now available with roller bearings. While possibly this subject does not come within the scope of this committee, it is referred to as being of unusual interest to the user. The steel mill electrical men have been particularly active in investigating the advantages and disadvantages of this type of bearing.

Control

A time-element magnetic control has been used for d-c. motors. Definite time intervals between the closing of successive accelerating contactors is secured by relays which have a lag in their operation due to the self inductance of a short-circuited coil.

Mine-hoist control in the past has been provided with current-limit acceleration relays. Definite time-accelerating relays have lately been employed with success.

Considerable progress has been made in the development and application of magnetic switches for throwing induction motors directly on the line. Special switches have been designed for dust-tight service in cement mills, etc.

A reversing master switch intended for use with magnetic switch starters and providing undervoltage protection in both forward and reverse directions has been applied for shipper-rod control of machine tools.

Temperature type overload relays have superseded older forms and are now developed for circuits of 2000 amperes.

Manually operated contactors have been applied replacing knife switches on motor circuits. These will safely interrupt ten times their continuous rated current and may be used on either a-c. or d-c. systems.

An electrically-operated pressure governor used in connection with a pressure-regulator control has been applied where water is either not available or not suitable for operating the hydraulic type of regulator.

One manufacturer reports the development of a new type of speed-regulating controller. With this equipment it is possible to maintain a substantially constant low speed on a slip-ring motor independent of load variations. The speed is maintained constant by means of an oil pump geared to the motor. The pressure developed by the pump varies with the speed and this change in pressure causes secondary contactors to open and close, thus regulating the speed. The same device provides automatic acceleration of the motor. It also disconnects the motor from the line at zero speed after it has been reversed to obtain a quick stop.

Inductive time-limit controllers have been applied not only to all types of mill auxiliaries, but also to bucket cranes.

Development was completed on a new type of space heater. In the new design, the resistor is imbedded in an insulating material of the refractory type, which produces a sturdy unit and one which can be overloaded with less danger of burnout.

There has been placed in operation a new type of liquid slip regulator. In this design, the electrodes are stationary and the liquid level is varied by forcing low-pressure air into and out of a displacement chamber. The regulator is remote-operated, a master switch controlling the primary contactors, the air compressor, and solenoid-operated valve which admits air to the

displacement chamber. A second valve provides slip regulation by bleeding air from the displacement chamber. In this way the liquid level is lowered on heavy loads and rises again as the load decreases.

A new line of a-c. controllers has been put on the market utilizing a new type of thermal overload relay. This relay consists of a pair of heaters enclosed in molded insulating material. An overload causes the melting of a special alloy and allows a contact mechanism to open the control circuit. The alloy hardens after the overload is removed and the contact mechanism can then be reset manually. The relay is provided with adjustment for varying the tripping point.

The application of Dean motor-operated valve units ahs been extended. A smaller unit has been brought out which has found its principal application in oil refineries. An explosion-proof station for this service has also been designed.

Some novel applications of magnetic clutches have been reported. A number of these clutches have been used to drive elevators, feeding gravity conveyors. If material backs up in the gravity conveyor, the circuit to the clutch is opened, thus stopping the elevator and preventing the feeding of additional material into the jammed conveyor.

Marine. Electrical propulsion of naval craft received a decided impetus in the launching of the airplane carriers U. S. S. *Saratoga* and *Lexington.* These are the largest naval craft afloat and each will carry propelling equipment of approximately 180,000 s. h. p.

The application of electrical drive to operate unloading machinery as cited in the case of the *"T. W. Robinson,"* a 13,000-ton Great Lakes Steamship, which itself is equipped with turbine electric drive, was a new departure.

In the past, numerous ferry boats have been provided with electric propulsion through fore and aft propellors. In 1925, for the first time, Diesel-electric drive was applied to the operation of a side-wheel ferry boat.

The city of Houston placed the first order for a Diesel electrically-driven and equipped fire boat.

The greatest advance in the marine field is probably the large increase in electrically-driven auxiliaries.

The first successfully operated electric platform hoists were installed on the S. S. *George Washington* and *Robert E. Lee*

Foreign Developments

The economical viewpoint involved in motor application when considered in connection with low speed driven machines has resulted in the development of a specially designed built-in, oil-immersed, high precision reduction gear, located in the end shield of the motor so as to form a unit. This application has been made to three-phase induction motors ranging from 1/3 to five h. p. and to three-phase and single-phase commutator motors from 5 to 15 h. p. A notable application has been to ring spinning frames in textile mills.

A-c. motors with built-in centrifugal starting device have found an increasingly wide application, being used to cover horse powers from 2½ to 250. The unusually difficult problems encountered in starting and accelerating sugar centrifugals have been successfully met by the use of this type of starting device on vertical motors.

The further development of three-phase and single-phase commutator motors with series characteristics has received a great deal of attention. Likewise extensive research work has been carried on in the development of 25-cycle, high-powered commutator motors with suitable controls for traction service.

Miscellaneous

The a-c. brush shifting motor was applied for the first time to the operation of punch presses, draw presses, and shears. These machines are ordinarily driven by a high-resistance type of squirrel-cage motor but the ability to adjust speed to the work in hand is very desirable.

The sale of "Texrope" drives increased tremendously. This is not particularly an electrical development but is of interest in the application of motor drive where the motor is placed close up to the work.

An interesting application is that of small induction motors operating on frequencies of 300 to 400 cycles and at speeds of 18,000 to 25,000 rev. per min. to grinding and polishing machinery. Even higher speeds are anticipated.

Synchronous motors of the vertical-shaft type have been applied for driving plate-glass grinders.

Refrigerating motors have been further developed by several companies. There is a real need of a satisfactory low-priced motor for this service, comparable if possible to automobile-starting motors.

Application of power apparatus for household purposes goes on apace. A new phonograph motor has recently been developed and is in use by some of the larger companies.

An improved type of mooring tower erected at the Ford Airport, Dearborn, Mich., afforded a new application for electrically-driven elevator and mooring mechanism.

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STEEL MILLS

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LIGHT SKETCHES HUGE FACES ON MOUNTAIN

Sketching out 60-ft. heads of Washington, Lincoln, Jefferson and Roosevelt on the bald rock face of Rushmore Mountain in the Black Hills of South Dakota is one of the huge tasks which Gutson Borglum, noted sculptor of memorials, is carrying out with electric light preliminary to the actual carving. Lantern slides projected at night against the mountain by powerful light were used for this work when Borglum laid out and partly executed the famous memorial of the South on Stone Mountain near Atlanta. The faces are drawn on the slides and thrown on the rock surface in the exact size of the finished work. Painters in slings hung against the sheer rock surface of the mountain drew the outlines indicated by the light so that on the following days the work of stone cutting could proceed.

Electricity in Mine Work

Annual Report of Committee on Applications to Mining Work*

F. L. STONE, Chairman

The Committee on Applications to Mining Work has done very little constructive work during the past year. From the nature of things, the Committee can only watch the development of the use of electric power in mines. This use is becoming more general every year and electric motors are supplanting every other kind of motive power. This is due, of course, to their higher efficiency and flexibility of control, combined with the fact that they are just as reliable, if properly designed for mine use, as any of the other forms of drive. I think that no mine operator who is contemplating the opening of a new mine would consider any other method of drive.

In coal mines there always exists the hazard of explosion from gas, and in the bituminous mines from both gas and coal dust. These explosions have destroyed hundreds of lives and ruined millions of dollars' worth of property. The operators consequently are making strenuous efforts to eliminate the initial cause of such explosions.

A small percentage of these explosions has been traceable to the electric arc. After such an explosion has occurred, all traces of its initial cause are usually obliterated. Consequently many explosions have been attributed, for the want of a better explanation, to electric arcs, without any real justification.

The hazard, however, does exist and it is entirely wrong for electrical engineers to attempt in any way to dodge the issue. It is unquestionably unsafe to operate open motors at the face of any mine that may become gaseous with little or no warning.

This condition, which is fully recognized by mining engineers, is putting a new problem to the electrical engineers. They must design apparatus which, to say the least, will be safer than that in use at the present time. The apparatus must be such that when its free space is filled with explosive gas or coal dust in suspension and this mixture ignites, sufficient heat will not be transmitted to the outside of the motor to cause the ignition of explosive mixtures surrounding the motor. The connections to the apparatus must be such that they cannot be tampered with or opened while power is on the motor, thereby drawing an arc. It is not the purpose of this report to outline in detail the many problems that are now up to the electrical engineer to produce apparatus which will be safe, even in gaseous atmospheres.

*Committee on Applications to Mining Work:

F. L. Stone, Chairman, General Electric Co., Schenectady, N. Y.

W. C. Adams,	G. M. Kennedy,	Charles H. Matthews,
M. C. Benedict,	R. L. Kingsland,	D. C. McKeehan,
Graham Bright,	A. B. Kiser,	W. F. Schwedes,
H. W. Eales,	Carl Lee,	W. A. Thomas,
L. C. Ilsley,	John A. Malady,	C. D. Woodward.

Presented at the Annual Convention of the A. I. E. E., White Sulphur Springs, W. Va., June 21-25, 1926.

The United States Bureau of Mines has rendered very valuable assistance to the manufacturers in describing in detail what constitutes safe apparatus, and will issue to manufacturers what is known as approval plates, which means that this particular piece of apparatus for which the plate is issued has been tested by them and has been found to be safe for use in explosive atmospheres in so far as they can ascertain. Quite a long list of such apparatus has been approved by the Bureau of Mines already and this list is increasing continually. The Chairman of this Committee believes that it will not be many years before state legislation decrees that all electrical apparatus used at the face of any coal mine must be similar to that which is now known as "approved apparatus."

Due to the great number of producing bituminous mines, the bituminous industry finds itself in a very precarious position. As a whole, the potential capacity of the industry to produce is very greatly in excess of the demand. Consequently, the price of the product is extremely low, and it would seem as though only the most efficiently operated mines can exist. This condition has led mining engineers to reconsider and intensively study their mining conditions with a view to reducing costs. The result of this study is that several new methods of mining have been evolved all of which require electric motors in some form or other. We have several successful mechanical loading devices where the coal is loaded mechanically into the cars after being shot. We have other schemes where the coal is drawn to the entry in large scraper buckets and there loaded directly in cars. There are also innumerable conveyor schemes which carry the coal from the face to the mine car, the conveyors being more or less portable and so arranged that they can follow the face as it recedes.

The electrical equipment for these entirely new devices does not present any very serious problem beyond the proper selection of motors to meet the conditions indicated.

In the effort to reduce further the costs at the mines, we find more and more fully automatic substations being installed for supplying direct current and also fully automatic pumping stations. We find the electrical engineers of the coal mines watching their peak demands and installing meters much more freely than in the past.

The electrification of power shovels continues at an ever increasing rate, the general scheme being the use of Ward Leonard controlled generators, using a motor and generator on each of the motions.

The metal mines have been fairly active this year, and electrification of these mines has proceeded along standard and well-defined lines.

Discussion at Niagara Falls

MEASUREMENT OF TRANSIENTS BY THE LICHTENBERG FIGURES[1]

(McEachron)

Niagara Falls, N. Y., May 27, 1926

Salt Lake City, Utah, September 7, 1926

(Discussion at Niagara Falls)

J. H. Cox: I am glad to note that the Lichtenberg figures are receiving attention, from the engineering standpoint, by others. All of this work will hasten a more thorough understanding of the phenomenon.

I may state that the klydonograph, the surge recorder which utilizes this principle, was placed in use not with the contention that we knew all there was to be known about the phenomenon, but rather that we knew enough about it to be sure that valuable and sufficiently reliable information could be obtained by its use and that any information so widely desired as that on transmission-line surges should not be withheld until all of the less important points were determined. Of course, the sooner these points are learned the better.

Although from the standpoint of a surge recorder the data obtained by Mr. McEachron at the extremes of wave front are of no practical value, they are interesting in view of the figures in the practical range.

In general, Mr. McEachron's results agree quite well with our own. I am surprised that he obtained such large positive figures with slowly applied potentials. Our tests show that the more sloping wave fronts produce smaller figures. This effect was noticeable to a slight degree at 60 cycles, true to a greater extent with the negative figures but also evident with the positive figures whether half-cycles or the full wave was taken.

Dr. P. O. Pedersen, who has probably done more work than any other investigator on this subject, states the following: "The figures appear only if the potential difference across the Lichtenberg gap is altered in an impulsive or sudden manner, and not if the potential is raised gradually." This observation was made by Reis and Mikola: "At a certain stage of the charging of the electrode the intensity of the field between it and the plate reaches a value at which ionization by collision commences. The ionization current charges the surface of the insulating plate and thus keeps the intensity of the electric field between the electrode and plate below the high value necessary to form the Lichtenberg figure. With a rapidly varying potential there is, however, a possibility of obtaining sufficiently strong fields because it takes some time to establish the compensating charge on the insulating plate."

In our work at East Pittsburgh we were able to obtain some figures but they were smaller than the impulse figures. We found that there were variations due to conditions of the emulsion and it is possible that Dr. Pedersen's emulsion was so conductive that his failure to obtain figures with slowly applied potentials was due to conduction current rather than ionization currents.

The nature of the formation of the figure is still unknown, but we all agree that it is caused by the state of stress in the gas adjacent to the emulsion.

In the klydonograph, when a potential is impressed on the electrode there is an electrostatic field set up between it and the metal plate. The gradient is of course more intense near the electrode and, proceeding away from the electrode, a point is reached where the gradient is not sufficient to form the figure, and hence the boundary of the figure. If the emulsion surface were conducting there would then be a charge distributed over the surface of the plate and the stress would be entirely in the dielectric. Since there would be no stress in the gas there would be no figure.

1. A. I. E. E. Journal, October, 1926, p. 934.

It is evident that with emulsions such as we get, which are only slightly conducting, there is no time for this charge to creep out from the electrode under impulsive conditions, but the slower the application the more creepage is possible and hence a smaller figure.

Surface conductivity increases with moisture content and we have found that under humid conditions 60-cycle figures are smaller than under dry conditions. As far as we have been able to determine, there is not time enough for this effect under any application rapid enough to be important in surge conditions on transmission systems.

Mr. McEachron's positive figures agree with ours, and as he states, their appearance is only an approximate measure of the rate of application. I am unable to understand the difference between his negative figures and ours. Our abrupt-front negatives were very clean-cut with straight rays. The five-microsecond negatives were clean-cut, but clover-leafed. It was only in the longer wave fronts that they had the fuzzy appearance.

We have found in practise that the negative figures are much less satisfactory to deal with than the positive, and agree that they vary more with frequency.

Fortunately, the large majority of surges found in practise are positive. I see no reason for this in the case of switching surges, but it is nevertheless true.

In the case of an oscillation the negative is evident and can be measured, although smaller than the positive, except in the case of a sustained oscillation. when we are not interested in it because it would have no higher voltage than the positive.

It seems rather remarkable that the distinct breaks shown in Mr. McEachron's curves for negative figures come at the same point of wave front for all voltages. There seems to be no explanation why there should be such an abrupt break in a phenomenon of this sort. Is it not possible that this was caused by the change in the type of circuit used when going from the long to the short wave fronts?

As to accuracy, I cannot help but feel that a great part of the variation in the figures is due to applied voltage. My reason for believing this is that when a potential was impressed on six terminals in parallel usually no measurable difference could be detected in the figures. We found, as Mr. McEachron did, that an occasional freak figure would appear. This would be perhaps 50 per cent smaller than it should be, never larger. However, such a picture would occur in less than one per cent of the tests and therefore does not throw a great amount of doubt on conditions found from tests over any appreciable length of time.

I would like to ask what degree of accuracy is possible with the cathode ray oscillograph. I noticed in some of Mr. Lee's work that the width of the zero line of an oscillogram was sometimes 20 per cent of the maximum deflection. I would also like to ask whether or not successive oscillograms taken with the same circuit with the same settings were identical in all respects.

It is desirable, of course, to know the accuracy of any instrument we use and therefore any work done to determine this is valuable. However, extreme accuracy in a surge recorder is not necessary. I believe it will be agreed that the operating engineer is interested only in the order of magnitude of the surge voltages on his line. Any instrument which will give this within 25 per cent is sufficiently accurate for practical purposes. I am confident that the accuracy of the klydonograph is well within that margin—within the frequencies present in actual lines. These frequencies range from one microsecond to a few hundred microseconds. I do not believe that we need worry about wave fronts steeper than one microsecond. Our tests have strengthened this belief.

(Discussion at Salt Lake City)

Joseph Slepian: The klydonograph is the only practical graphic surge recorder available at present, and its growing use is bringing us a wealth of information about abnormal voltages occurring on lines in practise. The proper interpretation of the figures obtained, therefore, is of highest importance, and Mr. McEachron is to be commended for his painstaking study of the relation between the figures and the surges which produce them.

As Mr. McEachron says, in spite of the interest which has been aroused by these figures, no adequate theory of them has yet been developed. However, there are a few facts which have been well established and which may be used in interpreting such data as Mr. McEachron presents.

First, we can be sure that the figures are produced by the high electrostatic stress in the air immediately adjacent to the film. Undoubtedly, the primary cause of the figures is some sort of electric discharge in the air. We know this because if a gas other than air is used or if the air pressure is changed, the figures are changed very radically both in appearance and size.

Second, we know that the figures are formed with extreme rapidity, in less than 10^{-2} seconds. In fact, the figures have been used to measure times as short as 10^{-11} seconds.

Now if the figures are produced by stress in the gas next to the photographic film, and in such very short times, it seems to follow inevitably that the figure size must accurately depend upon the peak stress in the gas, irrespective of the shape of the surge producing this stress up to the fastest surges with which we would be interested in practise. If, however, the figure size does vary under different circumstances with constant peak surge voltage in the line, it must be only because the peak stress in the gas does not bear a constant ratio to the peak voltage in the line. Such a variation in the ratio of stress in gas to line voltage is only to be expected if the electrostatic system in the neighborhood of the electrode on the plate is considered. It is evident that the electrostatic field at the electrode end will be determined not only by the voltage on the electrode but also by the dielectric properties of the glass, and by the surface electrical conductivity of the film. Evidently for extremely low frequencies, the surface conductivity of the film will play a significant part, and will operate to reduce the stress in the gas. Hence for these lower frequencies, from perhaps a thousand cycles downwards, the figures will come out too small. This agrees with Mr. McEachron's findings. For higher frequencies, however, the influence of this surface leakage should be negligible.

If there is any systematic variation in size of figure with frequency for higher frequency then this is to be attributed to the dielectric properties of glass under single impulses.

I do not believe that Mr. McEachron has proved that there is a systematic change in figure size with frequency for the higher frequencies, even for negative figures, for which Mr. McEachron shows the greatest per cent variation.

Examining Mr. McEachron's Fig. 6, and considering only those points to the right of, say, his 10-volt per microsecond line, we see that it is extremely hazardous to draw any kind of straight line through the points. The upward tendency of the lines which Mr. McEachron has drawn is largely due to his including low-frequency points on the lines. However, I believe it is erroneous to assume that the undoubted upward tendency of the points at low frequencies exists also at the high frequencies. If, as is likely, this effect is due to surface leakage, it will disappear at the higher frequencies. I suspect that we have here an erroneous extrapolation of the effect of surface leakage.

All that we may conclude from Mr. McEachron's points at the right of his Fig. 6 is that he obtained considerable variation in the figure size. I have plotted these points of Mr. McEachron on a sort of shot-gun diagram, and find that for a given figure size, the extremes of voltage differ by 33 per cent from their average. This, then, would be maximum error for practically occurring surges if the arrangement of Mr. McEachron were used in a klydonograph.

It is interesting to compare this result with the results obtained by Westinghouse engineers. Mr. Peters, in his early work with photographic plates, found that the figures produced simultaneously by a single surge, on a single plate, never differed in size among themselves by more than five per cent. When the figures were produced on different plates, differences as much as 15 per cent were found occasionally. When figures were produced by successive discharges from the same condenser circuit, Mr. Peters also found variations which he was led to attribute to variation in the surge voltage.

The character of the discharge in a short-impulse circuit is affected greatly by the state of the initiating spark-gap, and Mr. Peters believed that variations in the surge voltage due to the varying state of the initiating spark-gap caused apparent variations in figure size.

On this account, therefore, I would like to ask Mr. McEachron whether an oscillogram was taken for each point shown in Fig. 6, and if not, whether some of the variability was not due to the discharges not repeating accurately.

I would like to ask Mr. McEachron about the nature of his voltage-dividing system for the Dufour oscillograph, which is indicated as being a resistance potentiometer in Fig. 3, and particularly whether, for the very steep wave fronts, the capacity to space of these resistors might not cause the oscillogram to fail to portray the voltage on the Lichtenberg-figure electrode. Also, I would like to know whether these resistors contributed to the damping out of oscillations at the oscillograph, and if so, whether these oscillations might not still be present at the Lichtenberg-figure electrode.

Herman Halperin: It appears to me that Mr. McEachron deserves great credit for his exhaustive calibration of the Lichtenberg figures. These figures, as recorded on the commercial device known as the klydonograph, have been used in investigating transient voltages on several large systems during the past few years. There has been considerable discussion as to the frequency of surges on transmission systems, and the nearest that we could come to the nature of the surges up to this time was to use the klydonograph figures and estimate whether the surge was "fast" or "slow." Now from the data given in Figs. 5 and 6, it appears that a much more definite idea can be obtained of the steepness of the surges that occur on commercial transmission systems.

The figures obtained in the experience of the Commonwealth Edison Company on its 12-kv., 60-cycle, underground cable system showed that the surges were of the upper range of Type II. Its experience also indicated that most of the surges recorded were positive in nature. The probable reason for this is that when a negative surge occurred, the length of the figure was so small that it was covered by the line made on the klydonograph plate by the positive alternations of the normal 60-cycle supply. As shown by Mr. McEachron's paper, the positive figures are several times as large as the negative figures for a given voltage. This meant that a negative surge would have to be several times normal voltage in order to be found. The experience of the members of the various companies represented on the A. E. I. C. Subcommittee on Transients on Underground Cable Systems showed that the highest three per cent of the transient voltages on underground systems were 3.0 to 4.7 times normal operating voltage. It appears from the paper that the negative surges of even three times normal operating voltage would be covered by the figures caused by normal operating voltage of the positive polarity.

P. B. Garrett: It was my privilege to take a small part in the practical tests which were made on the system of the Southern California Edison Co. with the klydonograph. My primary interest in the Lichtenberg figures, therefore, lies in the practical knowledge which has resulted from their use.

From the studies made by Westinghouse engineers, it was felt that the klydonograph was sufficiently accurate, within the range of surge frequencies encountered in practise, to make it an entirely feasible and practical instrument for system studies. We felt it to be accurate within 25 per cent and it is particularly gratifying to find that Mr. McEachron's very thorough investigation bears this out. I believe that Figs. 6 and 7 in Mr. McEachron's paper indicate very clearly that the figures produced within the practical range of frequencies are well within the 25 per cent error just mentioned. In fact, these figures show in some cases an accuracy within approximately 10 per cent in the negative figures and considerably less in the positive figures. In this connection, it seems a happy circumstance that by far the greater number of the figures encountered in our practical tests were positive in nature. We know of no very good reason why this should be true, but it nevertheless is the case. The negative figures being so much less satisfactory to deal with in every way than the positive figures makes us very grateful for the positive figures we find in such large majority in practise.

K. B. McEachron: In conducting this investigation every care was taken to insure reliable results, many of the figures at the different wave fronts being checked several times.

The films used were not subjected, for this particular study, to any conditioning process either to increase or decrease the moisture content, as this would introduce a condition different from that usually found in practise.

The reference made by Mr. Cox to the lack of clearness of the negative figures compared with those obtained in the tests he made, can probably be best explained by stating that the increased clearness of figures seems to be due to the presence of oscillations on the wave front. The statement in the paper about this point is to be found in the last paragraph before the conclusions.

The experience of myself and those associated with me is that it is extremely unlikely that any impulse circuit producing impulses having fronts of the order of one microsecond will not be free from oscillation unless some proper oscillographic device is used to guide one in improving the circuit.

It seems likely that the reason why the switching surge is usually positive is because in a damped oscillation the negative, although occurring first, is obscured in many cases by the larger positive figures even though the positive lobe may have a much smaller amplitude than the negative.

The abrupt change in the negative figures with slow waves mentioned by Mr. Cox has not been accounted for as yet. With such slow waves, it seems doubtful that any circuit changes could have any effect when the voltage and time relations are known in every case. The circuit can only have an effect when it modifies the wave front.

Concerning the accuracy of the cathode ray oscillograph there is much to be said, but I am satisfied that for the results given in this paper the voltage is within five per cent and the time within one per cent of the correct values. The width of the trace on the photographic film is not troublesome as shown by the oscillograms given in the paper, the traces being as good as with the ordinary oscillograph, and frequently much finer and sharper lines are obtained.

It is true that successive impulses from the same circuit differ frequently, but since oscillograms were taken of every voltage application the changes in voltage and time relations could always be properly evaluated.

Dr. Slepian's discussion of the stress conditions in the air is interesting and agrees with our own analysis. I do not agree, however, that it is proper to consider only data beyond a certain arbitrary point such as the 10-volts per microsecond point in Fig. 6 without having experimental evidence to establish the existence of such a point. It is recognized that when dealing with Lichtenberg figures a curve or line drawn represents averages only, and that the true calibration is not a line but a band whose width is such that practically all the points fall within its boundary.

Dr. Slepian raises the same question as that asked by Mr. Cox as to the possibility of variation in succeeding impulses. The answer is the same, *i. e.*, an oscillogram was taken for each of the Lichtenberg figures.

It was early recognized in dealing with transients that stray capacities even of extremely small values could not be neglected. To make the dividing system function correctly without being dependent upon wave front it has been necessary to introduce proper compensation. The possibility of oscillations of disturbing magnitude existing between the dividing system and the surge recorder is rather remote because this possibility along with many others was foreseen and oscillograms were taken to determine whether or not such oscillations existed, and if found, the circuit was redesigned until the oscillations became small enough to be negligible.

SYMPOSIUM ON DIELECTRICS AND POWER-FACTOR MEASUREMENTS

(WHITEHEAD[1], CURTIS[2], HANSON[3], LEE[4], MARBURY, DOYLE AND SALTER[5], SIMONS AND BROWN[6], ST. CLAIR[7], KOUWENHOVEN AND BETZ[8])

NIAGARA FALLS, N. Y., MAY 26, 1926

P. L. Hoover: I should like to discuss briefly power-factor measurement in connection with bridge methods. There may be some doubt as to the accuracy of any bridge in measuring power factor, for, as Mr. Lee has pointed out, power factor is the ratio of the total power loss to the product of the voltage and the current. Now if a tuned vibration galvanometer is used for detecting the balance point of the bridge, only the losses due to a single frequency and not the total losses are measured. Fortunately in most cases the error that is introduced in this connection is probably very small and negligible. Nevertheless, most a-c. bridges cannot be regarded as precision power-factor bridges, since the power-factor balance is so critically dependent on an accurate capacity balance. For instance, with the Wien or the Schering bridge, if the capacity balance is off by one per cent the power factor may be off by as much as 50 or 100 per cent. Experimentally this means that the capacity balance must be made to a much greater precision than is required for the power factor. Such an experimental condition is to be avoided if possible.

A new type of bridge which is in use at the Harvard Engineering School and which was described recently before the Institute[9] avoids this difficulty. In this new bridge, a mutual inductance between the galvanometer circuit and one arm of the bridge measures the difference in phase of the two sides of the bridge so that the mutual inductance may be calibrated directly in power factor. Furthermore, with this new bridge the power-factor balance is not so critically dependent on an accurate capacity balance and it may thus be regarded as a precision power-factor bridge.

E. W. Davis: The problem of making dielectric loss measurements on reel lengths of cable as a part of routine testing in the process of the manufacture of a cable requires a method of great simplicity and of an accuracy equal to that of the knowledge of the variables involved. The use of direct-deflection wattmeters from the above point of view offers one of the simplest methods of making such measurements.

1. A. I. E. E. JOURNAL, December 1926, p. 1225.
2. A. I. E. E. JOURNAL, November 1926, p. 1084.
3. A. I. E. E. JOURNAL, August, 1926, p. 719.
4. A. I. E. E. JOURNAL, August, 1926, p. 746.
5. A. I. E. E. JOURNAL, June 1926, p. 556.
6. A. I. E. E. JOURNAL, June 1926, p. 524.
7. A. I. E. E. JOURNAL, August, 1926, p. 729.
8. A. I. E. E. JOURNAL, July 1926, p. 652.
9. *Ionization Studies in Paper-Insulated Cables.* O. L. Dawes and P. L. Hoover. JOURNAL A. I. E. E., April, 1926, p. 337.

Two direct-deflection wattmeters recently developed for this service have been thoroughly tested and found satisfactory.

One of these meters is of the single-pivot type with no damping; the other, of special suspension construction wherein jewel and pivot friction losses have been reduced to a minimum. The constants of these instruments have been obtained to a great degree of accuracy and have been found to remain constant over the range of operation of the meters. Both meters have a very small phase angle between the current and potential circuits, an angle considerably smaller than is ordinarily found in commercial instruments. One of the meters is designed with an inverted scale so that while the maximum reading is 0.2 watt, a minimum of 0.01 watt can be read easily and accurately. Check measurements made between these instruments and an Irwin dynamometer, usually used in such tests, show the existing errors to be negligible. Results of tests on hundreds of reel lengths in our factory check very satisfactorily with tests made by more complicated methods in our laboratory.

The lack of suitable standards for the calibration or checking of various dielectric-loss sets has for some time been appreciated. Attempts are being made to construct or use suitable standards of glass or similar material. The use of such standards does not seem to promise high precision of determination of accuracy, but for the present the accuracy may be sufficient.

By use of the same cable sample and very careful determination and control of temperature, duration of application of voltage and mechanical handling of the sample, etc., we have checked three separate methods (two dynamometer and one bridge method) and found them to give results within five per cent of each other. This of course is not high precision but for the present seems to be sufficient.

The calorimetric method of checking dielectric losses discussed by Mr. St. Clair offers a wide field for investigation, but the chances of error are great and the complication and time required reduce it to a very special laboratory test.

The use of identical samples and various series-multiple connections of them does not work out very well in practise due to the impossibility of obtaining exactly identical samples, which of course means uneven distribution of voltages for the various series connections tried.

The paper by Mr. Hanson on the "Accuracy Required in the Measurement of Dielectric Power Factor" offers too much material for adequate discussion at this time. With the tremendous variation of the thermal and electrical constants of insulating materials and with the still greater variation of the thermal characteristics of the medium in which the cable is installed, it is rather difficult to conceive why such great accuracy in the power-factor measurement is required. Purely as a laboratory measurement, such accuracy might be desirable. As a factory routine test we do not believe that such accuracy is necessary.

A dynamometer-wattmeter method of measuring dielectric losses which is radically different from those discussed in this series of papers, was suggested by Prof. Dawes, of Harvard, some years ago and used for a short time in our laboratory.

In this method, the wattmeter and also the ammeter are in the high-tension leads, enclosed in suitable metallic shields which are placed on insulators. The shield for the wattmeter is made sufficiently large to hold the compensating resistances and capacitances.

The potential circuit is supplied by potential transformers, the case of which is also on insulators and at line potential. All leads are shielded as well as ends of the cable sample.

By this method, all leakage currents are eliminated or at least prevented from affecting the meter readings. No run is necessary to determine set losses. By grounding the high-tension lead and the low tension of the potential transformers supplying the wattmeter through a second potential transformer, the potential differences between coils in the meter is reduced to a minimum.

I. M. Stein: I should like to suggest that a complete bibliography be made a part of this symposium. Some authors have given references that they have used in their papers, but no one of the papers gives a complete bibliography.

Mr. St. Clair's talk of shielded resistances brought to mind a recent publication of the Bureau of Standards. This is Scientific Paper No. 516, "A Shielded Resistor for Voltage-Transformer Testing." The Bureau of Standards designed and has been using for potential-transformer testing for a number of years, a shielded resistance that should be of interest in some dielectric-loss measurements.

J. D. Stacy: I should like to discuss Mr. Marbury's paper. It seems to me that perhaps the measurement of dielectric loss with the dynamometer wattmeter is largely a matter of application detail in order to make it as feasible to handle by the ordinary test man as the method which Mr. Marbury uses.

We have used the phase-defect, compensation, dynamometer-wattmeter method in the measurement of power factor of capacitors very successfully, making several thousand measurements per year. The initial calibration of the instrument was laboratory work involving the method described by Mr. St. Clair. Our general results in the use of this instrument have been very satisfactory.

Delafield Du Bois: What we need most is a means of judging the merit of any given testing set, so that we may not only determine if an installed equipment is satisfactory for its continued use, but may also determine the most satisfactory new test set to install.

I can do no more than outline what such a measure of merit might be in the hope that some one will perfect it.

In judging the merit of a test set there are three primary considerations: accuracy, convenience and cost.

Obviously, accuracy must meet a certain minimum for commercial testing, but greater accuracy than this is usually desirable.

Under the heading of convenience, many things may be listed, but the most important are speed and the skill required to test.

Cost should include not only the first cost, but the cost of such spare parts as might be necessary to carry in stock in order to put the set back in service following a puncture of insulation during test.

Accuracy, conveneince and cost may each be expressed numerically so that the sum of the three numbers will be the figure of merit of the test set considered.

The simplest means of reducing accuracy to a number is by establishing a standard test sample, such as the one Mr. Doyle has constructed. If a test set can measure the power factor of this test sample to within, say, B per cent accuracy, the figure of merit for accuracy will obviously be a function of B such, for instance, as $(C - B)\ D = A$ where C and D are well chosen constants. The actual values of C and D to be acceptable will, of course, have to be worked out by conference.

To arrive at a figure of merit for convenience let E be the time in man-minutes required to make two tests under widely different conditions. Then the figure of merit for convenience will be a function of E, such as $(F - E)\ G = H$.

If the skill required by the tester is greater than that of the usual laboratory assistant E should be corrected in proportion to the increased cost of testing.

If the number of tests per day can be estimated, cost can be reduced to a fixed charge per test. This can be expressed in equivalent man-minutes, and the figure of merit for cost I would be a function of these man-minutes similar to that used in determining the figure of merit for convenience.

If the constants C, D, F and G are well chosen, then $A + H + I = M$ will express the merit of the set.

This is only a suggestion but I believe it expresses an actual need.

Brian O'Brien: In classifying dielectric losses is it desirable to distinguish between (1) normal conductivity and (3) anomalous conductivity? The weight of evidence would indicate that no measurable electronic conduction similar to metallic conduction occurs in dielectrics, and that all conduction here is of an electrolytic character, that is, ionic, even when the conduction obeys Ohm's law. If this be true, the distinction between class (1) and class (3) lies only in the magnitude of the disturbing factors which cause departures from Ohm's law. If such a distinction is useful for the practical treatment of the subject, it might be well to emphasize the fact that the two losses are probably identical as regards the fundamental phenomena.

Granting that no measurable hysteresis effect occurs in dielectrics in the sense of a lag in polarization independent of time as found in magnetic materials, and that thus no permanent polarization of the dielectric as a whole will, in general, exist, this does not necessarily exclude the possibility of permanent polarization of the molecules of the dielectric. Kelvin and others have shown that such a polarization may exist without manifesting itself as a polarization of the whole dielectric. Therefore in dismissing dielectric hysteresis this possible molecular polarization and its effects on other forms of loss, such as absorption, must not be overlooked.

N. L. Morgan: Mr. Lee referred to the method of measuring dielectric loss by the use of the wattmeter and the water-tube multiplier. We have been using this method since 1917. The water-tube multiplier which we have been using consists of a straight quarter-inch glass tube about five ft. long and fitted with short brass tubes for making the taps. The ratio of the taps is 1, 2 and 4. Sufficient common salt is dissolved in the water to obtain the most convenient conductivity.

The form of the water-tube resistance used by Mr. Lee, I understand, was of the coiled-hose type used by Ryan and others. I think that the form of the resistance may be the reason why the check tests shown in Figs. 6, 7, 8 and 9 do not agree. In this resistance, I assume that the hose is coiled. There is an appreciable capacity between turns, and the capacity current passes through the potential coils of the dynamometer. The resistance is shielded against capacity to ground, but not against capacity between turns. This would also account for the large discrepancy between the curves of Figs. 8 and 9 obtained by using the full resistance and a portion of it respectively.

In the circuit I am using, the variation of the resistance of the multiplier with temperature is of no consequence. An ammeter is placed in this circuit and this current and the line voltage are observed at the time of reading the deflection of the dynamometer. Then variation of the multiplier current can be placed in the equation of power, which is

$$W = K\,D\,E\,/\,a$$

where

W = power
K = a constant
D = deflection of dynamometer
E = time voltage
a = current in the potential circuit

We have not found that shielding of the water-tube against capacity to ground is necessary on cable of greater lengths than five ft., if grounded metal is not closer than three ft. to the resistance.

The accuracy has been very good. We have sent cables to various laboratories and they have checked within close limits. As for convenience, a man can take five readings in about ten minutes. The parts, outside of the transformer and dynamometer, cost about 20 cents.

I should suggest that when using this method the potential coil be compensated for eddy currents as described by Rosa in a bulletin of the Bureau of Standards, otherwise the constant K will vary with the line voltage E. I should suggest also that when determining the constant of the dynamometer, alternating current be used instead of direct. I think that with these precautions and proper shielding of the dynamometer and low-tension leads this method of measuring dielectric loss is sufficiently accurate for commercial testing.

R. Notvest: In connection with Dr. Whitehead's paper it seems to me that in describing the process of deterioration of composite dielectrics, the tendency prevails to investigate symptoms only and to pay little attention to the primary cause. In other words, all has been concentrated upon the heating effect and gaseous ionization which are secondary phenomena only when certain investigations led to the belief that a piezoelectric effect is the primary cause.

Very little work has been done in this field. Madame Curie has been the pioneer; also the 1919 A. I. E. E. TRANSACTIONS contain a very valuable paper on the subject by A. M. Nicholson of the Western Electric Co.

It is a fact that practically all insulation materials, with the exception of glass (an undercooled colloidal liquid) contain more or less crystalline substances. This is true of the many grades of porcelain, marble, lava, soapstone and slate. The multitude of synthetic insulation materials consist mainly of an electric inert mineral filler embedded in a plastic or semiplastic matrix of either a natural or artificial gum of the phenol-resin type. Any crystalline substance subjected to a mechanical stress will produce a potential parallel to an optical axis and when subjected to an electrostatic stress, will develop a certain amount of kinetic energy at right angles to the direction of the stress. Since there is a tremendous quantitative difference in the value of the piezoelectric effect of the various mineral substances utilized for insulation materials, in some instances the effect can be identified only through a superfine and tricky arrangement of the means of observation; yet a piezoelectric effect contributes to the deterioration of the paper insulation of power cables since cellulose always contains a certain amount of SiO_2, silicic acid.

Under the direction of Dr. Booth of Western Reserve University, I have spent considerable time within the past few years in investigating this problem and hope to be able to present a paper soon covering the subject.

The matter can be expressed as follows. Whenever an insulation material is of, or has in its structure, crystalline substances, it is subject to a piezoelectric effect. Where such crystalline substances are embedded in a plastic or semiplastic matrix and exposed to an electrostatic stress, the individual crystals have a tendency to reorient themselves so that some optical axis (the one having the highest piezo effect) is at right angles to the direction of the potential pressure. When the direction of the electrostatic stress changes rapidly, a gradual microscopical opening of the structure takes place, increasing the amount and volume of voids and through molecular friction and the emission of charged particles from the crystals themselves, ionizing the occluded or infiltrated gases which in time causes the mechanical rupture and breakdown of the specimen.

J. B. Whitehead: We have had in foregoing meetings a number of excellent papers on the quadrant electrometer as a high-tension wattmeter. We have two such papers in this program, but the greater number are devoted to the electrodynamometer wattmeter. I have worked a great deal with the former, and have found it of great value and accuracy above a certain value of phase difference; but in the very low range, it suffers the serious disadvantage that the fractional value of voltage on the needle introduces a phase error, troublesome to determine and to eliminate. While I have not worked extensively with the electrodynamometer, it would appear that it is subject to the same type of error, as well as others of electromagnetic character, in the voltage circuit.

I have been working recently with the Schering bridge, and I prefer it to all other methods for the measurement of very low loss and power factor at high voltage. It is very rapid and the

possible errors are easy to detect and to eliminate; they arise principally in neutral capacity between the two sides of the bridge and to ground. Errors of this type are easily found and suitable screening will eliminate them. Particular attention must be given to the use of guard electrodes for both the sample under test and the air condenser, and to a screening system maintained at all times at the same potential as the test electrodes. This may readily be accomplished by resistance in the ground connection of the guards and their screening systems. Too little attention has been given to this source of error. I have found, for example, that 1200 ohms in a certain case was necessary in the guard-to-ground connection to ensure equality of potential with the test electrode. This connection in many cases is made directly to ground. In the case mentioned, a change of 100 ohms in 1200 was sufficient to unbalance the bridge. The principal disadvantage of the method is the requirement of a high-voltage air condenser, the capaity of which, for best accuracy, must increase with the capacity of the specimen to be measured. Thus the Schering bridge in its simple form is not suited to the measurement of the loss in long samples of cable. With a suitable air condenser and for relatively short cable lengths it possesses very great advantages.

Referring to Mr. Lee's historical review of the use of the electrodynamometer wattmeter, I wish to point out that in 1891, when I entered Rowland's laboratories, I found that in collaboration with Prof. Louis Duncan, he had developed a number of types of electrodynamometer, and was at that time investigating the value of the instrument for the measurement of dielectric loss. In a subsequent paper in the *American Journal of Science* he described a number of valuable methods for its use. Rowland's instruments were subsequently developed and sold by a well-known firm of manufacturers of electrical instruments.

H. L. Curtis: I should like to ask Prof. Kouwenhoven if the resistance of the battery in the electrometer method is negligible. It seems to me that in the final analysis it would have to be mentioned.

Mr. Hoover, in speaking of the bridge methods, stated that by a mutual-inductance method the sensitivity obtained in measuring the out-of-phase current was greatly increased. I regret that there are not a number of papers at this meeting on bridge methods. The bridge methods have much in common, the only difference being in the manner of making the adjustments. In all bridges it is necessary to vary the magnitude and phase of the current in one arm. What it amounts to is that the potential at the terminals of galvanometer is the same at each instant. There are a number of ways by which this can be accomplished. The Schering bridge has been used lately somewhat. This varies the phase by varying a condenser in parallel with the resistance in one arm. The adjustment, however, can be accomplished just as well and quite as conveniently by using the Rosa method where an inductance is in series with the resistance. The compensation can also be accomplished by putting a resistance in series with the condenser, or by a variable mutual inductance properly placed.

I cannot see that with any of these bridge methods or with the electrodynamometer method you are going to get away from the fact that you have to compensate for the magnitude of the current as well as its phase. If you try to avoid compensating one of these, you throw the burden on some other measurement. I also don't see that by using a mutual-inductance method you are necessarily going to gain in sensitivity over what you would obtain by any other method.

Mr. St. Clair mentioned the question of using two condensers in series as a check on the accuracy of measurement. I have always found that a very unsatisfactory method. It may work if you are using very large condensers where you can get them close together in value of capacitance and where the capacitance to ground is relatively unimportant; but with small condensers, the method of checking by using two in series is something which I have always found extremely difficult and feel that the check would be less satisfactory than some of the direct measurements which might be made.

There is one point in connection with Dr. Whitehead's suggestion about the potential of the guard plate of the condenser. It is essential that the potential of the guard plate and the guarded plate shall be the same at every instant. Generally, this condition is very closely approached by using a resistance between the guard plate and the earth, but if for any reason a phase angle is introduced in the measuring arm, an equal angle must be introduced also in the compensating arm.

C. F. Hanson: The particular phase of Mr. Lee's paper which I wish to bring to your attention is in regard to shunts generally supplied for use in connection with the dynamometer wattmeter.

The use of a shunt in measuring the power factor of a sample of cable 10 ft. long is not necessary, but it is necessary in measuring the power factor of a cable 500 ft. long, particularly if the same wattmeter is used for both jobs. The charging current of a 500-ft. cable may be of the order of one ampere corresponding to a voltage of 100 volts per mil, whereas the charging current of a 10-ft. sample of another cable may be only 0.002 ampere corresponding to a voltage of 40 volts per mil. A wattmeter which is sufficiently sensitive to measure power factor when 0.002 ampere is flowing, will not have sufficient current capacity to measure power factor when one ampere is flowing. A shunt is therefore necessary.

A shunt is usually constructed of two resistances and a capacitor of convenient dimensions. The capacitor is connected in series with the current coil of the wattmeter. The first resistance is connected in parallel with the capacitor. The magnitude of this resistance and the capacitor is so chosen that the current coil circuit behaves like a pure resistance at a given frequency. It is then a simple matter of connecting the second resistance, in the form of an Ayrton shunt, across the current-coil circuit containing the shunted capacitor.

The combination of the shunt and wattmeter coil may have a resistance of approximately 200 ohms when the shunt is set on 10, and 20 ohms when the shunt is set on 100. In other words, with a shunt setting of 10, a resistance of 200 ohms is connected in series with the cable and in some cases the error introduced may amount to 0.002 in the power-factor reading. With a shunt setting of 100 the error is only 0.0002 and is of no significance. The shunt settings chosen in this case typify those which might be used in an ionization test (the increase in power factor as the voltage stress is increased from 20 volts per mil to 100 volts per mil). Usually, by acquainting himself with his power-factor apparatus, the operator can avoid the foregoing error to a great extent if he exercises discrimination in the choice of his shunt setting.

One difficulty with most shunts is that the resistance coils in them are not provided with sufficient means for dissipating heat. This deficiency usually results in extraordinarily rapid deterioration.

The paper by Messrs. Doyle and Salter states that, in the case of three-phase measurements, they carefully control the voltage on a particular phase at the time when power factor is being measured on that phase. This voltage control does not eliminate a phase error, referred to in Appendix IV, which arises from inequality of voltage on the three phases. A similar error arises under two other conditions. The first is the condition of less insulation thickness on one conductor than on each of the other two, even though equality of voltage exists on all three phases. The second condition exists when the voltage vectors of the three phases are not equally spaced by 120 deg., even though the magnitude of the vectors may be equal and the insulation of the three conductors may be the same.

In Fig. 1 herewith are shown the vector relations between

charging currents flowing in the cable and the voltage applied to each conductor. The three voltage vectors are equally spaced at 120 deg. and the cable is symmetrical including equality of insulation thickness on the three conductors. The cable is considered to have zero power factor. The vectors E_1 and E_3 are of equal magnitude but E_2 is greater in magnitude. In other words, transformers No. 1 and No. 3 are supplying voltages of equal magnitude but transformer No. 2 is supplying a voltage of greater magnitude.

Fig. 1 is shown for a Y-connection of the supply transformers.

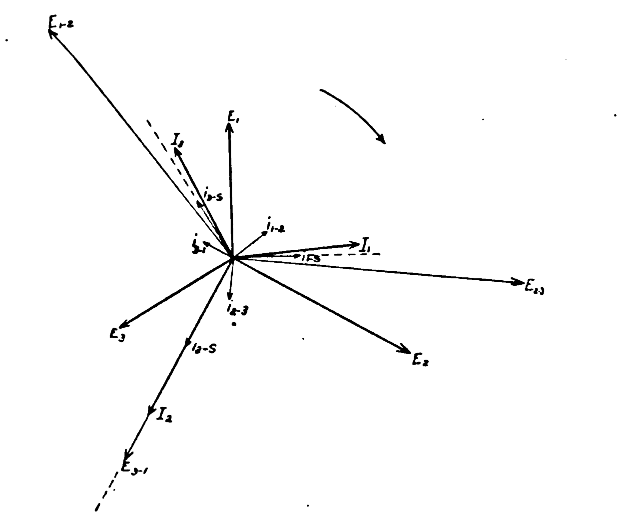


FIG. 1—THE VECTOR RELATIONS OF CURRENT AND VOLTAGES IN A THREE-CONDUCTOR CABLE WHEN IT IS CONNECTED TO A THREE-PHASE, Y-CONNECTED TRANSFORMER BANK

The common point of the transformers is connected to the sheath of a three-conductor cable and to earth. The high-voltage terminals of the transformers are each connected to a conductor of the cable. The various vectors shown are as follows:

- E_1 is the voltage to neutral on conductor No. 1.
- E_2 is the voltage to neutral on conductor No. 2.
- E_3 is the voltage to neutral on conductor No. 3.
- i_{1-S} is the charging current flowing from conductor No. 1 to sheath.
- i_{2-S} is the charging current flowing from conductor No. 2 to sheath.
- i_{3-S} is the charging current flowing from conductor No. 3 to sheath.
- E_{1-2} is the voltage between conductor No. 1 and conductor No. 2.
- E_{2-3} is the voltage between conductor No. 2 and conductor No. 3.
- E_{3-1} is the voltage between conductor No. 3 and conductor No. 1.
- i_{1-2} is the charging current flowing from conductor No. 1 to conductor No. 2.
- i_{2-3} is the charging current flowing from conductor No. 2 to conductor No. 3.
- i_{3-1} is the charging current flowing from conductor No. 3 to conductor No. 1.
- I_1 is the vector sum of i_{1-S}, i_{1-2} and i_{3-1} and is the total current flowing into conductor No. 1.
- I_2 is the vector sum of i_{2-S}, i_{2-3} and i_{1-2} and is the total current flowing into conductor No. 2.
- I_3 is the vector sum of i_{3-S}, i_{3-1} and i_{2-3} and is the total current flowing into conductor No. 3.

As the cable is considered to have zero power factor, the vector I_1 should be in quadrature with the vector E_1. The quadrature position is shown by the dotted line. Fig. 1 shows that I_1 is less than 90 deg. ahead of E_1. This condition exists because the vector E_2 is greater than E_1 and E_3, and indicates the error that will exist in the power factor as read on conductor 1. As the vector I_2 is in quadrature with the vector E_2 no error will exist in the power factor as read on conductor No. 2. The error of the power factor as read on conductor No. 3 will be of equal magnitude as the error existing in the conductor No. 1 power factor but of opposite sign.

The dielectric loss as read on conductor No. 2 will be abnormally high because the charging current I_2 is erroneously high. On conductor No. 1 dielectric loss will be abnormally high because of the erroneously high power factor. On the other hand, on conductor No. 3 dielectric loss will be abnormally low because of the erroneously low power factor.

In Fig. 1 of the paper by Messrs. Doyle and Salter the shielding problem is considerably simplified if the ground is removed from the lead sheath of the cable, and connected to the low-voltage terminals of the transformers. Any current then leaking over the transformer bushings and bus insulators will not flow through the current coil of the wattmeter but will return directly to the grounded terminals of the transformers.

In their Fig. 2, the ground cannot conveniently be removed from the lead sheath of the cable because it is not convenient to connect the current coil of the wattmeter into the high-tension lead from the transformer to a cable conductor. Therefore, in this case, the transformers must be insulated from ground. The case of each transformer should be connected to its low-voltage terminal. Likewise, all metal shields of the insulators of each bus should be connected to the low-voltage terminal of the transformer respective to the bus. Currents leaking over the transformer bushings and bus insulators will then return to the low-voltage terminals of the transformers without passing through the current coil of the wattmeter. These precautions are indicated in their Fig. 2 but hardly with sufficient clearness.

E. S. Lee: We have been told that there are no standards for these measurements. The question then is, how do we know we are accurate when we obtain a value?

In the General Electric Company, we used the dynamometer wattmeter first and obtained certain values. We had an opportunity to compare these with others observed more or less directly and they looked about right. Then we set up a Schering bridge and a year ago I reported our results. At that time I said that with the usual observers day in and day out we would check in general within about 0.002 on power factor, that is, 0.2 of one per cent. But we might expect at any time a difference of perhaps 0.004.

I always have wanted to see if we could not use some other method. In the paper he presented Mr. St. Clair told you of a calorimetric method which was used by himself and others in standardizing measurements made on capacitors. This was not an easy problem, either. It seems that there are difficulties at 2500 to 3000 volts, just as there are at the higher voltages.

From this work, it was found that the calorimeter method enabled these measurements as carried on in different laboratories to be standardized. Thus it occurred to us to apply similar methods to cables.

Two pieces of three-conductor cable, each 35 ft. long, were placed horizontally in a closed box as represented diagrammatically in Fig. 2 herewith. The box was 21 ft. long enclosing the central portion of these lengths.

Thermocouples were systematically placed along and around the sheaths of the cables over an 8-ft. length, the "hot" junctions being placed on one cable and the "cold" junctions on the other.

With copper-ideal thermocouples and a galvanometer of sensitivity 6.5 x 10^{-6} amperes per millimeter deflection at one meter scale distance, it was found that by using nine thermocouples in series for each unit, a temperature difference of 1/75 of 1 deg. cent. between the sheaths was indicated by a deflection of one cm. on

the galvanometer scale. In watts, this means that one cm. deflection indicated a difference of power dissipation of 0.005 watts per ft.

Measurements were made by applying three-phase potential to one cable, and circulating direct current through the conductors of the other cable until there was thermal equilibrium with the same sheath temperature as indicated by zero deflection of the galvanometer. The d-c. watt input was then calculated and considered to be equal to the dielectric a-c. power loss.

At this time we have only completed one test, the results of which are shown in Table I.

There are three tests: Nos. 1, 2 and 3.

The values of three-phase power loss calculated from single-

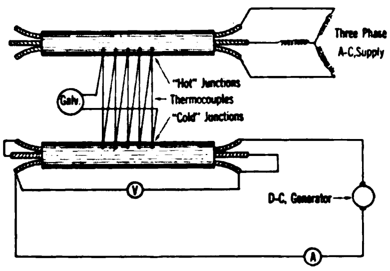


Fig. 2—Schematic Diagram Showing Layout for Determination of Dielectric Power Loss in Cables by Comparison of Heating

phase measurements in watts per foot are: 0.266, 0.276 and 0.275, or an average of 0.272.

By comparison of heating, the measured power loss in watts per foot for tests Nos. 1, 2 and 3 are: 0.297 which compares with 0.266; 0.289 which compares with 0.276; and 0.280 which compares with 0.275. The average is 0.282.

The differences are a little larger on the individual tests, but the average gives 0.272 three-phase power loss, calculated from single-phase measurements as against 0.282 by comparative heating, a difference of not quite four per cent.

Of course, if the watts check, the power-factor values should check. The value we obtain by taking an average of the results obtained in the three-conductor high measurement and the one-conductor high measurement, gives a value of 0.74 per cent. The power factor from the comparison of heating test was 0.72 per cent.

The voltage was a little bit higher in the comparison of heating tests: 36.0, 35.8 and 36.2 kv.

The results of these measurements are: first, our method of determining the power loss from three-phase supply from single-phase measurements seemed to give correct results; and second, that our standards in the outfit, our air capacitor and our method of compensation and our method of determining the watt constant evidently were quite correct.

The next thing we shall do will be to interchange the cables and then test at other voltages.

The thing that appeals to me is this; that here is a set-up that anybody can put up without very much trouble and be able to satisfy himself very adequately, I believe, of the accuracy of his own results by an independent method. The equipment is not considerable, though the time required is quite long, one or two days being required for each test.

Because of the most satisfying agreement obtained on these first measurements with the dynamometer-wattmeter equipment, it is our hope that other laboratories will provide similar set-ups as a means both of checking their equipments and of learning more concerning this method.

The results are satisfying to us, and I believe that in general the method is simple enough so that it provides a satisfactory method which can be used by different observers in different laboratories to satisfy themselves of the reliabiity of their results.

TABLE I

COMPARISON OF RESULTS

DETERMINATION OF DIELECTRIC POWER LOSS IN CABLES

Tests on three-conductor, 350,000-cm. (Sector) Cable, 7/32in. by 3/32 in. Treated Paper Insulation 1/8 in., Lead 15 kv.

A. By Compensated Dynamometer Wattmeter

Test	Three-Phase Power Loss (Calculated from single-phase measurements) Watts per Foot	Power Factor Per Cent Three-Cond. High	Power Factor Per Cent One-Cond. High	Voltage Kv.
1	0.266	0.70	0.78	35.3
2	0.276	0.60	0.88	35.3
3	0.275	0.59	0.87	35.3
Average	0.272	0.74 per cent		

B. By Comparison of Heating

Test	Measured Power Loss Watts per Foot	Power Factor	Kv.
1	0.297		36.0
2	0.289		35.8
3	0.260		36.2
Average	0.282	0.72 per cent	

E. H. Salter: In connection with the paper presented by Mr. Marbury on the resonance method of determining power factor as a factory or control method, there is one point of importance that has not been mentioned. By inserting a large inductance in series with the condenser under test the measuring instrument is protected in case of a short circuit or of failure of the condenser to stand the voltage.

Mr. Hanson has gone to great length to show what he terms the limits of accuracy in power-factor measurements of high-voltage cable. While a high degree of accuracy is desirable in such measurements, it seems that the stress is being laid on the wrong point when it is considered that two of the usual short samples of cable taken off the same end or reel of cable may show characteristics which differ by as much as 50 to 100 per cent, while the variation over a line, miles in length, may be much wider.

Mr. St. Clair suggested a method for checking dielectric-loss-measuring equipments by securing four identical condensers and after determining the characteristics of each, using series-parallel combinations. In precision measurements of the dielectric loss of condensers shielding and guarding play quite an important part. In making series-parallel combinations proper guarding would be difficult to obtain.

D. M. Simons: Mr. Lee's calorimetric method of comparing losses is of interest and should be of value. I think one warning should be included, and doubtless Mr. Lee had this in mind. Mr. Lee proved equality of losses in two cables by equality of temperature rise. This is true only if the two cables have equal thermal resistance from the sheath outward. The differences in surface thermal resistivity of different samples of leaded cable have been found to be great sometimes, though this effect should be minimized by the small temperature difference involved in Mr. Lee's method. This possible error can be eliminated by the method Mr. Lee has proposed of interchanging the a-c. and d-c. between the two cables, or it could be checked by heating both cables with equal values of continuous current, and proving equal temperature rises.

I should like to confirm Mr. Hanson's conclusion of the necessity for accurate determination of current-carrying capacity, and especially the effect of having a large number of cables in a

duct bank with very high-voltage cables. 66,000-volt cable is now in operation in two places with two circuits per duct bank. I doubt if it would be economical to include another circuit in the same duct bank, though it may be necessary in certain special cases. For 132,000-volt cable, careful consideration must be given in each case as to whether or not it is economical to use more than one circuit in a duct bank; that is, each circuit can carry less power if two circuits are in one duct bank than if they were in two separate duct banks. The gain in carrying capacity obtained by using separate duct banks may be worth the cost of one additional conduit line.

Mr. Hanson's figures show a rather dangerous condition of instability of temperature in some of the higher-voltage cables, particularly with large numbers of cables per duct bank. I do not believe the actual conditions are as bad as shown; I am under the impression that Mr. Hanson figured the temperature rise based on the calculation of dielectric losses assuming a constant power factor throughout the entire body of insulation. In an actual single-conductor cable with thick insulation there is usually a considerable difference of temperature between conductor and lead, which means that the power factor of the entire cable is by no means that of the layers of insulation near the conductor, and therefore the actual watt losses may be considerably lower than those used by Mr. Hanson.

As pointed out elsewhere, I believe the temperature rise of conductor above lead due to dielectric loss should be figured in terms of a constant power factor of the insulation at the maximum conductor temperature. For the temperature rise of the lead sheath above the duct structure and of the duct structure above the original no-load temperature of the earth, the actual watt loss in the cable should be used, including the fact that there is a temperature gradient in the insulation. If this method of calculation is used, the conditions of stability shown by Mr. Hanson will be probably more favorable.

A few years ago[5] Mr. Brown and I showed that the quadrant electrometer could be used in a null method by bringing back the deflection to zero by the insertion of a resistance in the lead to the electrometer needle. If the initial deflection should be "negative," we had to adopt special means. Dr. Kouwenhoven's method is, I believe, a distinct improvement. He reduces the deflection to zero by the insertion of a continuous potential in the needle circuit (as well as across the quadrants), but he has the advantage of being able to reverse the polarity of the battery in the needle circuit, and can thus use his method to balance deflections which are initially negative. I have not had an opportunity to try out his method, and do not know which of the two is the simpler, but I am sure that all those who have used electrometers will appreciate this new and valuable method of attack suggested and worked out by Dr. Kouwenhoven.

B. W. St. Clair: I am in agreement with the comments of Dr. Curtis about series-parallel methods of checking the voltage accuracy of a test equipment, when the samples are of small capacitance when compared with the capacitance of leads and parts of the outfit to ground. With samples of appreciable size where currents of milliamperes or amperes magnitude circulate, I believe the method is an excellent one for checking relative voltage accuracy. As pointed out in the paper it does not give a clue to absolute accuracy but does give a definite check on the accuracy of the shape of the voltage-power factor curve of a given test equipment.

I have been much interested in the self-contained instrument for checking dielectric loss of reel lengths of cable that was mentioned by Mr. Davis. In the design of one of these we had to depart somewhat from the more usual portable-instrument practise. Ordinarily a wattmeter is built to have full scale deflection at about 60 per cent power factor at rated current and voltage. Under these conditions it is possible to have very good operating characteristics without excessive losses. It is possible by sacrifice of torque and with increased potential and current-circuit losses to build portable instruments for operation at 30 per cent or even 20 per cent power factor. To reduce this to the 1.5 per cent or 2 per cent necessary for cable tests means at least a ten-fold increase in instrument sensitivity. Reduction in operating torque below this 20-per cent point will result in unsatisfactory performance from bearing friction, and likelihood of trouble from stresses incidental to transportation. Any attempt to retain a reasonable operating torque by the use of greater ampere-turns on the armature results in increased armature weight or increased phase-angle corrections or increased potential losses. For a given weight of armature there is a minimum operating torque below which operation will be unsatisfactory. The net result is that there is no compromise in electrical characteristics possible with the standard bearing construction. Two alternatives are possible; the use of the monopivot construction or the use of a strip suspension that will serve the dual purpose of torque member and supporting member of the armature. I have preferred the latter method because it completely obviates the bearing trouble that is almost necessarily coincident with the rather heavy weights and low torque of a well damped sturdily built armature, even in a single-pivot construction.

The suspension arrangement is not a panacea for all instrument failings and it does impose double duty on the suspension members. Fortunately the development of special bronzes and processes incidental to good spring characteristics has brought forth sufficient knowledge of the limitations of such doubly stressed material as to permit easy design for satisfactory operation with exceedingly good electrical characteristics. The dependability of such devices will be inferior to the more robust double-pivot ones but will be satisfactory for checking losses on a factory or routine basis.

I am a firm believer in calorimetrical methods of checking the fundamental accuracy of a dielectric test outfit. It is the only direct method I know that measures the losses in terms of some physical quantity that is easily amenable to accurate measurement. Thermal work of this sort requires a high degree of skill and considerable patience. It is a method that has been carried to a high level of certainty and usefulness by biologists interested in general metabolism work. It is quite customary for them to make tests of heat output where the total heat flow is but a very few watts with an error not over five per cent. I have seen many tests where the claimed error was less than two per cent. It is possible that we could learn much from a survey of their present methods and equipment.

C. A. Adams: This thermal-balance method of measuring dielectric losses seems to me a very interesting one. Mr. St. Clair spoke of the difference between the location of the material in which the heat is generated and the conductor material, and Mr. Simons spoke of another possible error, the difference in thermal conductivity.

I feel sure that neither of these considerations affects the test as outlined by Mr. Lee. When I saw that he had a long conductor with various sections and that the flow of heat must be substantially radial at the central section, it was obvious that the relative thermal conductivities have no influence. The amount of heat dissipated from the surface is dependent wholly upon surface conditions. The heat is practically all dissipated by convection, and at those low temperature differences is dependent wholly upon the nature of the surface and possible obstructions.

The thermocouple leads may possibly offer some such obstructions, but apart from that, as between two lead sheaths, it is quite unlikely that there will be any significant difference.

The question as to whether the heat is generated in the conductor or insulation has nothing to do with the case as long as the heat flow is radial.

One of the authors spoke of the use of reactance in series with the supply transformer for smoothing out the e.m.f. wave.

5 TRANSACTIONS of A. I. E. E., 1924, p. 311.

Ten years ago when I was making tests on some 25,000-volt cable in Boston, about five miles in length, where the charging current was some 1600 kv-a., we used that method for two purposes, to get double the transformer voltage on the cable and also to smooth out the wave.

We heard a great deal in the old days about the danger of resonance, but if you have resonance with the fundamental, you are a long way from resonance with the harmonics. The reactance in series; through the medium of almost infinitesimal harmonic current, will absorb practically all of the harmonic voltages, so that the actual voltage impressed upon the cable was practically sinusoidal, so nearly so in this case that it was impossible to detect the difference on the oscillogram.

The reactance proved useful in another direction, since any incipient failures in the joints which resulted in small transient currents gave distinct knocks in the reactance. You could put your ear to the core of this reactance and hear every little spit in the joints and there were a good many of them when the voltage was 50,000, which was double the normal operating voltage of the cables. That was some time ago when we didn't know as much about making joints as we do now. But in one case we stopped the test before failure and examined the junction boxes, 13 of which were found smoking. They had a semi-liquid filler compound through which these transient discharges had taken place.

Just one word in regard to this whole question of dielectric phenomena. There are few who realize how differently we employ words and what different meanings those words convey to different minds. I refer to some of the remarks concerning anomalous conduction. The fact is that we are dealing mostly with the superficial side of all of these phenomena. We don't know what actually is going on.

For example, take Maxwell's theory or hypothesis concerning the absorption current. That is what you might call an equivalent-circuit scheme and if it fits the facts it is very useful. And it may, as has been shown by Mr. Dunsheath, be transferable; that is to say, our knowledge of the absorption current may enable us to predict approximately what the dielectric loss is going to be; but that does not prove the hypothesis to be correct.

I think Dr. Whitehead is absolutely correct in saying that barring ionization (and in a good cable there should be very little ionization) the major factor of the dielectric loss is that which is represented by the absorption current, but these are all superficial considerations and tell us nothing of the ultimate nature of the phenomena.

There are a number of hypotheses that delve a little bit more deeply and have to do with the ionization of the dielectric material itself and with the tearing off of electrons from the molecules or atoms but we haven't yet come to the point where we can connect up the actual, practical phenomena that we observe with the fundamental laws of atomic structure.

There has been a great deal more written about this than most of us realize, but it has been done by scientists in their quiet way, and most of their articles are buried in the proceedings of the highly scientific societies. If we were to try to understand a little more thoroughly the ultimate nature of the phenomena and follow more closely the work that is being done by our scientific friends, we might perhaps arrive a little more quickly at some fundamental relationships which would enable us to predict from knowledge of the elements that go into a composite insulation what is going to happen under specified conditions.

As yet our work is too empirical, too superficial. Frankly, my real interest in this problem has to do almost wholly with that delving into the ultimate nature of things, trying to understand a little bit more the reason why, rather than merely collecting a lot of superficial information which is in the long run requires much more time.

Delafield DuBois: At one time I was associated with the Russell Sage Institute of Pathology, where we had a calorimeter to determine the heat radiated by the human body. To give an idea of the extreme sensitivity of the apparatus, let me tell of an incident. The doctor in charge of the laboratory happened to be in the calorimeter flat on his back and not moving, but looking out through the window, he saw me enter the laboratory. Not long after that the assistant who was plotting the curve of heat generated vs. time called me over to the test table and showed me a slight kink in the curve that indicated the time when I came in. Apparently the mere sight of me made a slight difference in the heat generated by the doctor.

C. L. Kasson (communicated after adjournment): In regard to measurement of dielectric loss and power factor,—are not the results dependent on wave form, especially in short-length measurements? What agreement can be expected between the results on ten-foot samples and reel lengths?

Has the possibility of end losses in short samples been investigated as a source of error? These end losses must consist of leakage over the end and energy dissipated into the air and then picked up again on the lead sheath. The usual form of guarding does not take into consideration this latter factor which is important.

P. A. Borden (communicated after adjournment): Except, possibly, in those laboratories where the facilities of time and equipment are almost unlimited, the outlook upon the measurement of dielectric losses is at best a rather gloomy one; and we must thank Mr. Lee for having introduced a distinct ray of optimism at the psychological moment. The thermal-balance method, which he describes, while at once scientific and precise, is at the same time capable of application in almost any electrical laboratory, and with equipment which is neither expensive nor highly specialized in its construction or operation.

As an alternative arrangement, and as a possible improvement, I would suggest the replacement of the thermocouples by a resistance bridge, the varying arms of which would consist of a number of turns of enameled magnet wire wound upon the sheath of the cable. There is no doubt that the assembling of this circuit could be more quickly accomplished than the placing of the thermocouples which Mr. Lee has described; and there is the added advantage of the superior sensitivity of the circuit, as well as of increased precision due to the equivalent of an infinite number of points of thermal contact.

If, as has been anticipated by some, there be a source of error due to difference in the conditions of the lead surfaces, it would be possible to surround the cables with oil baths of small dimensions, or to immerse the two sections in a common bath, either of which measures should reduce such an error to negligible proportions.

J. B. Whitehead: The question was asked why, in my list of causes of phase difference in dielectrics, I had included three different types of conductivity, and why all types of conductivity are not the same. There is every evidence that electric conductivity in every instance consists of the motion of some kind of an electric charge, but there are many different kinds of charges,—for example, electrons as in the process of metallic induction, molecular ions and molecular aggregates of various sizes. The presence of any one of these types of ions will result in conductivity and to that extent they well might be included in one class, but the conductivities resulting from these several types of ions follow quite different laws as regards voltage, temperature, frequence, etc. Until these laws are brought together, therefore, and until the nature of dielectric absorption is better known, it appears to me advisable to separate the conductivities arising from different causes.

C. F. Hanson: Mr. E. W. Davis has expressed his doubt of the necessity of the high degree of accuracy which I have pre-

scribed for power factor measurements of 132-kv. cable, in view of the variation existing in thermal constants and the inaccurate knowledge of them. Mr. E. H. Salter has expressed a similar doubt but for a different reason. His reason is that the power factor of a cable is too far from being uniform to warrant the accuracy prescribed. Both of them are correct in their views if the subject is considered from the point of view of present knowledge of thermal constants and the usual uniformity of power factor. This subject, as far as 132-kv. cable is concerned, should not be approached from that point of view. Rather, it should be considered from the point of view of the requirements of the accuracy of our knowledge of all the properties pertaining to the performance of a 132-kv. cable. If a 132-kv. cable is to perform in accordance with experience obtained with lower voltage cables, then I believe the accuracy I have prescribed is hardly too rigid, particularly for a six-cable duct bank. This statement, of course, implies that the power factor of the cable has to be uniform. The thermal properties of the cable and of the duct must also be uniform and known to a high degree of accuracy. If these conditions cannot be met, then it is possible that a 132-kv. cable will have to be replaced by a lower voltage cable.

I have used the term "uniform" loosely. In the case of power factor, it means a permissible variable excess above a certain value considered to be satisfactory. A deviation below this certain value is of no serious consequence because it does not impair the expected current capacity of the cable.

Power-factor uniformity varies with the operating voltage of the cable. In the case of 132-kv. cable the uniformity should be of the order of the accuracy required in the power-factor measurements. The case of lower voltage cables is quite a different story. For example, the permissible power-factor error and uniformity of a 13-kv. cable may be of the order of six per cent, depending upon the knowledge of the thermal constants. I am sure that this accuracy is not alarming and this uniformity is very likely well within the limits stated by Mr. Salter.

Mr. D. M. Simons has called attention to a rather important item in the matter of calculating the actual dielectric loss existing during the operation of a 132-kv. cable. The method which I did use is that prescribed by him in his paper which I have cited. I did not, however, follow the advice which he also gives in his paper, that in some cases a second calculation should be performed to obtain more nearly the actual dielectric loss. I have now done that for one cable.

Before proceeding to explain the method I employed in my second calculation, I shall present a few definitions in an attempt to clarify the subject.

1. The dielectric loss in a cable is usually considered to be that which exists when the entire insulation of the cable is at the same temperature. This is the loss measured in the laboratory according to American practise. I shall designate this loss as the "measured dielectric loss."

2. In actual use the entire insulation is not at the same temperature. The insulation near the conductor is at a higher temperature than the insulation near the sheath. The power factor of the insulation near the conductor, therefore, will be higher than the power factor near the sheath according to the power factor–temperature characteristic of the insulation. The dielectric loss of the cable under this condition, when the conductor is at the maximum permissible operating temperature, will be less than the "measured dielectric loss," and I shall designate this loss as the "actual dielectric loss."

3. The "actual dielectric loss" is distributed throughout the insulation of the cable. It is greater near the conductor than it is near the sheath, for two reasons:

   a. The electric stress is greater near the conductor than it is near the sheath, and

   b. The power factor is greater near the conductor than it is near the sheath.

In calculating current capacity it is difficult to deal with the "actual dielectric loss" as a distributed loss. It is much more convenient to deal with it as a concentrated loss on the surface of the conductor. This procedure may be followed by considering a fractional part of the "actual dielectric loss" as concentrated on the conductor surface. This fractional part of the "actual dielectric loss" I shall designate as the "conductor-equivalent dielectric loss."

The $R I^2$ loss in the conductor and the "conductor-equivalent dielectric loss" raise the temperaure of the conductor above that of the lead sheath. The $R I^2$ loss in the conductor, the "actual dielectric loss" and the sheath eddy-current losses, raise the temperature of the sheath above the base temperature of the earth.

In my calculations I used 50 per cent of the "measured dielectric loss" as the "conductor-equivalent dielectric loss."

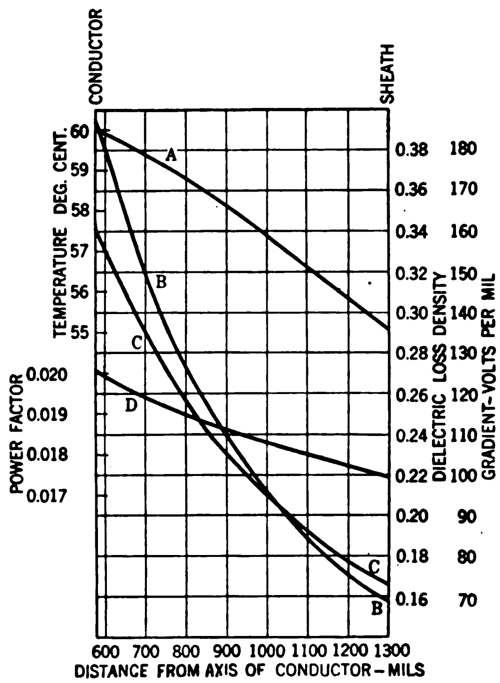


FIG. 3—ACTUAL CONDITION EXISTING IN CABLE No. 15

A—Temperature deg. cent.
B—Dielectric loss density, watts per ft. per 0.06-in. thickness
C—Voltage gradient
D—Power factor

I shall demonstrate by example that this procedure is not always rigorous. For my example, I have chosen Cable No. 15, the power factor-temperature characteristic of which is shown in Fig. 5. This cable was calculated to have a current capacity of 187 amperes under the conditions specified.

I divided the insulation of the cable into a series of 12 concentric cylinders, each having a wall thickness of 0.06 in. (approximately 1/16 in.). I started with the inner cylinder against the conductor. I calculated the temperature and the voltage gradient of this cylinder 0.03 in. from the surface of the conductor. With these values I calculated the dielectric loss per foot for the first cylinder. The second cylinder from the conductor will have this dielectric loss flowing through it in addition to the copper loss. After having calculated the temperature and volt-

age gradient in the second cylinder, I calculated its dielectric loss. I proceeded in this manner until I had reached the lead sheath. The results of this series of calculations are shown in the accompanying Fig. 3.

A summary of the results follows:

The "measured dielectric loss" of the cable at 60 deg. cent. is 3.09 watts per ft.

The "actual dielectric loss" of the cable when the copper temperature is 60 deg. cent. is 2.91 watts per ft.

The "conductor-equivalent dielectric loss" was found to be 1.46 watts per ft., which is 50 per cent of the "actual dielectric loss" and 47.2 per cent of the "measured dielectric loss."

It appears, therefore, that I have gone wrong in my original calculations to the extent that I used 50 per cent of the "measured dielectric loss" instead of 47.2 per cent as the value for the "conductor-equivalent dielectric loss."

I believe that the summarized results show that my original calculations are approximately correct, although they are not absolutely correct. The difference is even not as much as it appears because there is a compensating error. In Fig. 5, I have shown the unstable power factor–temperature characteristic, $E F$, as a straight line. In reality this is not a straight line but is a curve which droops at the higher temperatures. This drooping probably offsets entirely the little advantage gained in the revised calculations. In conclusion, I believe so far as calculations are concerned, that my Figs. 5 and 6 show very nearly a correct picture. The thermal constants I have used may not fit all cases by any means, but they do most likely fit an average case.

Mr. Lee: As regards the nature of the surface of the cable in the heat comparator method, that certainly is very important and we must take it into account. There is, however, this fact; that there is only a one- or two-deg. rise which enters into the proposition and it is simplified in that regard.

There is one question I should like to ask Mr. Simons. It comes up in connection with the use of the electrostatic wattmeter, and is about the maximum voltage at which he knows it can be used. I have stated in my paper that we have to go up to 100,000 volts in these measurements. As I understand it, the electrostatic wattmeter has not been used much above 35,000 volts. Above that voltage several disturbing factors are introduced.

Also, Prof. Whitehead spoke regarding the size of a resistor that he had which wasn't very large. Again, I had in mind 100,000 volts.

W. B. Kouwenhoven: Dr. Curtis mentioned the effect of the resistance of the battery. The resistance of the battery which is inserted in the needle circuit of the electrometer in the method described by Betz and me has a negligible effect upon the compensation. Simons and Brown produced zero deflections of the electrometer by the insertion of a resistance in the needle circuit. The value of the resistance needed in their method is of the order of 20,000 ohms. The resistance of the battery that Betz and I used in the needle circuit was small and therefore had no effect upon the results obtained.

Messrs. Simons and Brown state on the third page of their paper that one way of eliminating the charging current to the needle is to put the ground at the mid point of the quadrant resistance R_1. I have tried this method experimentally and found that it does not eliminate the trouble.

One advantage that the electrometer wattmeter possesses over the dynamometer wattmeter is its simplicity and range. If various sized samples are to be tested with a dynamometer wattmeter, either the instrument must be shunted or else several different current windings must be available. In the case of the quadrant electrometer wattmeter, different ranges may be obtained by changing the value of the resistance R_1, which shunts the quadrants. With the same electrometer I have measured losses in cables which were only a foot in length, whole reel lengths of cables and current-limiting reactors. In the measurements the values of the resistance R_1 varied from several thousand ohms to one one-hundredth of an ohm. The current ranged from a few milliamperes up to 200 amperes. This indicates clearly the wide range of the electrometer.

I used the zero method described by Betz and me for measuring the loss in the current-limiting reactor mentioned above. The measurements were made in the field and the results were quickly determined. The method worked very satisfactorily.

A number of different methods have been discussed here for measuring the power loss or power factor of cables and dielectrics. They are as follows:

Electrodynamometer wattmeter, bridge methods, quadrant electrometer wattmeter, and calorimeter methods. In using the bridge methods it is necessary to balance both for ratio and phase angle. The accuracy of the results depends to a large extent on the ratio of the bridge. The closer the ratio is to unity the greater the accuracy and ease of obtaining a balance. Consequently the bridges are limited to samples of approximately the same size. This is also true of the dynamometer wattmeter methods unless shunts are introduced with their attendant difficulties. In using calorimeter methods, care must be taken to see that the radiation coefficients of the lead sheaths of the cable under test and of the standard sample are the same. As pointed out, the quadrant electrometer has a wide range of application. Its use, however, also introduces those certain difficulties which have been discussed.

E. H. Salter: Mr. Hanson brought the question of the use of shunts in connection with the electrodynamometer wattmeter. We find that a dynamometer wattmeter which is sufficiently sensitive for use without a shunt on short samples of cable, can be used in connection with the shunt on cables up to the full reel. As an instance there we have made comparatively recently some tests using the compensated dynamometer or the phase-defect compensation method in which the apparent defect angle of an air condenser is compared with the apparent defect angle of the sample of cable.

In this particular case to which I refer, the air-condenser charging current was about 15 milliamperes, whereas the charging current of the cable sample which was a full reel ran in the neighborhood of one ampere.

In order to obtain sensitivity, the balance on the air condenser was made using the direct connection of the electrodynamometer in the circuit, whereas the balance on the full-reel sample was made with the shunt set for a multiplying factor of 1000.

We have used the shunted wattmeter over a complete range between those points, between the one multiplier and the 1000 multiplier, and have tried interchecks, shifting from one shunt position to another with the same voltage and the same cable sample and have found the result perfectly satisfactory.

Mr. Hanson also raised the question of the connection in Fig. 2 of our paper. I can state that the connections are made with the low-voltage end of these windings connected to the transformer case and that the transformer cases are insulated one from the other.

Mr. St. Clair raised a question regarding the statement: "With the present methods of determining compensation, it is believed that an accuracy of $\pm$ 0.05 per cent in power factor should be obtained." That refers to absolute power factor and not to percentage accuracy.

He raised a similar question with reference to the statement on the fourth page in the second column. There I think the percentage is clearly stated as measurements: "A careful operator should be able to make measurements to within $\pm$ 0.05 per cent power factor. The losses as computed from the current and power factor should be well within $\pm$ 5 per cent accuracy." There it is changing it over to the accuracy basis.

Discussion at Annual Convention

LAW OF MAGNETIZATION[1]

(GOKHALE)

WHITE SULPHUR SPRINGS, W. VA., JUNE 25, 1926

J. R. Craighead: In the study of any characteristic of a material for engineering purposes the first results must be obtained by measurement. From these results an empirical formula is usually developed which should be accepted until fresh data disagree, when the formula should be modified or extended to include all the data.

When knowledge of the characteristic advances sufficiently, a rational formula may be proposed. To be acceptable, the rational formula must not be inconsistent with the existing data and must meet the mental needs of engineers by representing a theory of the variation of the characteristic.

In this case the formula of Frolich with the other developments of it to which Mr. Gokhale has referred, constitutes a long step toward a rational formula. Weber's theory of molecular magnets is at present the fundamental on which magnetic formulas should be based.

Frolich's law is obtainable from Weber's theory by assigning a specific value to the distribution ratio. Mr. Gokhale's tests have shown that this value is not suitable for determining the actual performance in the region near saturation.

Consequently, Mr. Gokhale attempted to find a substitute for that value, and a new formula which would be at least equally in agreement with the Weber theory. He found this in the formula which is quoted in the paper.

Following this step he studied it in comparison with previous formulas and determined it to be a corollary of Lamont's equation, consequently basing it on Weber's theory in the same way that Lamont's equation is based. Thus the formula has a mathematical connection directly back to previous magnetic efforts and represents an effort to connect with the latest data those which were available to those who developed the earlier formulas.

It is not claimed that Mr. Gokhale's law of magnetization near saturation is the final one or that there will never be any more data which will extend it. It is possible that the fundamental Weber theory will be changed, in which case there may be radical changes in the formulas derived from it. But in establishing a step in advance of the formulas that have already been recognized, covering very much more thoroughly a wider range of data, Mr. Gokhale has made a definite advance in the art.

Hans Lippelt: The magnitude of the problem in hand is well illustrated by the fact that the author confines his work to the range of magnetization near saturation, limiting it at the lower end by a magnetizing force of $H = 300$, which is a high value for practical and industrial purposes.

In going over the experimental data given, it should be observed that no attention whatever has been paid to magnetic hysteresis. Small as it may be near saturation, it becomes noticeable and effective as the magnetization curve falls off the saturation value. The majority of the test data start with a high value of H, which is receding as the test proceeds. This state of affairs characterizes each of the respective β curves as part of the descending branch of a hysteresis curve. Both branches of the hysteresis curve should be subjected to test and observations recorded and presented.

The establishment of a new law of magnetization necessarily calls for conclusive evidence. With one-half of the evidence left out, the other evidence presented can hardly be called conclusive. This is said without depreciating the great merits of this exemplary piece of research work.

In connection herewith it should be observed that not all the β H curves are shown with their ordinates (or axis of ordinates) starting at the zero line. Fig. 1-8 has the first division at 13,000, and that seems to be the residual magnetism of the sample, being corroborated by Figs. 1-3 and 1-2. It is doubtful whether such a high residual magnetism will be accepted as the basis or starting value for a new law of magnetization. Strictly speaking, the maiden curve of magnetization, which goes through the origin of the system of coordinates, is the only pure representative of the true law of magnetization.

The author, in paragraph 15 of his paper, has explained the insensitive character of the reluctivity curve, and has pointed out that its apparent straightness is no reliable criterion for the course of other correlated curves. I believe it befalls the author to prove that the line of incremental permeability, Fig. 3-1, is inherently sensitive to the curvature of correlated curves. In other words, it should be proved that in spite of other correlated curves (say the β μ curve) possessing a certain *definite* curvature, the curve of incremental permeability is actually a straight line, and not merely the average value of several undulations such as are noticeable in Fig. 3-1.

The justification for such a proof will hardly be denied in view of the fact that the main equations (29) and (30), which represent one main result of the study, are derived from that line.

We also should not lose sight of the fact that the author of the paper violates his own theory (to a certain extent) when he eliminates β from equation (21) and reduces it to the form of (23) and (26).

Fig. 1-6 shows two straight logarithmic lines. They give rise to the question as to whether the material under test undergoes a distinct molecular change. Such a change may be either gradual and finishing, or occurring abruptly at the point of their intersection. Such a phenomenon would not be unusual with iron, which is known to suffer a change of its elasticity and strength, when under thermal stress. (Breaking strength of steel increases up to 300 deg. cent.)

Another possibility would be that the two straight lines are really the asymptotes of a curve which otherwise runs very close to its asymptotes.

It is conspicuous that no corresponding kink can be detected in the correlated H D curve of Fig. 1-6.

That Frolich's law permits a modification which renders it more flexible was shown by myself in a recent paper on the magnetic hysteresis curve.[2]

I believe it would be advantageous for the readers if, in Mr. Gokhale's paper, the method and wiring of the tests were illustrated by diagram.

J. E. Jackson: It is quite gratifying to find that Mr. Gokhale's saturation curve is a straight line, since it was a consideration of Weber's theory two years ago that led O. E. Charlton and myself[3] to predict that the a-c. iron losses would decrease as d-c. excitation was superposed on the core. Weber's theory states that hysteresis loss is due to friction between the molecules or electrons as they reverse their position or polarity under the

1. A. I. E. E. JOURNAL, September, 1926, p. 846.

2. A. I. E. E. JOURNAL, April, 1926, p. 355. See also Discussion A. I. E. E. JOURNAL, August, 1926, p. 770.

3. Losses in Iron under the Action of Superposed Alternating- and Direct-Current Excitations, by O. E. Charlton and J. E. Jackson, TRANS. A. I. E. E., 1925, p. 824.

influence of an alternating magnetomotive force. If this is true, a strong d-c. field should hold the molecules locked in one position so that they cannot reverse, and therefore the hysteresis loss would not appear. Also, the permeability of the specimen should approach that of air. Both of these facts were proved by actual tests; as d-c. excitation was increased the a-c. iron losses decreased.

A. E. Kennelly (communicated after adjournment): The paper is an interesting compendium of the various formulas which have been offered, at different times, to account for the phenomenon of magnetization in the magnetic metals, from the point of view of the physicist, and particularly in regard to the phenomenon of high magnetization, near saturation. It shows that the various formulas of Bosanquet, Emery, Lamont, and the speaker, are much more closely connected with each other than is generally evident or recognized, and also connected with the pioneer work of Frolich, in 1882. It shows, moreover, that none of them is quite satisfactory in the neighborhood of saturation. Near saturation, the paper advocates the formula given in the synopsis, which is a modified form of Lamont's formula.

When we consider the relatively complex and unstable molecular configurations involved in the generally accepted Ewing's theory of magnetization in iron, it would be quite surprising if any single and simple formula satisfied the entire process, from the feeblest to the most powerful magnetization. Near saturation, however, when the last dregs of latent magnetization are being evoked, an exponential relation of the type advocated in the paper seems very reasonable. That is, if we plot the latent induction γ against the magnetizing force $\mathcal{H}$, on arith-log paper, as in Fig. 1-7, we should look for a straight line, or a pair of straight lines, as saturation approaches. This relation should be carefully examined in future, with various samples of magnetic material. The technique of magnetic measurement for advanced values of magnetizing force, however, should be standardized for that purpose. If this straight-line relation between log γ and $\mathcal{H}$ is brought out, the paper will have supplied a valuable contribution.

In regard to the assumption on the fourth page of the paper about latent flux, namely, that "it is made up of two groups of flux lines in opposite directions making an algebraic total of zero lines," it seems to need some proof. The conception of each iron molecule inherently possessing its own bundle of magnetic flux, so that when they are all completely aligned, the resulting flux density is determined only by the number of molecules per square cm. of cross-section, is interesting but perhaps unsafe. It seems to go beyond the needs of Ewing's theory.

In regard to my paper of 1891, the ascending straight-line law of metallic or intrinsic reluctivity there pointed out, is indeed based upon the previously published researches of Ewing, Rowland and others, as the paper states. The speaker arrived at the relation, however, from his own tests of samples of dynamo steel, for which the notes and records are still retained. It was found that when the reluctivity ρ was plotted, on ordinary squared paper, as ordinates, against magnetizing force $\mathcal{H}$ as abscissas, the graph was always a pair of straight lines, one descending and then the other ascending, with an elbow connecting them, and with the maximum value of the permeability occurring at this elbow. From an engineering point of view, it appears to the speaker that this is still the simplest quantitative relation between the ordinary magnetic phenomena. From a strict physical theory standpoint, however, this pair of straight lines may be only a first approximation to a much more complicated phenomenon. It seemed more convincing, in 1891, to express the geometrical facts in relation to already published researches than in connection with new and unchecked tests.

S. L. Gokhale: I believe that some of the points brought out in the course of the discussion can be best explained by a brief history of the investigation which forms the subject of the paper under discussion.

In January 1913, I was called upon to add to our equipment a simple and reliable method for determination of saturation value of magnetic material used for engineering purposes. Prior to this date and also for some years afterwards, this determination was made by extrapolation according to Kennelly's law on the basis of data for $H = 50$ to 200. By the beginning of 1915 I had succeeded in developing a new method of measuring saturation value, (A. I. E. E. Trans., 1920, p. 819) together with a suitable instrument for that purpose, *viz.*, the saturation permeameter. (See Law of Magnetization, Table I-1.) The new method was easily recognized as the simplest method for this work but its reliability was seriously questioned because the saturation value determined by this method did not agree with the computed value by extrapolation according to Kennelly's law. (See Circular of B. of S. No. 17, p. 36.) When the result of a measurement by a new method conflicts with a law unanimously accepted by the scientific world for nearly forty years, the reliability of the new method should be questioned rather than the law; this was the generally accepted view, and I must confess that I held the same view at first. For about five years I tried unsuccessfully to detect error in the saturation permeameter, until by the beginning of 1920 I began to feel convinced that the permeameter was quite reliable and that the error was probably in the extrapolation method. In April 1920 I expressed this view in the discussion of Dr. Yensen's paper, but I could not convince him at that time. In May 1923 I was able to demonstrate the existence of the second inflection together with the left-handed curvature above that point (Fig. 4-2) by tests on toroid rings; this demonstration indicated the possibility of failure of Kennelly's law for values of β near saturation, although the point was still not proved conclusively. About this time I had also succeeded in obtaining by tests on toroid rings the curve for incremental permeability (Fig. 3-1) which suggested the linear equation of progress (equation **26**), together with the corresponding exponential law of magnetization (equation **30**). I showed these results to Dr. Steinmetz, who seemed to be well convinced by the evidence, but he suggested that a successful demonstration of the phenomenon of saturation would be much more convincing. In September 1923 I succeeded in demonstrating saturation for a toroid ring of standard sheet steel for a range of $H = 650$ to 1000 (Fig. 4-1.)

In May 1924, I showed my notes to Dr. Kennelly and solicited his criticisms. He made many valuable suggestions, the most important one being that I should secure more data on a larger number of test samples tested by approved methods. This advice has been carefully followed; in the preparation of the paper only tests on toroid rings were included for purpose of demonstration.

For purpose of data for the β H curve, the test procedure was the well-known procedure described in standard books. The curve obtained is what Mr. Lippelt calls the "maiden curve," which in every case probably goes through the origin as may be seen from the tables of data. In plotting the curve the lower part of the curve is generally omitted for the simple reason that this paper is limited to a study of the law of magnetization for values of β near saturation; the reason for the preference has already been explained.

In order to develop a sufficiently strong magnetizing force without excessive heating, a form of winding of the magnetizing coil has been developed. (See Fig. 6-0 accompanying this discussion.) This scheme of winding offers the best facilities for cooling; it was found in one case that a test at $H = 1000$ occupying a period of 15 sec. caused a fall in temperature from 23.4 deg. cent. to 22 deg. cent. instead of a rise, which demonstrates the cooling efficiency of this kind of winding.

Fig. 3-0 herewith gives the scheme of wiring for the test for incremental permeability and Fig. 4-0 herewith, for the β H

relationship; the method of test is described fully in the introductory paragraphs in Tables III and IV.

Mr. Lippelt observes that in my investigation "no attention whatever has been paid to magnetic hysteresis." The point is correctly observed; I have concentrated my attention for the present on the form of the normal induction curve near saturation, just as he has concentrated his attention on the form of the hysteresis curve. The field of magnetic phenomena is too vast to be covered fully and satisfactorily by any single explorer; it calls for the collective effort of a large number of physicists, who are expected to divide the field into sections, each one choosing for himself the part he is best fitted to study. Lord Raleigh and Dr. Kennelly made a special study of the magnetization curve below the point of maximum permeability. Dr. Kennelly carried the upper limit of test to $H = 90$; Dr. Steinmetz carried it to $H = 200$; Dr. Yensen covered the range $H = 200$ to 500. When my turn came, I started where my predecessors had stopped and carried the limit to $H = 1600$ on toroid rings, and to $H = 4000$ on the saturation permeameter. The problem of hysteresis is certainly very important, and I believe we are all glad to know that Mr. Lippelt has been studying it very carefully, but I fail to see what that problem has to do with the study of the phenomenon of saturation and allied phenomena.

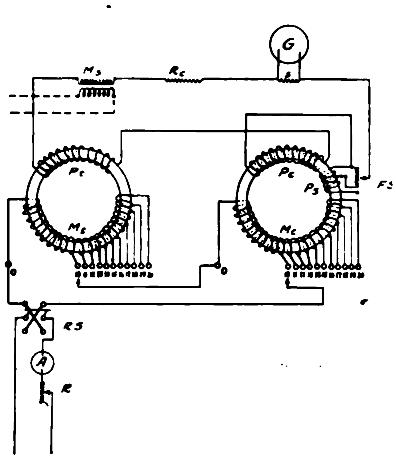


Fig. 3-0—Scheme for Test for Incremental Permeability

- *Pt* Potential coil for test ring (Sheet iron ring No. 1)
- *Pc* Potential coil for auxiliary ring (Sheet iron ring No. 2)
- *Ps* Potential coil for auxiliary (Supplementary)
- *Fs* Fractionizing shunt
- *Mt* Magnetizing coil for test ring (Sheet iron ring No. 1)
- *Mc* Magnetizing coil for auxiliary ring (Sheet iron ring No. 2)
- *Ms* Standard mutual inductor
- *G* Galvanometer
- *R C* Calibrating resistance

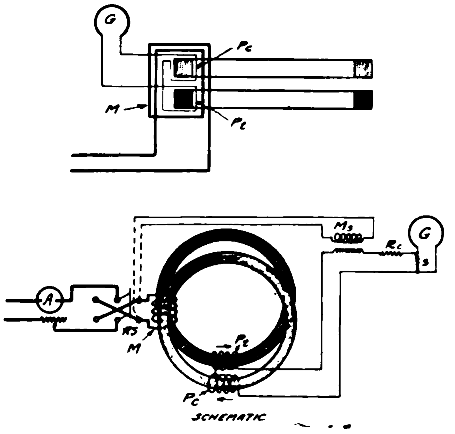


Fig. 4-0—Toroid Ring with Correction for Space Factor

- *Pt* Potential coil for test (Sheet iron ring)
- *Pc* Potential coil for compensation (Bakelite ring)
- *M* Magnetizing winding
- *G* Galvanometer
- *Ms* Standard mutual inductor
- *Rc* Calibrating resistance
- *RS* Reversing switch

Incidentally, I may mention here that the β H curves in the paper under discussion are normal induction curves; they are not the descending side of the hysteresis loops, as has been assumed by Mr. Lippelt. A large part of his criticism is based on this assumption and needs no further discussion.

With reference to the comparative sensitiveness of the several types of curves, it should be remembered that this peculiarity has no reference to curves expressing the relationship of directly measured variables; it refers to derived variables only. For example, in plotting a H ρ curve the values of H are plotted directly from measurement, but the values of ρ are derived by computation from values of β and H.

The question of sensitiveness has no reference to the β H curve; it is relevant in reference to the H ρ curve; this is also true of the β μ curve because the values of μ are not obtained by direct measurement, but are always derived by computation from values of β and H. In the case of the β μ' curve (Fig. 3-1) the data for β or μ' are both obtained directly, which makes irrelevant any question about the sensitiveness of the β μ' curve.

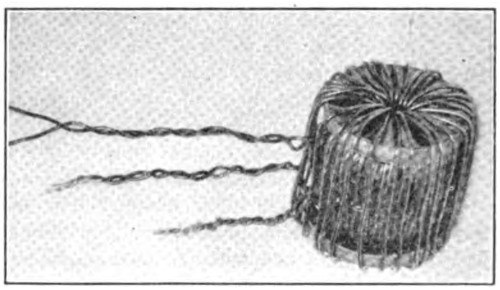


Fig. 6-0—Crate-Wound Iron Ring Sample

As to the law of magnetization, the function of the straightness of the β μ' curve (Fig. 3-1) is purely suggestive; it is not intended to demonstrate the law. The law in its final form is an equation expressing the relation of β to H (equation 30); its legitimate demonstration should consist of an agreement of the β H curve by observation, with the corresponding curve by computation from the equation in question (see Figs. 1-8, 4-4, 12-4, etc.).

For the same reason the H, log γ curve is not well suited to the purpose of demonstration. There is no method available at present for direct measurement of log γ for any required value of H. The values of log γ are derived by computation from measured values of β. The value of the H, log β curve for purpose of demonstration is dependent on the sensitiveness of the curve, which is quite insensitive for low values of H, and supersensitive for high values of H, as saturation approaches. In view of these facts I have based my demonstration on the agreement of the β H curve with the corresponding reconstruction curve, rather than on the straightness of the H, log γ curve.

One part of Mr. Lippelt's criticism is not clear to me; he says: "The author of the paper violates his own theory (to a certain extent) when he eliminates β from equation (**21**), and reduces it to the form of (**23**) and (**26**)." I should be glad to give full consideration to his criticism on this point, if I only knew what he meant thereby.

As to the two straight lines in Figs. 1-6 and 3-4, the study of that part of the problem has just been started. It is not possible to say anything confidently at present, while further experiments

are in progress. Mr. Lippelt's suggestions are noted for consideration. The absence of a corresponding kink in the $H\ D$ curve is not significant, as none was to be expected. Such kinks are scarcely noticeable except when they are very pronounced, or unless the curve is very nearly straight. For example, the practically abrupt bend in the $H\ \rho$ curve has long been noticed, but nobody notices a corresponding kink in the $\beta\ H$ curve.

With reference to Mr. Lippelt's modification of Frolich's law, that modification does not affect the form of the curve near saturation. The law even in its modified form, therefore, is not expected to give any better agreement with the observation curve than the law in its original form.

With reference to Dr. Kennelly's comments, it is satisfactory to note his agreement on all the main points, except one which will be discussed later.

With reference to latent flux, he takes exception to the assumption that "it is made up of two groups of lines in opposite directions making an algebraic total of zero lines." Perhaps he is right; the assumption may need more evidence than has yet been presented, but I fail to see how that criticism concerns me. All I have done in paragraph 4 of the paper is to present the Weber-Ewing theory in my own words, so as to be able to reduce the theory to an analytical form as represented by equations **5** and **6**. Valid or invalid, it is their theory and my duty was merely to paraphrase it correctly in my own words. It is easy to see that that aspect of the theory to which Dr. Kennelly takes exception is really a part of the original theory as presented by Prof. Ewing. This may be seen from the following extracts from Ewing's Magnetic Induction, Chapter XI, Molecular Theory.

"The Weber molecule is a magnet before it begins to act, and the *amount of magnetism in it need suffer no change,* however widely the magnetism of the bar be altered. Hence Weber's theory explains the process of induction to this extent, that it makes the magnetic change in the bar be brought about by a change in the position of the molecules, and *not by any change in* the quality of the molecules."

"The fact that a definite saturation value is now known to exist adds much probability to Weber's hypothesis."

In article 179, "Amount of Retentiveness Possible Under Molecular Theory," Prof. Ewing takes m = magnetic moment of a single molecule, and treats it as a constant in the integral equations which are functions of the angle of orientation α. It is obvious, therefore, that the constancy of flux in a magnetic molecule is one of the requirements of the Weber-Ewing theory.

Incidentally, I may add that this is also my personal view, but that this consideration is not responsible for my statements in paragraph 4 of the paper, which is merely a presentation of the Weber-Ewing theory, irrespective of my own views on the subject.

On one point it seems we have not been able to reach an agreement; the best I could do is to state the difference as I see it, in explicit terms; I hope that in the course of time one of us or perhaps both of us will have reason to revise the present views, and thus reach an agreement.

Dr. Kennelly's view is that for a range of magnetizing force up to about $H = 90$,

(1) The $H\ \rho$ curve has the form of approximately two straight lines with a short elbow connecting them. (This is Kennelly's law.)

(2) This law was well supported by test data prior to the discovery of the law; later test seems to have confirmed it. Some new tests seem to contradict it, but these are yet unchecked and their evidence is yet unconvincing.

(3) From an engineering point of view, the straight-line relation presented by the $H\ \rho$ curve is the simplest relation, connecting the fundamental quantities H and β.

(4) From the physical theory point of view, the straight line is the first approximation towards a more complicated law, and the straight-line law is therefore quite correct in that limited sense.

My own view is:

(5) The straightness of the $H\ \rho$ curve is not approximate straightness as is generally believed, but only an apparent straightness caused by the insensitive character of the $H\ \rho$ curve.

(6) Assuming that the reliability of Kennelly's law was well proved by the data presented by Dr. Kennelly in the first place, it must be conceded that no new data have been presented by me or by anybody else to refute it.

(7) On the contrary, my own tests have strongly supported the law over a limited range, *viz.*, (a) for the region of first inflection, (b) for the region of second inflection, (c) for the region of saturation.

(8) My objection to Kennelly's law is merely this—that it is not reliable for purpose of computing saturation value. On this point there is no difference of opinion between me and Dr. Kennelly. This objection to Kennelly's law is not an objection to that form of the law, but to Frolich's law in general, of which that law is only one form.

(9) In addition to the above mentioned objection, which holds against all forms of Frolich's law, there is one objection peculiar to the Kennelly form of the law, *viz.*, that the reluctivity curve is insensitive and misleading. The straightness of the curve is only apparent due to the insensitive character of the curve, and is therefore illusive. The insensitiveness of the reluctivity curve has been demonstrated in the paper analytically by equations **31-2**, and graphically by Figs. 5-1 and 5-2. I believed that this evidence of insensitivity should have been quite convincing. Fig. 5-2 was expected to convince Dr. Kennelly in particular, as it represents data (Table V-2) on which he had based his law, instead of what he calls "new and unchecked tests."

(10) Kennelly's law is not the simplest form of Frolich's law. Bosanquet's law, $\mu = a\ \gamma$, is certainly a much simpler form, as may be ascertained by anybody who tries to compute the values of H for any required value of β.

(11) The only reason why Bosanquet's law never became as popular as Kennelly's law is that in that case the failure of the law to represent facts is so obvious as to compel one to reject it. In the case of the failure of the linear law of reluctivity not being so obvious, some of the best scientific minds have been misled by the apparent straightness. For example, in 1891, while expounding the law of reluctivity, Dr. Kennelly had said that the purpose of his paper was to show that while the $\beta\ \mu$ curve is a "complicated curve"—a curve which "you would not like to define by any particular formula"—the "curve which follows from the conception of inverse of permeability is fortunately a very simple one," being made of two straight lines connected by an elbow. In the paper under discussion, I have shown by mathematical reasoning that if for any range of magnetizing force the $H\ \rho$ curve consists of two straight lines, the $\beta\ \mu$ curve for the same range must also consist of two straight lines, and conversely if, as Dr. Kennelly admits, the $\beta\ \mu$ curve be incapable of representation by a pair of straight lines, neither can the $H\ \rho$ curve be so represented. The appearance of straight lines in such a case must be recognized as illusory and misleading, and its value as evidence must be ignored.

The above conclusion (No. 11) is the main point of difference between myself and Dr. Kennelly. The conclusion is not based on any particular tests old or new, checked or unchecked; it follows a mathematical reasoning, based on a study of the relation of $\beta\ \mu$ and $H\ \rho$ curves irrespective of any test data. If, therefore, this conclusion is unacceptable to Dr. Kennelly, it must be only by reason of some fallacy in that reasoning of which I am unconscious and which he has not yet disclosed. I would be very thankful if he makes himself clearer on this point.

SYNCHRONOUS MACHINES—I[1]

(Doherty and Nickle)

White Sulphur Springs, W. Va., June 23, 1926

C. A. Adams: In nearly every piece of electrical machinery we have two or more magnetomotive forces. There are two general methods of dealing with these m. m. fs. They may either be combined into a resultant m. m. f. and the corresponding flux computed therefrom, or the several fluxes produced by the several m. m. fs. acting separately may be computed and combined into a resultant. These two methods yield the same result, provided the reluctances of the magnetic circuits in which they act are constant.

In the part of the machine under consideration—namely, the air-gap region—reluctances may be assumed approximately constant, although varying from point to point along the air-gap.

I have never quite liked the method of dealing with the total apparent reactance of the armature of an alternator, either for the salient-pole or the non-salient-pole machine, since it deals with a hypothetical flux in a very complicated magnetic circuit. I much prefer the method in which the field and armature m. m. fs. are combined or compounded. In the case of the non-salient-pole machine, this method may be applied as follows:

Leaving the local variation of gap reluctance, due to the presence of the teeth, to be considered separately in terms of the resultant tooth harmonics, the air-gap permeance may be considered constant from point to point around the periphery. First, compute the peripheral distribution of field m. m. f. and resolve this into its space fundamental and space harmonics. Combine this space fundamental with the space fundamental of the armature m. m. f. in their proper space-phase relation. The resultant sinusoidal space distribution will yield a sinusoidal flux which determines the fundamental of the armature e. m. f.

The space harmonics of the field m. m. f. will yield corresponding harmonic fluxes, which will generate harmonics e. m. fs. in the armature, the magnitude of which will depend otherwise upon the nature of the winding. In most non-salient-pole machines these harmonic e. m. fs. should be small, particularly in three-phase machines with an armature coil pitch of about 86 per cent.

The harmonics of the armature m. m. f. distribution considered separately will yield space harmonic fluxes revolving at speeds inversely as the orders of the harmonics; that is, they will induce in the armature winding e. m. fs. of fundamental frequency. Moreover, as these fluxes are proportional to the armature current, the resulting e. m. fs. will be in quadrature with the armature current and therefore reactive e. m. fs., the sum of which is nothing more nor less than what has been called the belt-leakage e. m. f., as Mr. Doherty has already pointed out. The question as to whether this includes the tooth-tip leakage e. m. f. depends upon the definition of tooth-tip leakage. Personally, I prefer to consider the tooth-tip leakage as involving only that flux which passes between the tops of two adjacent teeth by way of such iron surface as may partially close the circuit on the other side of the air-gap, which in large alternators is usually small and may be included as an extra term in the individual slot leakage.

This method would leave only three items for the reactance voltage of the machine: the slot leakage, including a small amount of tooth-tip leakage above described; the coil-end leakage; and the belt leakage, which is nothing more than the e. m. f. induced in the armature conductors by the space harmonics of the armature m. m. f. This latter in a three-phase machine with balanced load and 5/6 coil pitch is a fraction of 1 per cent.

In the case of the salient-pole machine, there is no method available superior to Blondel's two-reactance method, although the method outlined above can be applied with certain rather crude approximations to take account of the lack of uniformity in air-gap reluctance in different parts of the periphery.

Mr. Doherty's amplification or extension of the Blondel method is certainly a very interesting and valuable contribution to this important subject.

P. L. Alger: There are three points about this paper on which I think it is worth while to enlarge somewhat. In the first place, the paper is very long and it might appear that it would be possible to combine all these long series into a few terms and get shorter equations which would be simpler to use. The answer to that is that we have a great many problems which require very complete analyses and others which require only incomplete analyses, so that we need a theory which will satisfy either demand.

The old approximate theories are sufficient for ordinary problems, but if we have to abandon them and go to another extensive theory for special problems, it is too inconvenient to tolerate. Therefore, by developing the whole problem in terms of series in which the first few terms are important, later terms less important and the last terms very unimportant, we can solve all problems by the same method no matter how complicated they may be by carrying the calculations only as far as each case demands. Thus we have a complete theory for all purposes and yet the work done in each case is suited to the particular need at hand. So I think this method of carrying the whole analysis out in infinite series is by all means the best, and the one which should be followed in most problems of a similar degree of complication.

The second point I should like to enlarge upon is that of showing the need for such extended solutions in every-day life. Nowadays we try to make a study of the conditions and make a machine to fit those conditions. Thus we have a great many freak machines or machines that are not at all good electrically, but yet are so designed as to serve a particular purpose most economically. For example, in manufacturing we desire to have only a few dies, and to keep in stock only a few sets of punchings, and yet to be able to apply these to all cases. This requires that we have fractional slots per pole on almost all machines. We put up with the inconvenience of having irregularities in the winding to get the greater convenience of manufacturing simplicity.

This leads to the result that our armature windings are sometimes unbalanced by a small amount, and also they are nearly always irregular.

Messrs, Doherty and Nickle assume throughout that each pole is like every other pole; that is, that the number of slots per pole is integral. We actually have a variation of armature reaction around the periphery which makes each pole different from its neighbors, but which balances around the whole machine. These variations lead to additional harmonics and other things not touched upon by this paper.

But the method is such that these features can be added at any convenient time by simply calculating the *variation* of armature reaction around the periphery and treating that as an additional source of harmonics, additional fluxes and voltages without disturbing the structure of the whole theory.

One case where a practical problem to which this theory lends great aid arises is in making a synchronous machine without external excitation. We ordinarily think of synchronous machines as requiring some supply of d-c. excitation from outside, although by making a salient-pole machine such as Mr. Nickle has shown, a synchronous speed can be obtained with a certain amount of power without external excitation.

Suppose we make a machine with one large harmonic in addition to the fundamental in its m. m. f. distribution, and with a variable permeance as well. By so selecting the harmonics of the m. m. f. and permeance distribution that the flux made by the fundamental m. m. f. acting on a permeance harmonic will have

1. A. I. E. E. Journal, October, 1926, p. 974.

the same number of poles as the harmonic m. m. f. acting on the average permeance, we can produce a new type of machine.

For this machine will have two separate revolving fields produced by different sources whose relative speeds depend on the speed of the rotor, and will synchronize at a certain rotor speed. That will give a synchronous machine operating with quite a large torque without any external excitation. It can be done, to be sure, only if the machine operates below the synchronous speed for the fundamental itself, which leads to high losses; but it is quite feasible for small motors such as those used for driving control instruments, so that there is quite a field for this kind of machine.

This paper gives a theory which explains and enables us to solve quite completely many of these special problems.

The final point which I should like to bring out is that touched upon by Professor Adams and Mr. Doherty; this is the problem of calculating the reactance due to the slots. Both Professor Adams and Mr. Doherty have given the impression that the reactance due to the slot harmonics, themselves, is very small; but if we build a machine with very few slots per pole, this reactance may become a large part of the whole, and a very important feature of the machine.

In the case of an induction motor, the theory in the articles such men as Arnold and Professor Adams have worked out and published, involves the calculation of the effect of the slot openings, as that of the average overlapping. These formulas are rather hard to apply, and they are indefinite in the case of a large ratio of slots. By taking another point of view, a much simpler and more accurate solution can be obtained. This point of view is to consider that each coil in a slot makes a rectangular m. m. f. wave and a corresponding flux distribution, and to show that the total flux is simply made up of the sum of all the various rectangles made by all the coils. It is evidently possible to calculate the total voltage made by each rectangle of flux, and hence the total voltage produced in the winding by the total air-gap flux. Subtracting from the total the voltage due to the useful or fundamental flux, which is easily calculated, the difference gives the reactance voltage due to all the harmonics of the air-gap flux.

The formula so derived for the total zigzag leakage reactance is very simple. It is this:

$$X_T = \frac{\pi^2}{10}\left(\frac{P^2}{S_1^2} + \frac{P}{S_2^2}\right) X_M$$

where P is the number of poles, S_1 and S_2 the number of primary and secondary slots, respectively, and X_M is the magnetizing reactance corresponding to the fundamental of the air-gap flux.

By zigzag leakage I mean the harmonics of air-gap flux produced by the localization of the m. m. f. in slots, which are the harmonics that have distribution and pitch factors equal to the corresponding factors for the fundamental.

This formula shows the reactance due to the tooth harmonics in the flux, obtained by subtracting the useful from the total e. m. f. produced by the air-gap flux. The analysis assumes, of course, that the slot m. m. fs. are concentrated at points rather than distributed across the slot openings.

In the infinite series of air-gap flux harmonics, those which have unity values of distribution and pitch factors with respect to the fundamental are included in my formula. They are much more important usually than the other harmonics which correspond to the true belt leakage.

The belt leakage is due to the winding arrangement as regards pitch, and number of phases; and is nearly independent of the zigzag reactance with which I have been dealing. It is best to separate the two and keep them distinct.

By taking the same idea of a rectangular m. m. f. applied over the permeance distribution worked out by Mr. Doherty, we hope to obtain a similar formula for the tooth-tip leakage reactance of synchronous machines. We know this reactance may be large and in some cases we find it is a vital element in the design of a machine. So, by utilizing these ideas of permeance distribution calculated from flux plots, and m. m. f. waves made up of certain totals and certain useful fundamentals, we hope to derive simpler formulas for the reactance than have heretofore been available. If our plans go well, a paper along these lines will be presented to the Institute in the near future.

C. A. Adams: Mr. Alger must have misunderstood what I was saying. I was referring exactly to that same point of view. I spoke of the armature combination of magnetomotive forces and the separation of the total magnetomotive forces and the fundamentals. Those harmonic fluxes are proportional to the currents and generate reactance voltages, but it was a cross-gap flux to which I referred when I spoke of the particular case of less than 1 per cent.

M. I. Pupin: An alternator or an a-c. motor may sometimes look like a queer machine, depending upon the purpose for which you wish to use it.

Now I shall give a brief description of an alternator that I have been working with for a number of years. Consider an alternator with suitably laminated field and armature cores. Send a small direct current through the field coils and rotate the armature, the armature being short-circuited. What do we get? We get alternating electromotive forces in the armature as well as in the field coils, not one of them but an infinite series in each; the components of the series are harmonically related to each other.

I have treated this scheme mathematically and find that, mathematically, the problem can be solved. You get two beautiful series, each of which is convergent. The coefficients of the various harmonics are also infinite convergent series.

Suppose I want to use that machine for the purpose of modifying the feeble field current by a cable signal. As long as you have a constant current in the field the machine will generate an alternating high-frequency current of constant amplitude. Now superpose the cable signal and you will have an alternating current with amplitudes varying in accordance with the variation of your cable signal. The machine generates a high-frequency e. m. f. modulated by the cable signal and it is obvious that it offers a means of amplifying low-frequency cable signals. It works beautifully except for some of the difficulties the gentlemen brought out this morning.

If the air-gaps vary, or if the field core and the armature core vary from point to point, then you get fluctuations, even without the cable signals. Therefore, when rectified, you will not get a straight line but a wavy line, and that is absolutely useless for cable signaling purposes. It may be useful for some other purpose, but not for cabling. Experimentation with a machine of that kind will show how difficult it is to make an alternator which will give a constant electromotive force of definite frequency and amplitude. It is practically impossible as long as you use iron in the field and in the armature. I have tried it and failed.

Then I did this: I used an alternator without any iron in the field or in the armature. There you don't get any variations due to the material of which the magnetic field is made, the variation due to the variation of the air-gap is negligibly small because the whole machine is an air-gap.

You will say that this is a very inefficient machine. It is, but it does the trick, and you don't care how inefficient it is because you can use the amplifier and amplify to any desirable limit.

R. W. Wieseman: I should like to say a few words about the graphical solution of plotting magnetic flux distribution as shown on the fifth and sixth pages of this paper.

It is sometimes thought that the predetermination of flux-density curves is purely a theoretical operation. On the contrary, it is a very practical problem and it is used extensively in

the design of dynamo machinery. A number of flux-distribution coefficients can be obtained by the graphical solution and their values check test results very closely. A good example of this is the predetermination of the characteristic curves of a two-speed, salient-pole, synchronous motor.[2]

In the near future, I shall present a paper which will show the practical application of the graphical solution of plotting flux-density curves to the design of synchronous machines.

R. D. Evans: I should like to suggest to those interested in the matter of space and time harmonics, comparison of the method presented in this paper with that given by C. L. Fortescue in his paper on *Symmetrical Coordinates*.[3]

With reference to the variation in leakage reactance caused by the non-cylindrical rotor construction salient-pole machines, I note that the authors pointed out that the variation is quite small. In such investigations that I have carried out for other purposes, my experience would indicate that such variations are small.

In regard to the power-angle diagrams, which are quite important for such studies as stability, the use of a two-reaction method of some sort is, of course, very necessary. Otherwise, as pointed out, large discrepancies in the relation of rotor position to terminal voltage would arise. The use of a two-reaction method seems to be particularly desirable for transient investigations because the paths of the direct-component flux and the cross-component flux are physically different and the resolution into two parts would permit taking them into account separately. In connection with the determination of the relation between rotor position and terminal voltage and excitation, Mr. Wagner and I carried out some investigations measuring the rotor position by another machine on the same shaft. We obtained very close checks of rotor position relative to terminal voltage from test results with the classical method of Blondel.[4]

John F. H. Douglas (communicated after adjournment): This paper is an important step forward in the theory of synchronous machines, since it considers for the first time the effects of the harmonics in the magnetomotive force wave, upon the characteristics of the machines. One striking conclusion of this paper is the fact that the reactance and reaction coefficients can be obtained from the analysis of the wave of air-gap permeance. Another, shown by Figs. 5-11, is that the permeance in the interpolar regions of these machines, is considerable. It is not generally appreciated that the permeance of the air-gap is different for field and armature magnetomotive forces, and that it is different for different orders of the armature harmonics of m. m. f.

The accompanying Fig. 1 shows a method of testing air-gap permeance used by the writer and E. W. Kane of Marquette University. While our tests gave waves of the zero order, yet our values check closely with those given by the authors of this paper. It is noteworthy that Table II in conjunction with equations (**1c**) and (**2c**) yield a ratio of transverse to direct reaction of approximately 50 per cent. This ratio is substantially higher than that obtained by those authors who neglect the permeance of the interpolar regions.

It is a fact that in predicting reactance, the flux paths assumed lead to values less than the experimental value. Considerable discrepancy exists between rational and experimental values of reactance. It is to be noted that the third and fifth terms in eq. (**3c**) may in some cases increase values of reactance calculated by some 30 per cent. Thus the refinement in theory is well justified, if more accurate estimates of reactance can be obtained.

Some of the results of this paper are negative. For instance eq. (**7**) indicates that direct and transverse reactance are substantially equal. This conclusion, however, is based on the definition of reactance as due to local fluxes, and fluxes in relative motion to the field structure. A more useful definition is that "reactance" and "reaction" are those vectors proportional to the current in the e. m. f. and the m. m. f. diagram respectively. Since only tests can determine this question, the existance of a "variable leakage reactance" must still be regarded as an open question.

The authors say, "The effect of salient poles on the magnitude of required excitation is very small." While this is generally the case, there are exceptions under conditions of abnormal conditions of operation, as for example in the "nose" region of the synchronous-motor characteristic and near the unstable

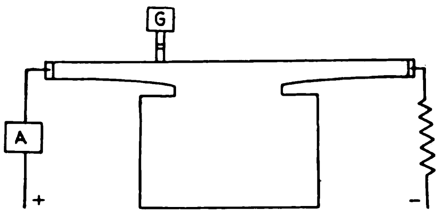


FIG. 1—METHOD OF TESTING AIR-GAP PERMEANCE

point of generator operation. Consider Fig. 2 herewith for a generator carrying heavy charging current of a transmission line and no other load. The drop $I X_q$ is less than the terminal voltage, and this in turn is less than the drop $I X_d$. The Potier diagram gives a positive, the Blondel, a negative excitation. Fig. 2 also shows the complete zero-leading power-factor characteristics predicted by both methods.

Fig. 27 is based on three assumptions; saturation in the armature and cross field negligible, and a transverse reactance identical with direct reactance. In deciding whether a given component of the effect shall appear in the m. m. f. diagram the question is whether experiment shows this factor as more constant as an e. m. f. or an m. m. f. vector. The writer knows of no way to settle this point theoretically. It is conceivable, for example, that all the cross fluxes, not only those represented by X_{aq} but those of X_{1q} might be affected by saturation.

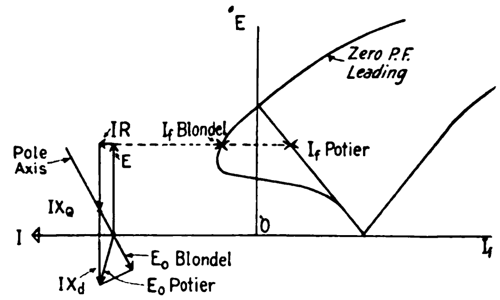


FIG. 2—COMPARISON OF BLONDEL AND POTIER DIAGRAMS NEAR UNSTABLE REGION

The data given by the writer in a paper on "Synchronous Motor Characteristics"[5] indicated at least that X_{aq} is greatly affected by saturation.

Quentin Graham (communicated after adjournment): Messrs. Doherty and Nickle have dealt in a comprehensive way with a problem that is treated usually in a much less rigorous manner. The method of harmonic analysis is certainty the only one that is adequate for the treatment of many of the more complex problems of synchronous machines. It seems to me that the chief usefulness of the paper is not in a refinement of reactance and reaction calculations, with which Part I is concerned, but

2. A. I. E. E. TRANS., 1925, p. 436.

3. A. I. E. E. TRANS., 1918, p. 1027.

4. Studies of Transmission Stability, by R. D. Evans and C. F. Wagner, A. I. E. E. JOURNAL, April, 1926, p. 374.

5. Douglas, Engeset and Jones, A. I. E. E. TRANS., 1925, p. 164.

rather in the solution of innumerable special problems in which a similar method of attack is required.

Since the assumption of uniform permeance is a common one in considering synchronous-machine performance it may be well to emphasize some of the differences that a variable permeance produces. It is shown in the paper that fundamental voltages are set up in the armature conductors by the following fluxes:

a. The flux which results from the fundamental of the armature m. m. f. and the zero-order component of the permeance series.

b. The flux resulting from the fundamental of the armature m. m. f. and the second-order component of the permeance series.

c. The flux resulting from the combination of any higher harmonic of the armature m. m. f. and the zero-order of the permeance wave.

d. The flux resulting from the combination of any higher harmonic in the armature m. m. f. and the second-order term in the permeance wave.

e. The fundamental component of the no-load field form.

In a machine having a cylindrical field member with uniform permeance the fluxes *b* and *d* are absent. There is left then the flux *a*, which is the usual armature reaction flux, and *c* which is a wave of short span traveling at slow speed whose effect is more conveniently grouped with the reactance fluxes. With the assumption of uniform permeance, that is, with only the zero-order term present in the permeance expression, we may say that all harmonics in the armature m. m. f. wave including the fundamental set up fluxes which generate fundamental voltage in the armature. Further, no voltages of other frequency are generated or, expressed differently, no time harmonics appear.

The introduction of salient poles and variable permeance is responsible for the flux *b*, which adds to the armature reaction flux, and *d* whose effect is grouped with the reactance. The fluxes under *d* are of various wave lengths but travel at such speeds as to give fundamental voltages. In addition there are the various fluxes having combinations of wave length and speed of rotation such as to produce frequencies which are multiples of the fundamental. It is the variable permeance that is responsible for the presence of time harmonics except of course, those that are due to the shape of the field flux form and which are present even though there is no current flowing in the armature.

These facts are all contained in the original paper but are repeated here in different form and with a slightly different point of view.

There are two points of possible importance which the authors appear to have omitted in their paper. The first is the effect of a damper winding on the magnitude of the various harmonic fluxes. Any m. m. f. wave which has a velocity other than synchronous may set up secondary currents in the rotor which will have the effect of reducing the magnitude of the flux waves set up by that m. m. f. The paper contains a discussion of the induced currents in the field winding and concludes that they may be neglected. It is probable that the same conclusion was reached concerning the induced currents in damper bars although I believe these currents should be considered in cases where particular time harmonics are of importance. Their effect on reactance in the steady state is probably imperceptible.

The other point to which I wish to call attention is the phase sequence of the fundamental voltages generated by the various fluxes. Since the fifth space harmonic, for example, travels against rotation and produces a flux wave with the same direction of travel, the voltage induced in the three-phase armature winding has opposite sequence to the main induced voltage. This negative sequence voltage which is grouped among the reactances appears at the terminals as an unbalance in the three voltages. In Fig. 15 of the paper e_{5d7} and e_{5q7} are voltages produced by positively rotating flux while e_{5d5} and e_{5q5} are the result of fluxes rotating negatively. The same is true of part of the fundamental voltages arising from the 11th and other space harmonics of the armature m. m. f. It is surely incorrect to add these various voltages in the final reactance equation just as though they were all induced by positively rotating flux waves. I realize that the voltages calculated are for one phase and that equations (**58a**) and (**59a**) could give correct values for the voltage of, say, phase 1. But since the time relation of between voltages induced by positively rotating and negatively rotating fluxes is different for phase 2 and phase 3 the same equations would not apply.

I have been particularly interested in the footnote on the thirteenth page which refers to the harmonics of irregular windings since I have in the course of preparation a paper which covers in some detail the calculation and the effects of these harmonics.

R. E. Doherty: Professor Adams has said that it is immaterial, so far as final results are concerned, whether fluxes or m. m. fs. are superposed. When saturation does not exist, such quantities which exist at the same point may be superposed. All armature m. m. fs. are distributed along the armature surface and hence may be superposed. The field m. m. f., however, is located at some distance from the armature surface and, hence, cannot, in general be superposed directly with armature m. m. fs.

I am just raising the point that every now and then we are likely by habit to superpose quantities that properly cannot be superposed. If we assume a fictitious m. m. f. which, if located at the armature surface, would produce the same effect as the actual field winding, then of course we may superpose this fictitious m. m. f. with those due to the armature since they are now at the same point. In cylindrical-rotor machines, this fictitious m. m. f. would be practically the same as the actual m. m. f. and it would be immaterial which we use. In salient-pole machines, however, the fictitious m. m. f. would be greatly different from the actual m. m. fs. In such cases it becomes much simpler to superpose fluxes than to attempt to obtain the correct m. m. f. to use.

As to the question of fractional slots which Mr. Alger has brought up, we especially stated that the treatment of this is beyond the scope of this paper. I hope that some one in the future—perhaps Mr. Alger—will treat this case.

Mr. Graham has stated that the fifth-harmonic flux, rotating backward with respect to the armature, will induce a negative-sequence fundamental voltage in the armature winding. For a fundamental wave, phases 1, 2, and 3 are located at 0 deg., 120 deg. and 240 deg. respectively. For a fifth-harmonic wave these angles become 0 deg., 600 deg. and 1200 deg. which of course are the same as 0 deg., 240 deg., and 120 deg., respectively. This phase rotation for a fifth harmonic is thus opposite to the phase rotation for the fundamental. Hence it is necessary that a fifth-harmonic flux wave travel in a direction opposite to that of the fundamental wave in order to generate fundamental voltages having the same sequence as the fundamental.

Mr. Graham also raises a question regarding the effect of a squirrel-cage winding. The present paper does not cover this case. However, it is important to call attention to the fact, as Mr. Graham has done, that squirrel-cage currents may have an important effect on the value of the harmonic flux waves, and therefore upon the leakage reactance of the machine, even under steady-state conditions. It is the authors' opinion that the effect of such currents is not negligible, and an appropriate approximation would have to be made in case a squirrel-cage winding is present.

REPORT OF COMMITTEE ON ELECTRICAL MACHINERY[1]

(HOBART)

WHITE SULPHUR SPRINGS, W. VA., JUNE 22, 1926

H. B. Dwight: The report states that the committee desires that suitable commercial test methods be developed for a more accurate determination of the efficiency of synchronous machines than is given by the present Standardization Rules. Possibly one of these items is the amount of core loss corresponding to full-load conditions.

At present the Standardization Rules specify the core loss for full load and rated voltage to be practically the same as that for no load and rated voltage, the small correction for resistance drop being almost negligible. If a satisfactory, precise test for determining the internal voltage of a synchronous machine were to be devised, full-load core loss could be taken equal to the reading on the core-loss curve corresponding to the internal voltage. This under full-load conditions would mean an increase in core loss of from 20 to 50 per cent, which is of considerable importance.

The internal voltage is equal to the vectorial sum of the terminal voltage and the reactive drop in the winding. What is desired, therefore, is a dependable test for the leakage reactance of a synchronous machine. There is a possibility that for certain types of machines and for certain purposes, the leakage reactance may be taken equal to the measured reactance of the armature with the rotor removed. While this may not be precisely equal to the true leakage reactance, it is nearly equal to it for many usual machines, and it has the advantage that it is a definite, easily measured quantity.

Two students of the Massachusetts Institute of Technology, C. F. Kirsch and M. L. Libman, have arranged a sample machine so that they could make a direct measurement of the leakage reactance and compare it with the reactance when the rotor was removed. To do this, they isolated part of the winding which was large enough to be representative of the total winding. They put a load on the main part of the winding and measured the difference in the terminal voltages of the main part and the isolated part. This difference, corrected for the number of coils in each part, was equal to the reactance drop in the winding, and the voltage on the unloaded part was proportional to the internal voltage of the machine. The difference between the reactance measured in this way and the reactance of the main part of the winding when the rotor was removed, was about 20 per cent.

This "search winding" method is not intended to be a commercial measurement of the reactance of a complete machine, since it requires part of the winding to be set aside as a search winding. It is a means for judging other methods of measuring or calculating the reactance of synchronous machines.

1. A. I. E. E. JOURNAL, October, 1926, p. 940.

Discussion at Pacific Coast Convention

VARIABLE-VOLTAGE EQUIPMENT FOR ELECTRIC POWER SHOVELS

(MCNEILL)

SALT LAKE CITY, UTAH, SEPTEMBER 9, 1926

P. S. Stevens: Mr. McNeill has mentioned the effect of electric power on the mechanical design of the shovel, such as better gearing, lubrication, etc. I would like to further point out that the variable-voltage control with separately excited motors described by Mr. McNeill is so complete and well suited to shovel operation that it has been possible to simplify the mechanical design of electric shovels without any sacrifice. For example, on two models of medium-sized shovels recently developed, the usual band-type air-operated clutch previously required for disconnecting the engine or motor from the hoisting drum has been omitted. This clutch has been omitted for the same reason also on a large 12-yard Diesel-electric dipper dredge recently put in operation. The elimination of this clutch and its operating mechanism, reduces the care and maintenance of the shovel and is made possible by the quick acceleration and quick and smooth stopping afforded by the separately excited motor control with motor lowering. The motor is actually driven down to a certain extent, so that fast lowering speed is obtained and the shovel operator can graduate his lowering speed or check it any time under perfect control.

On the swing and thrust motions the variable-voltage control with separately excited motors is so perfect in stopping and plugging that swing and thrust brakes having large heat capacity and requiring air operation are omitted from the two models of shovels mentioned above, being replaced by the usual solenoid-operated motor brakes for holding and infrequent stopping. Hence the complete compressed-air equipment, including compressor, governor, tank, piping and all magnet valves, is eliminated, reducing operating costs and resulting in a more reliable shovel unit.

R. W. McNeill: Since preparing this paper the writer has been fortunate enough to secure graphic meter records showing the performance of a 4½-yard railway shovel, equipped with variable-voltage electrical equipment. This shovel is one of a number which are in operation at a mine of a large western copper-mining company, which has recently gone through the process of converting all of its steam shovels to electric drive.

Electrical equipment on these 4½-yard railway-type shovels consists of a main motor-generator set, an exciter motor-generator set, two hoist motors, a swing motor, a thrust motor, and a motor-driven air compressor. With this equipment is included necessary starting and control equipment for all items. The main motor-generator set consists of a 225-h. p., 80-per cent power factor, 1200-rev. per min., 5000-volt, 3-phase, 60-cycle synchronous motor designed for starting at full line voltage; a 125-kw., 1200-rev. per min., 250-volt, differential compound-wound d-c. generator for operation of the hoist motion of the shovel, and two 30-kw., 1200-rev. per min., 250-volt, differential compound-wound d-c. generators for operation of the swing and thrust motions. The generators are designed to give a maximum voltage of 400 at no load, and a maximum current under stall conditions of approximately 1000 amperes in the case of the hoist generator and 250 amperes for the swing and thrust generators. The exciter set is of 7.5-kw. capacity at 125 volts and is driven by a 220-volt, 3-phase, 60-cycle motor. The hoist motors are of series type each rated 95 h. p., 230 volts, 440 rev. per min. These motors are operated in parallel from the 125-kw. hoist generator. The swing and thrust motors are of the separately excited shunt-wound type, each rated 50 h. p., 230 volts, 485 rev. per min. The air compressor is operated by a 7.5-h. p., 220-volt, 3-phase, 60-cycle motor. Transformers are used to step down the power for the compressor motor and the motor driving the exciter motor-generator set from 500 volts, the line potential, to 220 volts for the motors.

Fig. 1, herewith, shows power input to this 4½-yard shovel, measured on the 5000-volt line feeding the shovel. The upper curve is made with high paper speed and shows variations in power requirements of the shovel throughout several cycles of operation. The lower curve is made with low paper speed and shows to some extent the percentage of operating time obtained

with this shovel equipment. Records kept over a considerable length of time show that the shovels are in operation approximately 60 per cent of the time, the other 40 per cent being taken up with delays due to causes outside of the control of the shovel operator, the principal cause of these delays being waiting for empty cars. The power consumption on this property for

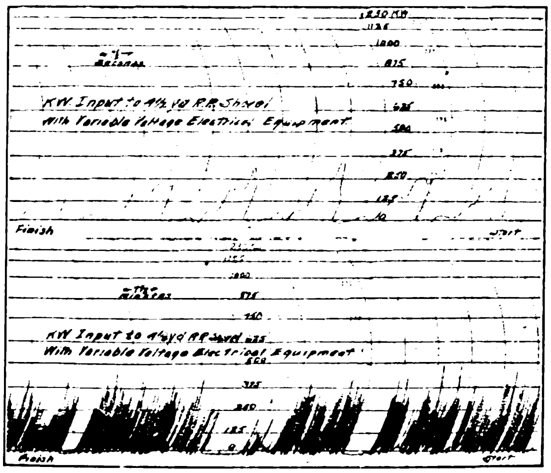


Fig. 1

shovel service averages approximately 0.2 kw-hr. per ton of material excavated. The amount of material excavated in a given time will depend upon a number of factors; however, average daily loading on this property is approximately 5000 tons per shovel per 8-hr. day. This is roughly equivalent to 3300 cu. yd. per day or 700 cu. yd. per hour of actual digging time.

Fig. 2 shows volt and ampere input to the hoist motors of the shovel over several cycles of operation. I would like to call especial attention to the regularity and uniformity of these charts. The largest area on the voltage chart represents digging areas, while the smaller areas, occurring regularly between

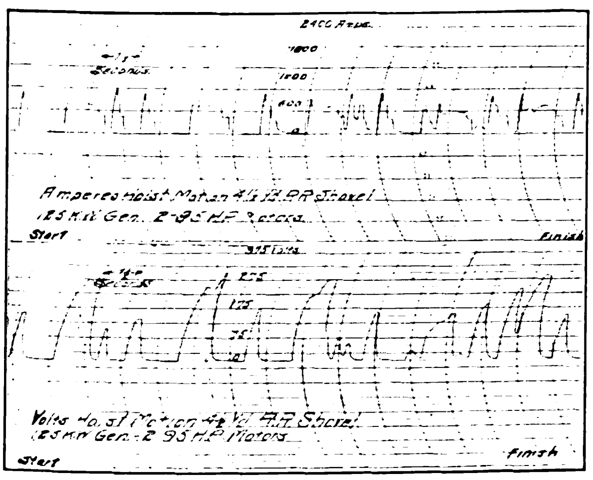


Fig. 2

the digging areas, represent power requirements for hoisting the loaded dipper during the dumping period.

Similiar areas can be distinguished readily on the ampere curve. It will be noted that neither the current nor the voltage shown on the chart reverses in direction. This is due to the fact that the shovel dipper is lowered by gravity, during which period the hoist motors remain stationary, lowering of the dipper being accomplished by release of a clutch between the hoist drum and the hoisting motors.

Fig. 3 shows volt and ampere charts taken on the swing motion. The same regularity is apparent on this chart as on those taken on the hoist motion with the difference that the current and voltage both reverse in direction, as the swing motor has to furnish power in both directions of swing. The charts as shown on Fig. 3 were made simultaneously and it will be noted that the current reverses at times when the voltage stays in the same direction. This reversal of the current without the voltage reversing gives regenerative braking, which is used to stop the swing motion at the end of travel.

Fig. 4 shows volt and ampere charts taken on the thrust

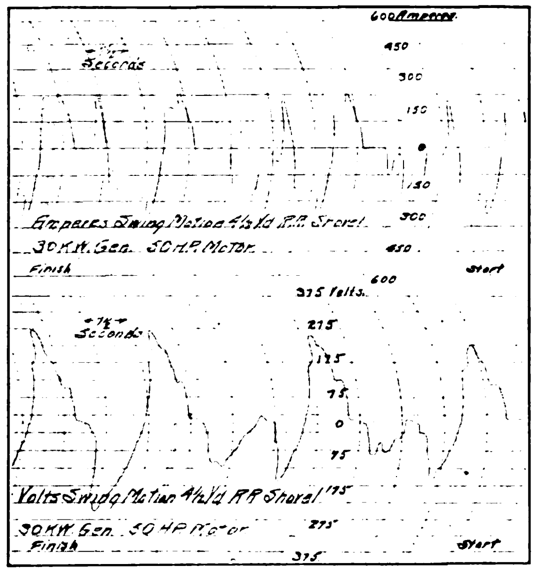


Fig. 3

motion. While there is an appearance of considerable regularity on these charts it is not so pronounced as in the case of the hoist and swing motion as operation of thrust motion does not follow nearly so definite a cycle as is the case on the hoist and swing

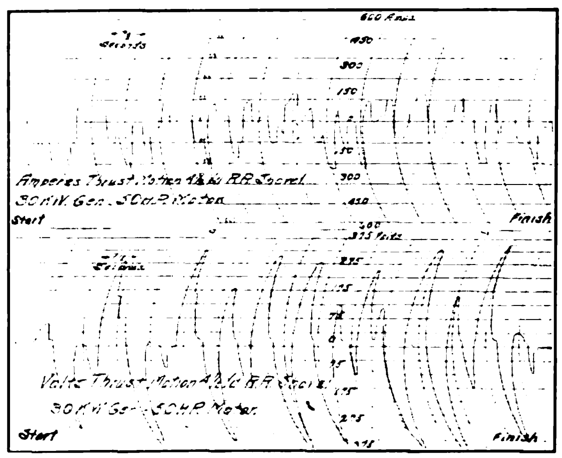


Fig. 4

motion. The operations, however, are more numerous and a snappy thrust motion contributes considerably to the successful operation of the shovel. Plugging or regenerative braking contributes in no small degree to the successful operation of the thrust motion. The curves as shown on Fig. 4 were made simultaneously and the action of the current in reversing at plugging can be seen quite clearly.

Mr. Stevens in his discussion mentions that he has found the action of the variable-voltage control with separately excited

motors to be so perfect in stopping and plugging that swing and thrust brakes having large heat capacity and requiring air operation are not necessary and that they can be replaced by the usual solenoid-operated brake designed for holding and infrequent stopping. Along the same lines I would like to say that the user of the 4½-yard railway-type shovels, on which the curves presented herewith were taken, has found that on his variable-voltage equipped shovels he obtained improved operation by not using the motor brakes on the swing and thrust motions in ordinary operations. His method of operation is to allow these brakes to remain released during the greater part of his operation. On the swing motion about the only time the brake is used is when the shovel is traveling, at which time the brake is applied to keep the shovel boom from swinging. On the thrust motion the brake is used when it is necessary to thrust the dipper out beyond the end of the shovel boom for dumping, and where digging conditions are very severe. The shovel operator has the option of using the motor brakes if he chooses, as the only modification made in the control equipment to allow operation with brakes "released" was the installation of a small switch to short-circuit the controller contacts used for releasing the brake magnet coil. When this switch is closed, the brake will stay released, and when switch is open the brake will respond to the operation of the controller, that is, it will release when power is applied to the motor and will apply when the controller is brought to the off position. The advantages of operating without swing or thrust brakes are readily apparent as with the motors free to turn even a small amount, sudden impacts are softened and mechanical strains on the shovel parts decreased.

TEMPERATURE OF A CONTACT AND RELATED CURRENT-INTERRUPTION PROBLEMS[1]

(SLEPIAN)

SALT LAKE CITY, UTAH, SEPTEMBER 9, 1926

F. E. Terman (communicated after adjournment): The results obtained by Dr. Slepian and his speculations on their significance are most fascinating. After reviewing the approximate temperature rise for different cases, as given in Table I, it is interesting to consider at least qualitatively the effect of some of the factors which have not been taken into account in the formula the paper derives for temperature rise.

The principal modifying influence is the temperature coefficient of resistivity. At the high temperatures which are often obtained at the last point of contact, it is apparent that there must be a large change of resistance of this active spot which carries the final burden of the break. While the derivation of a formula to take this change of resistivity into account is complicated by the fact that the voltage gradient cannot then be correctly expressed by equation (3), it is at least possible to speculate on the nature of this effect without resorting to a lot of mathematics of doubtful value. In the case of conductors which increase their resistivity with an increase of temperature, as is the case with most metals, the temperatures at the final contact point will be considerably less than indicated in Table I. With other materials, such as carbon and many poorly conducting bodies, the temperature rise reduces the resistivity. In these latter cases the temperature of the contact spot will be more than indicated in Table I. The change in resistivity in any case depends upon the temperatures generated, and this is influenced by the voltage to be broken. Accordingly, the results given in Table I are more nearly exactly correct as the temperature rise becomes smaller, and the temperatures will depart more and more from a proportionality with the square of the voltage broken as this voltage increases.

The results in Table I also assume that the steady-state temperature conditions at the contact spot are instantly established. Any failure to establish the steady state completely will give lower temperatures than indicated in Table I, and although it is evident that the speed by which the steady state comes into existence is very rapid as the contact area gets smaller and smaller, yet at the last instant the speed of break at the contact is also infinitely great. I would enjoy seeing a discussion of this by Dr. Slepian, for I know from personal discussion with him that he has considered this point.

J. Slepian: Mr. Terman's remarks as to the influence of the temperature coefficient of resistivity of the electrode materials are very good and to the point. The increase of resistivity of metals with temperature will certainly greatly reduce the temperature rise at a last contact with a given voltage applied. If the formula of the paper is used, a value should be taken for the electrical resistivity larger than the resistivity of the cold metal.

The reason I believe that steady-state conditions apply at the last contact point is as follows: The mass of the material to be heated varies as the cube of the linear dimensions of the small contact area, whereas the electrical and thermal conductance vary as the first power of the linear dimensions. Hence, regardless of the speed with which the contact area is reduced to zero, the mass to be heated will play a vanishingly small part in the balance between the heat input, proportional to the electrical conductance, and the heat lost, proportional to the thermal conductance.

In the six weeks which elapsed between the presentation of my paper and the preparing of this closing discussion, some experiments have been carried out under my direction which require me now to take the unusual role of adverse critic of my own paper.

As critic, I must point out that in the formula for temperature rise as given, no account is taken of a specific contact resistance. It is assumed that all the resistance is through the material of the two electrodes up to the area of contact, and no account is taken of the voltage necessary to carry the current out of the one electrode and into the other, across the contact surface. Such a voltage is necessary, however, and it is found that this voltage varies nearly proportionally with the current density crossing the contact area, and also approximately inversely as the pressure on the contact area. Thus for clean copper surfaces, at 1-lb. per sq. in. pressure, the contact resistance is of the order of 0.0002 ohms per cm.^{2}

When electrodes separate, this contact resistance varies inversely as the area of contact (and also inversely with pressure) whereas the resistance discussed in the paper—that is, that of the electrode material up to the contact area—varies inversely as the square root of the area. Hence, this contact resistance will certainly predominate when the area is small enough, and will limit the current so that very much lower temperatures will result than are given by the formula of the paper. In fact, it would seem quite possible to separate two metal electrodes in a circuit of a few volts so rapidly that no high temperature results at the last points of contact.

Now, replying as author, I explain the failure to consider contact resistance as due to my belief that such contact resistance was caused by surface oxide layers, and did not exist for clean metals. Also I believed that these surface layers were broken down at very low voltages so that a contact drop of more than a fraction of a volt was not obtainable. Since it appears that I was mistaken in these ideas, I must admit that the basis of much that is in my paper is lost. However, it is certain that it is almost impossible not to draw an arc between contacting metal electrodes in a circuit of a few volts, and that the difficulty of drawing an arc goes up with resistivity of electrode material in the way indicated in my paper. This may indicate, perhaps, that the contact resistance at the last contact point is for some reason negligibly small. It would be very desirable to have this whole paper worked over again, taking contact resistance into account.

Lest it be thought that this change of viewpoint follows upon a paper which was prematurely presented, I wish to state that the paper was written more than three years ago. The information

1. A. I. E. E. JOURNAL, October, 1926, p. 930.

on contact resistance at very high current densities (more than 100,000 amperes per cm.[2]) was obtained only in the last few weeks.

110-KV. TRANSMISSION LINE CONSTRUCTION OF THE WASHINGTON WATER POWER COMPANY[1]

(GAMBLE)

SALT LAKE CITY, UTAH, SEPTEMBER 6, 1926

C. R. Higson: I should like to ask Mr. Gamble regarding the effect of this powder on cattle or on a man's hands, or if it is poisonous in case a man should happen to get it in his mouth.

Harold Michener: In the paper, weights are shown at points where there are uplifts due to the structures being low. The author attributes the necessity of these weights to a slight error in profile. In general, for lines over rough country, there will be unavoidable structure locations which, because of being lower than one or both of the adjacent structures, will require either a weight, a tie-down, or a dead-end, to maintain proper clearance between the conductor and the structure under a heavy wind across the line. Usually there will be no actual uplift of the conductors at these structures. The angle to which any unrestrained suspension insulator will swing is the angle the tangent of which is the horizontal wind pressure on the conductor in one-half the sum of the adjacent spans divided by the vertical load on those insulators. The wind pressure on and the weight of the insulators themselves can usually be neglected without appreciable error. If this angle is greater than the allowable clearance will permit, one of the previously mentioned methods of restraining the conductor swing must be employed.

L. R. Gamble: On all the tests we have made in the use of this powder or treater dust, we have never had any cattle or any animal get poisoned. However, the dust is poisonous and to get any of it on the hands, especially if there is an open sore, may cause a little trouble which will necessitate treatment, but such a condition is not dangerous. Dr. Gardner of the Anaconda Copper Mining Co. at Anaconda, Mont., is the chemist who has worked out various uses of this compound and has put it on the market. On his ranch in Montana where he has a number of sheep and cattle he has used this dust for several years in the treating of fence posts and none of his sheep or cattle has in any way been injured by it. In our specifications for the use of dust on poles we specify very definitely that a man should wear gloves when placing the dust around the poles and should also be very careful not to rub his face or eyes while he is applying it. If the dust enters the nose or mouth it is very irritating, and care should be exercised in its handling.

In the design of our lines we use the celluloid sag templets and spot poles from these templets, giving the required clearance to ground. These curves are made up for 100 deg. fahr. and −30 deg. fahr. The −30 deg. fahr. curve is our cold curve and we apply it to the profile of the line and if we find any evidence of upstrain, we immediately re-spot the poles to get away from that upstrain. There is a certain amount of variance in making these sag templets, so we always allow a margin of 4 ft; that is, if we are sagging between two structures and use the cold curve, we put the cold curve between the structures on the two consecutive spans and if the template rests above the pole in the center of these two spans it indicates upstrain. If the cold template rests below the top of the pole there is no upstrain. We usually allow about 4 ft. below the top of the pole in order to play safe. We find that sometimes a little error actually exists in the profile, and 4 ft. is not enough. When we find during construction that there is upstrain it is taken care of by conductor weights. We very rarely find any case in which more upstrain than we can take care of by the use of weights exists. In one instance, however, it was necessary to make a dead end out of the structure.

1. A. I. E. E. JOURNAL, December, 1926, p. 1255.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

PRACTICAL COLOR PHOTOMETRY*

By the usual methods of photometry, two lights are compared by balancing the brightness of adjacent surfaces which are illuminated by the two sources. In this way, lights from sources of slightly different color can be compared with a probable error of photometric measurement of about 1 or 2 per cent. When the color difference is considerable, however, as when red, blue or green light is compared with white light in determining the transmission of colored glass or accessories for colored lighting and the luminous output of colored lamps, the measurements become extremely difficult and the observational errors may be quite large.

There are two better methods available for evaluating lights of decidedly different color. The first requires an analysis of the spectrum by which the luminous effect of the amount of energy radiated in the different wavelengths can be calculated. This is the more accurate method, but it is long and tedious.

Lights of different colors can be compared also by the use of a flicker photometer in which surfaces illuminated by the two sources are presented alternately and rapidly to view. This method is quicker but somewhat less accurate than the former.

An investigation has been made recently by the Lighting Research Laboratory at Nela Park to determine the accuracy with which the relative illuminating value of lights of decidedly different color can be measured with the flicker photometer. The test was conducted by determining the transmission factors of eight color filters by both the spectrum analysis and the flicker photometer method.

This set of eight filters was representative of practically all colors encountered in practise, with the exception of light sources having line spectra. The commonest examples of which are mercury arcs, other arcs and gaseous discharge tubes. The color sensitivity characteristics of each observer were determined with the standard Ives test solutions of copper sulphate and potassium bichromate, and a Kingsbury type flicker photometer. The standard test solutions have been designed to transmit such amounts of yellow and blue light that the illumination obtained therewith, when used in connection with a carbon lamp operating at four watts per candle, appear equal to an observer with normal eyesight. If the observer does not judge the yellow and blue light transmitted by these solutions

*Abstract of a paper on "Heterochromatic Photometry" presented at the 1926 Annual Convention of the Illuminating Society, by A. H. Taylor of the Lighting Research Laboratory, Nela Park, Cleveland, Ohio.

as being of the same brightness, a correction must be applied to his measurements.

Each observer made a set of readings on a flicker photometer with each color filter when it was used to filter the light from a tungsten lamp operated at the color temperature 2680 deg. K. The illumination of the photometer screen was approximately 50 meter-candles (4.6 foot-candles) and the speed of flicker was practically the minimum at which the flicker could be made to disappear or at which a photometric observation could be made. In most cases, a filter of intermediate color was kept on the opposite side of the photometer in order to reduce the decided color difference between the two measurements with and without the test filter. In the case of one of the red filters—a very saturated red—the measurements were made in terms of two other lighter red filters in order to avoid the very great color difference involved in direct measurement.

The transmission factor of each color filter was computed from the curve showing the distribution of energy in its spectrum by using the standard visibility curve showing the illuminating power of a given amount of energy radiated in various wavelengths.

Table I shows the transmission factors of the eight color filters as observed by the flicker photometer and as computed from spectrophotometric data.

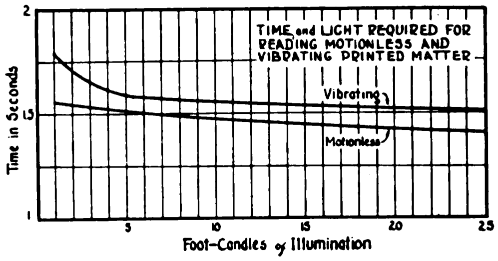
Color	Transmission Factor: As observed by flicker photometer per cent	Transmission Factor: Computed from spectrophotometric data—per cent
*Light red	28.0	30.3
*Purplish-red	17.6	18.3
Deep red or ruby	8.0	9.5
*Light amber	65.5	64.5
Dark amber	36.7	37.7
Yellow-green	25.1	23.2
Light blue-green	36.9	36.7
Blue	5.44	5.04

*Dyed gelatine on glass.

Assuming the results obtained by computation of spectrophotometric data to be correct, the flicker photometer gave, for these particular screens, values that were high for the blue and low for the red light. The average difference between computed and observed transmission values was only 5.8 per cent, however, which is a very small error for color differences as great as these. By a modification of the method of interpreting flicker photometer results the average error would be reduced to 3.1 per cent. Thus under the conditions of this test the flicker photometer furnishes a very practical method of color photometry with many advantages.

MUST THE TRAVELER READ SLOWLY?

Common experience tells us that it is more difficult to read on a train when it is in motion than when it is stationary. Most methods of travel are by no means free from vibration. This means that in such visual processes as reading, it takes the eyes longer to function properly in transmitting thoughts from the printed page to the brain. Inasmuch as reading is perhaps the most common means of passing time for those who must commute daily between their homes and places of business, and for those who use the street cars, busses and railroads considerably, the effect of light on the reading of "jiggling" printed matter is of special interest. Will exceptionally good lighting materially increase the ease of reading under such conditions?



In a series of tests which was carried out at the Lighting Research Laboratory at Nela Park, this subject was studied briefly. Sixteen observers were asked to read two pages of printed matter which were fastened to a vibrating mechanism, the movements of which closely approximated the motions encountered on moving trains. In these tests the time required to read a given amount of material was recorded for both stationary and vibrating conditions under various levels of illumination. The accompanying curves tell the story of the results. The lower curve is the usual form of speed of vision curve. The upper curve shows the performance of the eyes under different foot-candle values and for vibrating conditions. These curves lead us to the conclusion that for the same relative ease of reading a person needs a higher level of illumination when riding than he would in his home or office.

AUTOMATIC AND SUPERVISORY CONTROL OF HYDROELECTRIC STATIONS

In the publication of the discussion on the paper *Automatic and Supervisory Control of Hydroelectric Stations* by F. V. Smith, in the October issue of the JOURNAL, a part of the discussion presented by C. F. Publow was transposed by mistake to the end of the comments presented by Mr. Smith. This part of the discussion consisting of the last eight paragraphs (pages 1034 and 1035) should have appeared as a subcaption under Mr. Publow's Fig. 2 on page 1033.

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A. I. E. E. Regional Meeting

NEW YORK CITY DISTRICT

A program of great interest was presented at a two-day meeting of District No. 3 of the A. I. E. E. at the Engineering Societies Building, 33 West 39th St., New York, November 11-12. The attendance was approximately 700, comparing favorably with some of the national meetings. The technical sessions, which were well attended, included papers under the three general subjects of a-c. distribution networks, illumination, and communication. The technical program was augmented by a very interesting lecture on Thursday evening by Professor Robert W. Wood, of Johns Hopkins University, who spoke on some of the latest accomplishments and discoveries in the field of physical research, and on Friday evening by a demonstration of the Vitaphone, arranged through the courtesy of the New York Electrical Society.

There were five organized inspection trips, on which the attendance was unexpectedly large, in addition to numerous unorganized trips which were made by members individually.

A buffet luncheon was served on the fifth floor of the Engineering Societies Building on both days of the meeting, which not only conserved the time available for luncheon but afforded an additional interval for social intercourse.

THURSDAY MORNING SESSION

The first session was called to order by G. L. Knight, Vice-President of District No. 3, who after a few words of welcome Introduced Chairman Philip Torchio of the Transmission and Distribution Committee. Before commencing the technical program, President Chesney was called upon to address the meeting and responded with a brief address describing his visit to the Pacific Coast and numerous Western Sections of the Institute.

The technical program was then resumed and the following papers were presented by the authors: *Recent Progress in Distribution Practise*, J. F. Fairman and R. C. Rifenburg, *Automatic A-C. Network Switching Units*, G. G. Grissinger, *Evolution of the Automatic Network Relay*, J. S. Parsons, *Operating Requirements of the Automatic Network Relay*, W. R. Bullard, *A-C. Network Relay Characteristics*, D. K. Blake.

These papers were discussed as a group by Messrs. John C. Parker, A. H. Kehoe, Harry Richter, H. R. Searing, O. C. Traver, Gordon R. Milne, H. C. Forbes, J. H. Brooks, D. K. Blake, C. A. Corney and W. B. Jackson.

THURSDAY AFTERNOON

This afternoon was set aside for inspection trips, no technical session being held. The organized trips for which transportation both ways was furnished were as follows:

Lighting Institute, Edison Lamp Works, Harrison, N. J. An interesting display of all types of lamps and lighting.

American Telephone and Telegraph Co. Walker St., New York City. Demonstrations of picture transmission by telegraph, and telephone machine switching.

Electrical Testing Laboratories, East End Ave. and 80th St., New York City. All of the departments of the Laboratories were open to visitors.

Vehicular Tunnel, connecting the New York and the New Jersey shores. The tunnel is now rapidly approaching completion.

Hudson Ave. Station of Brooklyn Edison Co. Installed capacity 230,000 kw., including an 80,000-kw. generator, the largest in the world.

THURSDAY EVENING

One of the outstanding features of the meeting was the lecture *On the Frontier of Science*, by Robert W. Wood, Professor of Experimental Physics, Johns Hopkins University. Professor Wood talked briefly on a number of the most interesting experiments and theories of modern science. He told of experiments made on certain metals at the temperature of liquid helium at which temperature the metals have no electrical resistance and an electrical current started in them will continue indefinitely if not subject to outside influence. He talked on the modern quantum theory of light and showed how, to some extent, it could be reconciled with the theory of wave propagation. One of his most absorbing topics was that of supersonic vibrations, or mechanical vibrations in liquids at frequencies far above the audible frequencies. He mentioned particularly the experiments made on physiological effects of these vibrations.

FRIDAY MORNING

This session was a joint one with the N. Y. Section of the Illuminating Engineering Society. The first paper presented was *Remote Control of Multiple Street Lighting Systems*, W. S. Dempsey. This was discussed by Messrs. A. H. Kehoe, Nicholas J. Kelly, H. R. Searing, William H. Suydam and O. F. Haas.

The next paper was entitled *Lighting of Railway Classification Yards*, G. T. Johnson, and was presented by the author. It was discussed by Mr. J. A. Sommers.

The last paper of the session was preceded by a brief talk by Mr. Saul Dushman, setting forth the theoretical considerations underlying the new lamp described in the following paper: *The Induction Lamp, a New Source of Visible and Ultra-Violet Radiation*, T. E. Foulke, which was presented by the author who also demonstrated several different types of the induction lamp. A discussion followed by Messrs. Herman Goodman, C. H. Sharpe, Selby Haar, John B. Taylor and O. H. Oyler.

FRIDAY AFTERNOON

The last technical session of the meeting was on Friday afternoon and was devoted to the field of electrical communica-

tion. The first paper was entitled *Frequency Measurements with the Cathode-Ray Oscillograph*, F. J. Rasmussen, which was presented by the author and discussed by D. E. Shea.

The next paper, *A Shielded Bridge for Inductive-Impedance Measurements*, W. J. Shackelton, was read by the author and was not discussed.

The last paper of the session was *Radio Broadcast Coverage of City Areas*, Lloyd Espenschied, presented by Mr. R. W. King in the absence of the author. It was discussed by Mr. Zammataro, John B. Taylor, W. D. A. Peaslee, G. T. Crocker and K. B. Lyman.

FRIDAY EVENING

The closing feature of the meeting was the demonstration of the Vitaphone and this presentation filled the Auditorium to capacity at 7:30 p. m. and again at 9:30 p. m. Mr. E. B. Craft, of the Bell Telephone Laboratories introduced the demonstration in person rather briefly, after which a talking picture of himself explaining the principles and operation of the Vitaphone told its own story. This was followed by the overture from Tannhaeuser by an orchestra and brief sketches by Al. Jolsen, Mischa Elman, Mary Lewis and other well-known artists. The combined screen and vocal reproductions were rendered with wonderful perfection and were accorded most enthusiastic applause. This demonstration by courtesy of the New York Electrical Society, was a repetition of its program at a meeting on October 27.

The plans for this meeting, which were carried out with notable success, are due to the committee in charge of the New York Regional Meeting, of which the personnel is as follows: G .L. Knight, Vice-President, District No. 3, H. A. Kidder, General Chairman, O. B. Blackwell, W. A. Del Mar, H. V. Bozell, E. B. Meyer, H. E. Farrer, G. H. Stickney.

Transportation to be Discussed Before New York Section

On the evening of Friday, December 3, 1926, the New York Section of the A. I. E. E. will hold a meeting on the subject of "Transportation." Two speakers of the evening will be men of great prominence in the New York field; Mr. Frank Hedley, President of the Interborough Rapid Transit Co. will talk on "The Interborough Rapid Transit System—A General Description of Its Operation," and the second speaker will be the Honorable George S. Silzer, Ex-Governor of New Jersey and Chairman of the Port of New York Authority. Mr. Silzer will have for his subject "The Port of N. Y. Authority—Its Functions and Progress."

Because of the size and formation of New York City, the transportation of passengers and the distribution of freight present difficulties met in no other city of the world. It is important both in the interest of the public and of the profession that engineers should acquaint themselves with these problems, and at this meeting they will have an unusual opportunity to obtain from men who are leaders in their respective fields, a broad, general picture of the progress that has been made by way of a solution of these problems. The meeting will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York City, at 8.15 p. m. All engineers interested are invited to attend as guests of the New York Section.

Future Section Meetings

Akron

Outdoor Substations, by a specialist from the Delta-Star Company. Moving pictures of substation construction will be shown. December 17.

Power-Factor Problems, by Frank Wallene. This talk will be accompanied by a demonstration in the Electrical Laboratory of the University of Akron. January 14.

Baltimore

The Influence of Residual Air and Moisture on Impregnated Paper Insulation, by J. B. Whitehead, Johns Hopkins University. December 16.

Boston

Talk by Dean Dexter S. Kimball, Cornell University. Tremont Temple. December 9.

Cleveland

The Transmission of Pictures over Telephone Lines, by R. D. Parker, American Telephone and Telegraph Co. December 16.

Mercury-Arc Rectifier for Power Transmission, by D. C. Prince, General Electric Co. January 20.

Columbus

Standards, by C. E. Skinner, Westinghouse Electric & Mfg. Co. December 3.

Railway Electrification. January 7.

Pittsfield

Why Intelligent People Do Not Vote, by W. J. Millard, National Municipal League. December 16.

Relation of Capital to Labor, by C. F. Kettering, General Motors Co. (Tentative) January 18.

St. Louis

Radio-Photography, by Dr. E. F. W. Alexanderson, General Electric Co. December 15.

Banking of Transformers, by M. T. Mitschrich, Moloney Electric Co. January 19.

Seattle

Diablo Development of the Skagit River Project, by J. D.Ross, Supt. of the Light and Power Dept., City of Seattle. December 15.

Vancouver

Electric Boilers, by Douglas Robertson. December 7.

Visit to Dunbar Automatic Substation. Demonstration of Operation by R. L. Hall. January 11.

A. I. E. E Appointment

Professor Henry H. Henline of Stanford University, California, has been appointed Assistant National Secretary of the American Institute of Electrical Engineers, and will join the headquarters' staff of the Institute in New York about January 1, 1927.

Because of the constantly increasing activities of the Institute, the desirability of adding to the permanent staff has long been appreciated by members of the Board of Directors and by the National Secretary; this appointment was made accordingly by the Board upon the recommendation of President Chesney and National Secretary Hutchinson.

Professor Henline was born in Colfax, Illinois, March 12, 1889, and was graduated from the University of Illinois in the Electrical Engineering course in 1914. After two years' experience in Chicago, he became an instructor at Stanford University in 1917 and was later promoted to his present position of Associate Professor of Electrical Engineering.

Professor Henline has been deeply interested in the Institute for many years and is well equipped by training and experience, including personal participation in Institute activities, for his new work. He was elected to membership in 1919, has presented several papers at Institute conventions, was elected Chairman of the San Francisco Section in 1922, is at present Counselor of the Institute Branch at Stanford University, and at the recent Pacific Coast Convention in Salt Lake City, was elected by his associate Counselors in the Pacific District, Chairman of the Committee on Student Activities for that District.

Mechanical Engineers Plan Big Program

The program of the coming Annual Meeting, Dec. 6-7 inclusive, as planned by The American Society of Mechanical Engineers, will include five speakers of international repute. William L. Abbott, the retiring president, will deliver his president's address the evening of December 7th, and will introduce as the president-elect, Charles M. Schwab. Upon Mr. Elmer A. Sperry, a member of the A. I. E. E., will be bestowed the John Fritz Medal. The Robert Henry Thurston Lecture will be delivered at 4:30 on the afternoon of December 7th by Dr. Cecil H. Lander, English civil and mechanical engineer, Director of Fuels Research, Dept. of Science and Industrial Research, London and, during the World War, Lieutenant R. N. V. R. in charge of the Electrical Section of Explosive Paravanes. The technical sessions have been arranged with great care and there also will be special features of interest to the visiting ladies. No inconsiderable attention will be devoted also to the student activities; in fact, the meeting will close Friday night with the college reunions.

Many Novelties at Power and Mechanical Engineering Exposition

The Fifth National Exposition of Power and Mechanical Engineering, to be held in the Grand Central Palace, New York, December 6-11, will be inclusive of all types of power and mechanical equipment. The exposition will occupy four full floors of the Palace and power generating apparatus and accessories will furnish the main attraction. There also will be numerous exhibits in the displays of refrigeration apparatus, heating and ventilating equipment, materials handling devices and other mechanical power transmission machinery.

No less than 200 projects are under way subject to the cooperation of 350 national technical societies, trade organizations and government departments.

The exposition is under the able leadership of Mr. I. E. Moultrop, Chairman of the Advisory Committee and member of the Institute. Managers of the Exposition are Fred W. Payne and Charles F. Roth, with offices in the Grand Central Palace

American Association for the Advancement of Science

A meeting of Section M of the American Association for the Advancement of Science will take place Wednesday, December 29, 1926, in the auditorium of the Franklin Institute, Philadelphia, Pa., with Doctor Charles Russ Richards, Chairman of Section M, presiding.

The meeting will open at 9:30 a. m. with a symposium on the contributions made by pure science to the advancement of engineering and industry. This symposium will include the following subjects: Astronomy, Dr. Frank Schlesinger, Director of the Yale Observatory; Biology, by Dr. Vernon Kellogg, Permanent Secretary, National Research Council; Chemistry, Dr. Charles H. Herty, President of the Synthetic Organic Chemical Manufacturers' Association; Economics, Dr. Joseph H. Willets, Head of the Department of Industry, Wharton School of Finance and Commerce, University of Pennsylvania; Geology, Dr. Heinrich Ries, Professor of General and Economic Geology, Cornell University. The afternoon session, starting at 2:30 p. m., will continue the symposium as follows: Mathematics, Dr. G. A. Bliss, Professor of Mathematics, University of Chicago; Medical Science, Dr. Randle C. Rosenberger, Professor of Preventive Medicine and Bacteriology, Jefferson Medical College; Physics, Dr. R. A. Millikan, Director of the Norman Bridge Laboratory of Physics, California Institute of Technology; and Psychology, Dr. J. McKeen Cattell, President of the Psychological Corporation, Editor of *Science*, the *Scientific Monthly* and *School and Society*. This session will be followed by general discussion.

An informal dinner, under the auspices of the Engineers' Club of Philadelphia, will be served at the Hotel Bellevue-Stratford. The following addresses will be made:

The Stimulation of Research in Pure Science That has Resulted From the Needs of Engineers and of Industry, Dr. W. R. Whitney, Research Laboratory, General Electric Company, Schenectady, N. Y.

Imhoff Tanks, Harrison P. Eddy, Consulting Engineer, Boston, Mass., representing the American Society of Civil Engineers.

The Scientific Aspects of Lighting, Dr. M. Luckeish, Director, Lighting Research Laboratory, National Lamp Works, Cleveland, Ohio.

The Relationship between Science and the Study and Testing of Engineering Materials, W. H. Fulweiler, Chemical Engineer with the United Gas Improvement Company, Philadelphia, Pa.

New Louisville Section Holds First Meeting

The organization meeting of the new Louisville Section of the Institute was held October 27. Section officers were elected and a talk was given by Arthur G. Pierce, Vice-President in the Second District, A. I. E. E., on the subjects, *The Electrical Engineer in Industry* and the *Relation of the A. I. E. E. to Industry*. This first meeting was very enthusiastic.

The officers elected were as follows: Chairman, D. C. Jackson, Jr.; Secretary-Treasurer, W. C. White; Executive Committee, consisting of E. D. Wood, H. W. Wischmeyer, G. M. Miller and Philip P. Ash.

The formation of the Louisville Section brings the total number of Institute Sections up to fifty-two.

Standards Committee Meeting

The Standards Committee met at Institute Headquarters on Friday, November 5; the following were present: J. Franklin Meyer, Chairman, H. E. Farrer, Secretary, and Messrs. H. M. Hobart, H. S. Osborne, A. M. McCutcheon, C. H. Sharp, W. I. Slichter, R. H. Tapscott, J. C. Parker, E. B. Paxton, and C. M. Gilt. The Board has authorized the employment of an assistant in the office of the Secretary of the Committee, and the chairman was directed to make the necessary arrangements as soon as possible. The work of the committee can be made more efficient by having the office of the secretary handle details that are now necessarily done by chairmen of working committees.

In order that there may be the fullest cooperation between the various technical committees and the Standards Committee, the chairman of each technical committee was asked to designate some member of his committee to serve as a "point of contact" with the Standards Committee. The following members of technical committes have been designated as such "points of contact" for their respective committees: Protective Devices, F. L. Hunt; General Power Applications, A. M. McCutcheon; Communication, K. L. Wilkinson; Electrical Machinery, E. C. Stone; Research, Harold Pender; Instruments and Measurements, J. R. Craighead; Applications to Marine Work, J. S. Jones; Electrochemistry and Electrometallurgy, G. W. Vinal; Power Transmission and Distribution, R. H. Tapscott; Transportation, J. V. B. Duer; Applications to Mining Work, W. H. Lesser.

The report of the Marine Rules Committee having been approved by the Board as Section 45 of the Institute Standards, under the title "Recommended Practise for Electrical Installations on Shipboard," the Standards Committee now submits these rules to the Sectional Committee on Standards for Electrical Installations on Shipboard for consideration.

The report of the Subcommittee of the Protective Devices Committee on Automatic Substations was received and ordered printed as a report for comment and criticism. The report of Working Committee No. 29 on Standards for Electrical Measur-

ing Instruments was ordered submitted to letter ballot. The result of the letter ballot of the Committee on the report of the Sectional Committee on Standards for Hard Drawn Aluminum was reported and the Standards Committee submitted this report to the Board of the Institute for approval and adoption.

A. I. E. E. Branch at College of Engineering, Newark Technical School

A new Branch of the A. I. E. E. has been formed at the College of Electrical Engineering of the Newark (N. J.) Technical School. The officers of the Branch are: H. G. Patton, Chairman; Edward Bush, Vice-Chairman; Robert Meyer, Treasurer; C. H. Clarendon, Jr., Secretary; and Prof. J. C. Peet, Councilor.

Two meetings have been held since the authorization of the Branch, October 15. On October 20 two papers were presented: *Mineral Wool*, by W. Condit, student, and *The Great Men of Electricity*, by S. Fishman, student. On November 3, F. E. McKone of the faculty spoke on the subject of aerodynamics and F. R. House of Sperry Gyroscope Company gave an illustrated lecture on *Electrification of Air Ways.*

AMERICAN ENGINEERING COUNCIL

MEETING OF ADMINISTRATIVE BOARD

Meeting at Cornell University November 11-12, 1926, with its president, Dean Dexter S. Kimball, the Administrative Board of American Engineering Council weighed several of the outstanding national engineering problems. Important among its actions were decisions to assist in minimizing the volume of corporate reports, to assist in the Hoover plan for the development of a national policy for water resources, to sponsor a standardization program for street and highway safety signals, to continue its prosecution of the effort to secure a National Department of Public Works and Domain, to make further study of the proposed Standard State Mechanics Lien Act, to regularize patent procedure and urge a more adequate patent office building.

Recognizing the burden and high cost annually saddled upon industry by demand for data for the Federal and State Governments, the Board took its first step in cooperating with the National Association of Manufacturers and other bodies to minimize this waste. Plans were also laid for suitable coordination and simplification of these data and reports, so that the data collected could be used by all governmental agencies and be made available in a larger way to outside organizations. Reports to the Board brought out the fact that though much data had been assembled for special purposes, it was seldom useful in other studies even though they might be related to the original subject for which the data were gathered.

Endorsement of the plan of Secretary Hoover for a national policy in the development of the water resources of the country was enthusiastically given together with a pledge of the active support of the Council in carrying out this plan. The Secretary's plan includes more extensive development of inland waterway transportation, irrigation, reclamation, flood control, power, and a suitable federal organization to handle all of this work. The plans of Secretary Hoover harmonize closely with three pieces of national legislation now being endorsed by American Engineering Council; namely, the bill proposing an inventory of the water resources of the country, the bill which would establish a national hydraulic laboratory, and the National Department of Public Works bill.

As an outgrowth of American Engineering Council's work in the National Conference on Street and Highway Safety, a special committee on Street Signs, Signals and Markings was authorized and directed to secure the necessary funds in cooperation with other interested organizations so that it may prosecute a nationwide study of the whole problem. Determination of the present practises relating to size, shape, color, illumination and location will be involved. The relative merits of manual or automatic methods, location of signs, etc., will be included. The appointment of a committee of engineers who have been prominent in this field was authorized to carry on the work.

The report of a committee of organization experts who have been making a special study of a suitable internal organization for the proposed Department of Public Works was adopted in so far as it had been completed. The study, which has been in progress for over a year, has covered all of the engineering and public domain functions of the Federal Government and resulted in recommendations that the following offices be included in the proposed department: from the Department of the Interior—Geological Survey, Bureau of Reclamation, The Alaska Railroad, National Park Service, General Land Office; from the Department of Agriculture—The Bureau of Public Roads; from the War Department—Board of Road Commissioners for Alaska, Alaska Telegraph and Cable System, Northern and Northwestern Lakes Survey, and the non-military river and harbor work of: Office of Chief of Engineers, Board of Engineers for Rivers and Harbors, Mississippi River Commission, California Debris Commission, and Supervisor of the Harbor of New York; from the Treasury Department—the Office of the Supervising Architect; also the following independent offices, commissions, etc.,—Federal Power Commission, Office of Public Buildings and Public Parks of the National Capital, Departmental Services for Maintenance and Operation of Buildings, and the Office of the Architect of the Capital. The layout for the new department will be completed and submitted as a part of this report.

The Administrative Board went on record as being definitely opposed to the extension of the time limitation on patents and the enactment of any special patent legislation for the benefit of individuals. Those in charge of the present buildings program for the United States Government were urged to provide better housing facilities for the United States Patent Office out of the $50,000,000 appropriation available for Federal Government Buildings in the District of Columbia.

The general subject of compensation of professional engineers was widely discussed as the result of a report to the Board. This report stated that because of the major purpose of American Engineering Council to "support movements affecting public welfare when from an economic viewpoint such movements are believed to be worthy of support," it was the opinion of Council's Committee on Compensation of Engineers that Council should not enter into the field of discussion as to the compensation which professional engineers should receive. According to the report, the "solution is wholly an internal problem of the profession calling for no publicity but self-examination and criticism."

A further study of the Standard State Mechanics Lien Act, which was developed under the auspices of the department of Commerce, will be made by a special committee of council, appointed for that purpose.

A cordial welcome was extended to the Board by Dr. Farrand, President of Cornell University, and Dean Kimball, President of American Engineering Council. The next meeting of the Board will be in conjunction with the Annual Meeting of American Engineering Council, to be held in Washington, D. C., January 13-15, 1927, at The Mayflower.

The Sterling Fellowships for Research

For the academic year 1927-28, Yale University again announces the Sterling Fellowships for Research, previously mentioned in the January 1926 issue of the Institute's JOURNAL.

The Fellowships are divided into the two general classes of Research or Senior Fellowships and Junior Fellowships, candidates for the first restricted to those holding a Ph.D degree or an equivalent of the experience in Research which it indicates; the Junior Fellowships taking only those well advanced in work

toward the Ph.D. degree. Applications should be addressed to the Dean of the Graduate School of Yale University, New Haven, Conn., on blanks obtainable upon application. All applications must be submitted by March 1.

Bureau of Standards 25th Anniversary

Twenty-five years of successful scientific research work will be celebrated by the twenty-fifth anniversary of the Bureau of Standards, Department of Commerce, on Saturday, December 4, 1926, when the Bureau will keep "open house" and give a banquet at which its many friends may meet the staff and reminisce with them regarding the achievements of the last quarter century, as well as discuss the present and future work. A group of distinguished guests will attend. The event is of interest to the world of science as well as to the industrial experts who have worked so closely in cooperation with the Bureau, in turn making application of its discoveries and developments in perfecting the measured control of processes.

The Bureau will extend a welcome to its many friends and take pleasure in affording them this opportunity to inspect its experimental research facilities.

Business Historical Society Preserving Documents

Engineers will be interested to know of the foundation of the Business Historical Society, incorporated in 1925, the purpose of which is to encourage and aid the study of evolution of business in all periods in all countries.

The Harvard Business Library has become the depository of the society's collections. Among the material which the society wishes to collect are the data on early railroading, money and banking, commerce, and economics statistics.

It is planned to use every effort to increase the original data so that facilities for research and study may be constantly promoted.

A. S. T. M. Tentative Standards Now Available

The 1926 edition of A. S. T. M. TENTATIVE Standards, issued annually, is now available. This volume comprises 1100 pages and contains 227 Tentative Standards as follows:

33	relating to	Steel, Ferro-Alloys and Wrought Iron
20	" "	Non-Ferrous Metals
22	" "	Cement, Lime, Gypsum and Clay Products
15	" "	Preservative Coatings
22	" "	Petroleum Products and Lubricants
49	" "	Road Materials
2	" "	Coal and Coke
6	" "	Timber
16	" "	Waterproofing
11	" "	Insulating Materials
4	" "	Shipping Containers
3	" "	Rubber Products
10	" "	Textile Materials
3	" "	Slate
11	" "	Miscellaneous

The Standards and Tentative Standards of the American Society for Testing Materials are recognized as authoritative in the field of engineering materials. The term "Tentative Standard" as distinguished from "Standard" is applied to a proposed standard which is printed for one or more years with a view of eliciting criticism of which the committee concerned will take due cognizance before recommending final action toward the adoption of such tentative standards by formal action of the Society.

The volume is available at the price of $7.50 in paper and $8.50 in cloth binding and may be obtained by addressing C. L. Warwick, Secretary A. S. T. M., 1315 Spruce St., Philadelphia, Pa.

New Radio Stations Established

Sixty-three new radio broadcasting stations and 62 changes in wavelengths have been reported between July 1 and October 15 to the Department of Commerce by its radio supervisors in the nine radio districts of the United States.

According to officials, practically all of the 62 wavelength changes were made presumably because of the lack of restriction and regulation of radio broadcasting brought about by the Attorney General's decision divesting the Department of Commerce of regulatory control and by the failure of Congress to enact radio legislation at the last session.

Of the 62 changes in wavelengths, most are said to be from the old Class A wavelengths below 280 meters to wavelengths in the former Class B band, ranging from 280 meters to 545 meters.

Work in Accident Prevention Praised

Representatives of several industries interested in accident prevention were told recently by Ethelburt Stuart, Commissioner of Labor Statistics, that while the casualty companies were doing valuable work in accident prevention in the compilation of statistics, there was further opportunity for improvement in the usefulness of these statistics by basing accident rates upon hours of exposure to employes. At present accident statistics are based for the most part upon volume of payrolls, so that a much lower rate is figured when wages and accidents are high than when wages are lower and accidents fewer.

Mr. Stuart further stated that he wanted to point out to all interested in accident prevention that what the State and Federal Governments want in the way of accident statistics is within the power of industrial companies to supply even though present methods of compiling such statistics might not give, in every instance, the direct information desired.

Important Engineering Subjects for Next Congress

Congress will reassemble at noon on Monday, December 6th, faced with a program including passage of all of the big appropriation bills, a plan for disposition of alien property, varying proposals for tax reduction, the disposal of Muscle Shoals, radio legislation, the Federal Judges Salaries Bill, Public Works legislation, Rivers and Harbors bill, the survey of the water resources of the country, regulation of the coal industry, railroad consolidation, etc. In many of these pieces of legislation, American Engineering Council and its constituent organizations are greatly interested. Since the session will be restricted to approximately ten weeks of actual legislative work, intensive effort will be necessary to show any real accomplishment.

Supervisory Control Safety System for Hudson Tunnel

An electrical protective system based on the supervisory control system developed for railway and power stations and modified to meet the particular conditions of the tunnel will insure super-safety to the Holland Vehicular Tunnel between New York and New Jersey. The new vehicular tunnel is to have the most elaborate provisions for safety of any place in the world. Three kinds of traffic signals will direct motorists—green for "go-ahead"; red for "stop" with a special "stop-engine" signal beside. These lights will be spaced 240 ft. apart. Traffic officers every 480 ft. will patrol the tunnel and for each

officer there will be a traffic light control station and telephone. A board located in the administration building in New York and carrying 926 pilot lights will inform a central operator of everything going on within the tunnel enabling him to take full charge of any situation at any time. All changes in the traffic lights made by the traffic officers will be registered in the control room, and, if necessary, the central operator, himself, will be able to stop traffic at any desired point. When this happens, however, the traffic officers in the tunnel cannot reset the signals; but this can be done by the central operator only. The tunnel will be illuminated by lamps every 20 ft. except at the entrances where they will be placed every 10 ft. to help in counteracting daylight. Each lamp is placed in an enameled reflector set into the wall and screened with a special frosted glass panel.

Army Engineers Oppose Ocean-To-Lakes Ship Canal

It was stated orally October 29, that, through the Chief of Engineers of the Army, the Department of War will report to Congress against the proposal of an all-American ship canal across the State of New York to connect the Great Lakes and the Atlantic Ocean through the Hudson River and New York Harbor.

For some months the Board of Engineers has been holding hearings on the matter and following the decision against the proposal, information was sent according to law to approximately 100 witnesses who testified in favor of the proposed all-American canal.

No announcement, it was stated orally at the Department of War, has been made officially from the office of the Chief of Engineers in Washington. The first official announcement will be the report to Congress.

Muscle Shoals Fight in Next Congress

Effort to reach a decision as to the disposal of Muscle Shoals will be one of the outstanding issues of the approaching session of Congress. Since those favoring Government ownership will probably be augmented in the 70th Congress, advocates of sale to private parties are preparing to bring about a final vote before the session ends March 4th, 1927. On the other hand, the Government operation advocates will make a determined fight to prevent a vote until the next Congress. Senator Deneen, Republican of Illinois, Chairman of the committee, will seek passage of the bill and Senator Norris of Nebraska will direct the opposition.

Significant in connection with this legislation is the Boulder Canyon Bill which proposed to provide for a gigantic development of the Colorado River by the Government. Proponents of Government operation feel that if this can be gotten through it would be a precedent for Government Operation of Muscle Shoals.

Air-Cooled Engine Airplane Successfully Tested

The Navy Department announces that a Navy Curtiss airplane equipped with a new Pratt-Whitney 400-h. p. radial air-cooled engine has just completed a test flight from Washington to San Diego and back without mishap or delay.

It was thoroughly inspected and tested at San Diego before returning to Washington by way of Seattle, Salt Lake City and Dayton. The total flying time for the round trip was about 65 hr., covering a total of approximately 7000 mi.

Air Rules Discussed

A recent announcement from the Assistant Secretary of Commerce for Aeronautics, William P. MacCracken, Jr., shows that the seven conferences which were contemplated by the Department have been held and have assured "mutual cooperation by the Department and commercial operators, manufacturers, and insurers."

The work of the air registration and inspections, as discussed during the series of conferences, will be divided into four classes, as follows: Registration and inspection of commercial or industrial aircraft, licensing of pilots and mechanics, rating of air navigation facilities and air traffic rules.

The registration of aircraft will be divided into three classes: Private aircraft engaged in no commercial work; industrial aircraft, and transport aircraft; planes to be subject to inspection from time to time regardless of the annual inspection.

The license of a pilot will be good until revoked for cause, subject to semiannual physical examinations and minimum flying requirements, while the license for aircraft will remain in force for a period of one year. No pilot will be permitted to operate a registered plane without first being licensed by the department. He will be given a physical and professional examination before the license is issued.

ENGINEERING FOUNDATION

PROGRESS IN TESTING EXPERIMENTAL DAM

From time to time progress reports have been issued with regard to the testing of the experimental dam erected at Stevenson Creek, California. A recent interesting report from Engineering Foundation gives results obtained to date. The dam was completed June 4, the progress work involving the testing of concrete to an average strength of 2000 lb. at 28 days, or 10 per cent more than the 1800 lb. desired. Tests with the reservoirs filled to a certain level and then emptied were made more or less continuously from July 12 to September 22, the depth of the water varying by intervals of 10 ft. from 20 ft. to the total 60 ft., and most of them at night when temperature changes were minimum. At present the testing proper has been stopped and the staff is busy interpreting observations.

PERSONAL MENTION

R. F. Carbutt, Engineer, Henry L. Doherty & Co. has also become an officer of the Metropolitan Section of the American Electric Railway Association November 5, 1926, as its 1st vice president.

Harold W. North is now employed as a technical assistant in the Department of Personnel and Statistics, Brooklyn Edison Co., having resigned his position with the Duquesne Light Company of Pittsburgh on Oct. 15th.

L. Burbridge, president of R. A. Lister & Co. Inc., announces that his company's business will combine with Peet & Powers, Inc., under the joint supervision of their respective directors and Mr. Burbridge's own surveillance.

T. R. Langan, manager of transportation, Westinghouse Electric & Manufacturing Co. was chosen president of the Metropolitan Section of the American Electric Railway Association at its meeting of November 5, 1926.

R. A. Manwaring formerly with Dwight P. Robinson & Co., has resigned to accept the position of Secretary and Treasurer of the Philadelphia Electrical & Manufacturing Company. Mr. Manwaring will succeed Mr. C. L. Bundy, who has held this position since 1906.

R. M. Bayle will be service manager in charge of the new Fairmont Service Station of the Westinghouse Electric and

Manufacturing Company with headquarters at Fairmont, W. Va. Mr. Bayle was previously with the home office at East Pittsburgh as supervising field engineer.

Henry O. Diefendahl, on November 1, 1926, accepted a position with The American Fire Prevention Bureau, Inc., New York City, as supervising engineer. Mr. Diefendahl has previously taught in the New York Electrical School, but he is now giving up his teaching work to enter the practical field.

William G. Angermann, who, for the past two years has been Instructor in Electrical Engineering at Cornell University, has been appointed Instructor in Electrical Engineering at the University of Southern California, where he will start work this fall. He will have charge of the Electrical Engineering courses for juniors.

Clarence G. Hadley has given up his position as superintendent of the Municipal Electric Properties of Rochester, Minn., to take charge of the Central Heating and Power Plant which is now being designed by Ellerbe & Co., architects of St. Paul. This plant will supply light, water, heat and power to the various buildings belonging to the Mayo Clinic and Kahler Corporation.

J. C. Somus, who for approximately three years has been schedule engineer in the office of the chief engineer, Duquesne Light Company, Pittsburgh, Pa., in charge of production and improvement budget, and also doing valuation engineering for the company, resigned November 1st to engage in similar work for the Pennsylvania Water and Power Co., Baltimore, Md.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street, New York.

All members are urged to notify Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, accuracy of mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—J. M. Andress, 55 Hanson Place, Brooklyn, N. Y.
2.—J. A. Arcaute, 85 Pleasant St., Claremont, N. H.
3.—E. A. Aspnes, 260 W. 6th St., St. Paul, Minn.
5.—Matthew M. Becker, Public Serv. Prod. Co., 54 Park Place, Newark, N. J.
6.—R. L. Bertolacci, 2937 S. Normandie Ave., Los Angeles, Calif.
7.—Lincoln Bouillon, 731—21st Ave. N., Seattle, Wash.
8.—F. D. Burr, 378 S. Corona St., Denver, Colo.
9.—Andres R. Conde, 505 S. 5th Ave., Maywood, Ill.
10.—J. E. Contesti, 352 W. 58th St., New York, N. Y.
11.—Edward A. Crosse, 319 W. 89th St., New York, N. Y.
12.—Earl E. Deitrich, 922 N. Payson St., Baltimore, Md.
13.—John C. Donahue, 1601 N. 8th St., Tacoma, Wash.
14.—I. H. El-Kordi, Royal Consulate of Egypt, 103 Park Ave., New York, N. Y.
15.—John C. Fretz, N. Y. & Queens Elec. Lt. & Pr. Co.. Bridge Plaza, Long Island City, N. Y.
16.—L. M. Gamble, 1829 Decatur St., Brooklyn, N. Y.
17.—Wm. F. Gilman, Belgrade Lakes, Me.
18.—Newman D. Gray, 41 Sanford St., St. Augustine, Fla.
19.—H. A. Hallead, 53 W. Jackson Blvd., Chicago, Ill.
20.—Edward C. Hanson, Box 59, Pinelawn, N. Y.
21.—A. Hirth, 519 Lincoln Pl., Brooklyn, N. Y.
22.—D. Brainerd Jones, 131—25th St., Jackson Heights, N. Y.
23.—Daniel Jund, 1194 Sherman Ave., Bronx, New York, N. Y.
24.—Eric Kjellgren, 145—13th St., Milwaukee, Wis.
25.—Otto U. Lawrence, Avenue A., Bound Brook, N. J.
26.—Archie L. Lewis, 1609½—11th St., Sacramento, Calif.
27.—Akos Ludasy, P. O. Box 1841, Chicago, Ill.
28.—A. W. Manby, 438 John St., Niagara Falls, Ont.
29.—A. W. Mann, Haines City, Fla.
30.—W. W. Marshall, 106 S. Portland Ave., Brooklyn, N. Y.
31.—Eugene Messinger, Otis Elevator Co., 26th St. & 11th Ave., New York, N. Y.
32.—Stafford Montgomery, Riverside, Ill.
33.—J. N. Mullen, 63 Boutelle Road, Bangor, Me.
34.—Syed Mustafa, Box 1194, Indianapolis, Ind.
35.—Anders Oxehufwud, 222 Genesee St., Utica, N. Y.
36.—F. H. Parker, 8112 Sixth Ave., Brooklyn, N. Y.
37.—Harry D. Ramsay, 1424 Felicity St., New Orleans, La.
38.—Alwin Schmidt, 251 W. 95th St., New York, N. Y.
39.—E. J. Schouw, 775—27th St., Milwaukee, Wis.
40.—Paul H. Schulz, 332—35th St., Milwaukee, Wis.
41.—Bartolomeo Scola, 227 Ave. U, Brooklyn, N. Y.
42.—Wm. E. Seamen, 1253 Leland Ave., New York, N. Y.
43.—Clifford S. Sharp, 9 Seymour Ave., Jamestown, N. Y.
44.—Bertrand Smith, W. E. & M. Co., 3451 E. Marginal Way, Seattle, Wash.
45.—Oliver Smith, 1324 State St., Schenectady, N. Y.
46.—Angelos A. Spilios, 572 Ocean Parkway, Brooklyn, N. Y.
47.—Edw. G. Stone, Cassel, Shasta Co., Calif.
48.—Frederick L. Suttle, 20 Seventh Ave., New York, N. Y.
49.—E. A. Swiedom, 231 McClellan St., Schenectady, N. Y.
50.—L. H. Thullen, Machinery Club, 50 Church St., New York, N. Y.
51.—Herman A. Tischer, 3801 Montgomery Road, Norwood, Cincinnati, Ohio.
52.—James A. Weddell, General Delivery, Mansfield, Ohio.
53.—Brian Wheeler, Westinghouse Club, Wilkinsburg, Pa.
54.—Chas. W. Whitall, 340 Edwards Court, Bayonne, N. J.
55.—Geo. F. Whitworth, Geo. F., Hotel Carleton, Berkeley, Calif.

Obituary

Alexander E. Keith, Chief Engineer of the Automatic Electric Company, Chicago, and Fellow of the Institute since 1913, died at his home, Hyde Park Boulevard, September 24th, following a brief illness with pneumonia. He had just returned to Chicago from his summer home in Wisconsin, preparatory to spending the winter in Texas.

Mr. Keith was a native of Baltimore, Md., and his early education was acquired in the public schools of that city; his technical training was largely a matter of personal study during the prosecution of his own work, but his rise in the profession was rapid. Starting as a messenger boy of the Baltimore and Ohio Railroad in 1874, Mr. Keith, in two years' time had advanced to telegraph operator, B. & O. Express. In 1877 he engaged with the American Bell Telephone Company, until 1886 being associated with its subsidiary companies in Baltimore, Nashville, Tenn., Philadelphia, New York and Washington in varying and responsible capacities. In 1886 he was sent to Venezuela by his company to care for telephone and electric light work, but he returned in 1889 to become superintendent of the Brush Electric Company, Baltimore, Md., until 1892. Then the Automatic Electric Company was organized to continue the business previously carried on by the Strowger Automatic Telephone Exchange and Mr. Keith was made chief engineer. He remained the engineer in charge of development of the automatic telephone exchange apparatus for over 20 years. The United States patents and 34 unissued applications are to his credit, the two most notable of his productions being the plunger type of line switch and the present arrangement of automatic central office trunks.

Mr. Keith joined the Institute in 1912 and was elected a Fellow the following year.

Hazen Greeley Tyler, Professor of Experimental Engineering

in the College of Engineering and Director of the evening Engineering Division of New York University, died October 27, 1926, following an operation.

Dr. Tyler was born in Brooklyn, N. Y., March 21, 1890. He attended the Brooklyn public schools and the Polytechnic Institute, from which he was graduated in 1911 with the Electrical Engineering degree. Remaining at the Institute as an assistant in Mechanical Engineering until 1916, he received his M. S. degree in 1912 and M. E. in 1913. During this same period he was studying at the New York University and in 1916 he received its degree of D. Sc. He then went to Rensselaer Polytechnic Institute for a year as instructor in Mechanical Engineering. October 1917, Doctor Tyler was chosen Assistant Professor of Mechanical Engineering at the New York University, in 1921 he was made Associate Professor in Mechanical Engineering and in 1924 he was made Associate Professor of Experimental Engineering.

He was a member also of The American Society of Mechanical Engineers, the Society for the Promotion of Engineering Education and the American Physical Society.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is adminstered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (OCT. 1-31, 1926)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

CAST IRON FOR DIESEL ENGINES.

By A. Campion. Lond., E. & F. N. Spon, 1926. (Reprint of paper read before The North East Coast Institution of Engineers and Shipbuilders, January 22, 1926). 27 pp., illus., diagrs., 10 x 6 in., paper. 3s 6d.

The unusual conditions of temperature and stress to which oil engines are subjected have given rise to much trouble with cast-iron parts. The present pamphlet discusses the effect of these conditions upon the strength, growth, hardness and structure, the metallurgical principles which must be applied in determining the type of iron to be used for the various parts of the engine, and the factors concerned in the production of metal which will retain its strength at the temperatures encountered, will not change in shape or size and will resist abrasion.

CHEMICAL ENGINEERING CATALOG, 1926.

N. Y., Chemical Catalog Company, 1926. 1175 pp., illus., 12 x 9 in., fabrikoid. Purchase price, $10.00. Leasing fee, $2.00 in U. S.: $3.50 in Canada and European countries.

This useful catalog again appears in its 11th edition and gives to chemical engineers, works managers and purchasing agents the information on equipment, supplies and materials, which they frequently need, in convenient reference form.

The classified directory section contains listings of more than 2000 manufacturers, and the technical and scientific books section includes practically all available chemical books in the English language. The entire catalog has been carefully revised.

ELECTRICAL MACHINE DESIGN.

By Alexander Gray, revised by P. M. Lincoln. 2d edition, N. Y., McGraw-Hill Book Co., 1926. 523 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

The reviser has retained Professor Gray's presentation of fundamental principles and his methods of analysis without modification. He has taken account of the development that has occurred in electrical machinery in the past fourteen years and has modified the example machines so that they represent current designs and changed the various curves, tables, illustrations and other data to conform with present practise.

ELEMENTS OF HEAT-POWER ENGINEERING, v. 1; Thermodynamics and Prime Movers.

By William N. Barnard, Frank O. Ellenwood and Clarence F. Hirshfeld; 3rd edition. N. Y., John Wiley & Sons, 1926. 493 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.50.

This is a new edition of the portions of Hirshfeld and Barnard's Elements of Heat-Power Engineering which relate primarily to thermodynamics and the elementary principles of prime movers. In preparing it the authors have found it necessary to rewrite practically all of the text, in order to incorporate new methods of treatment and to include new material. The new edition is intended as a text for a full year of instruction, and the authors also believe that it will be of interest to practising engineers as an account of recent notable advances in this field.

ELEMENTS OF RADIO COMMUNICATION.

By Ellery W. Stone. 3rd edition. N. Y., D. Van Nostrand Co., 1926. 433 pp., illus., diagrs., 8 x 6 in., cloth. $3.00.

This textbook, written originally for radio students in the U. S. Navy, attempts to present the subject from the physical rather than the mathematical point of view, without sacrificing accuracy. The book is written for laymen, with no previous knowledge of the subject.

The third edition has been thoroughly revised and new material has been added.

DER GENAUIGKEITSGRAD VON FLUGELMESSUNGEN BEI WASSERKRAFTANLAGEN.

By A. Staus. Berlin, Julius Springer, 1926. 35 pp., illus., diagrs., tables, 9 x 6 in., paper. Price not quoted. (Gift of Dr. A. Ott).

The current meter is almost universally used for measuring water powers in continental Europe, while in this country and England other methods are generally preferred. This variance in custom has led Dr. Staus to investigate the accuracy of the current meter, in order to ascertain what justification there may be for our distrust of them.

His monograph first systematically discusses all the possible ways in which errors in measurement may arise, through the selection of the point of measurement, the plotting of the profile, the meter itself, the time measurements, the method of measuring the velocity, and the calculation of results. Various improvements are suggested. At the close the degree of accuracy obtainable with current meters is reviewed. A very thorough bibliography is included.

DIE GETRIEBEKINEMATIK ALS RUSTZEUG DER GETRIEBEDYNAMIK.

By Friedrich Proeger. V. D. I. Verlag. 1926. (Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, heft 285). 74 pp., diagrs., 10 x 7 in., paper. 6 m. 70 pf.

The study of kinematics has first become of considerable importance in practice during recent years, when it has proved helpful in solving many dynamic problems. A number of graphic processes have been developed here, but they have been adapted only for the specific problems. The present work is intended to show that a solution of dynamic problems in general can be obtained.

In the first part of this book the author treats of the principles of the kinematics of gearing. A systematic classification of gears permits a further schematic treatment of the speeds and accelerations of the individual gear points, and the graphic processes necessary for this are explained in detail.

In the second section this knowledge of the kinematics of gearing is applied successfully to the solution of important general problems in their dynamics, and makes possible, according to the author, reductions in the mass of the gear links without harm.

HANDBOOK FOR PROSPECTORS.

By M. W. von Bernewitz. N. Y., McGraw-Hill Book Co., 1926. 319 pp., illus., 7 x 5 in., fabrikoid. $3.00.

The first part of this book gives advice on equipment, transportation and mining laws. The second part contains elementary information on geology, ore deposits, prospecting, sampling, testing, developing prospects. The third part consists of brief notes on the occurrence, detection and uses of the various minerals, both metallic and non-metallic.

The book covers concisely the topics upon which the prospector is most likely to wish information. The author has had long experience as a miner and metallurgist.

INDUSTRIAL SAFETY ORGANIZATION FOR EXECUTIVE AND ENGINEER.

By Lewis A. De Blois. N. Y., McGraw-Hill Book Co., 1926. 328 pp., illus., tables, 9 x 6 in., cloth. $4.00.

This is an attempt to deal intimately and at length with the basic principles of safety organization. It summarizes, in a way, the profuse amount of information scattered through periodicals, codes, rule books, bulletins, etc., and presents a connected account of the subject. The author writes from the background of fourteen years of accident prevention work in the du Pont Company.

LABORATORY MANUAL OF TESTING MATERIALS.

By William K. Hatt and H. H. Scofield. 3rd edition. N. Y., McGraw-Hill Book Co., 1926. 182 pp., tables, 8 x 5 in., cloth. $2.00.

This manual, which is based on long experience in testing and in teaching, attempts to show the student the technological purpose of various tests, train him in the technique of testing and give him some knowledge of materials. It also endeavors to develop his critical faculties.

The third edition reflects recent changes in standard methods and shifts the emphasis upon the several experiments. Some changes of omission and addition have been made.

MACHINE DESIGN.

By Louis J. Bradford and Paul B. Eaton. N. Y., John Wiley & Sons, 1926. 249 pp., illus., diagrs., tables, 9 x 6 in., cloth. $2.75.

An unusually brief textbook, intended for use in courses where time is limited. The objects sought are to ground the student in the fundamental facts and processes; to train him to analyze problems, recognize the principles involved and apply sound methods of solution; and give him a general knowledge of good practice. The book is designed to be covered in about twenty-five lessons and is intended to teach the use of data rather than to be a source of data.

MATHEMATICAL AND PHYSICAL PAPERS, 1903-1913.

By Benjamin Osgood Peirce. Cambridge, Harvard University Press, 1926. 444 pp., illus., port., diagrs., tables, 9 x 6 in., cloth. $5.00.

The twenty-one papers here assembled appeared originally in the *Proceedings of the American Academy of Arts and Sciences* or in the *American Journal of Science*. They include practically all those published by Professor Peirce during the last ten years of his life, and this republication will be welcome to many scientists. A bibliography of Professor Peirce's writings is included.

MODERN HARBORS; Conservancy and Operations.

By E. C. Shankland. Glasgow, James Brown & Son, 1926. 244 pp., illus., maps, 9 x 7 in., cloth. 21 s.

Commander Shankland, Chief Harbor Master and River Superintendent of the Port of London, here presents the data on navigation, seamanship and conservancy, as they relate to the functions of modern harbors, which he has derived from his wide experience and from visits to the principal harbors of the world. Beginning when the ship gets in communication with the harbor authorities, he follows her course until she is safely docked, describing proper methods of navigation through the waterway, mooring, anchoring, etc. He discusses in detail such topics as wireless, subaqueous and visual signals, pilotage, anchorages, moorings, salvage in harbors, buoying and lighting. A large section is devoted to conservancy, including the preservation of estuaries, harbor charting and sewage in tidal rivers. There are also chapters on oil in waterways, meteorology in harbors, aviation in harbors and life saving stations.

OCEAN MAGNETIC AND ELECTRIC OBSERVATIONS, 1915-1921. (Researches of the Dept. of Terrestrial Magnetism, v. 5).

Wash., D. C., Carnegie Institution of Washington, 1926. 430 pp., illus., maps, tables, 12 x 9 in., cloth. $7.25.

This book, the second on ocean magnetic and electric observations, gives the final results of those made aboard the non-magnetic ship "Carnegie" in the Atlantic, Indian, Pacific and Southern oceans during 1915-1921. These are given in two reports on magnetic results, by J. P. Ault, and on atmospheric-electric results, by J. P. Ault and S. J. Mauchly. Appended are special reports on: the Hudson Bay expedition, 1914, by W. J. Peters; the navigation of aircraft by astronomical methods by J. P. Ault; the compass-variometer by Louis A. Bauer, W. J. Peters and J. A. Fleming; the sunspot and annual variations of atmospheric electricity with special reference to the "Carnegie" observations, 1915-1921, by Louis A. Bauer; and Studies in atmospheric electricity based on observations made on the "Carnegie," 1915-1921, by S. J. Mauchly.

SCIENCE AND LIFE; Aberdeen addresses.

By Frederick Soddy. N. Y., E. P. Dutton & Co., [1926.] 229 pp., 9 x 6 in., cloth. $4.00.

These papers by the eminent investigator of radioactivity were first published in 1919. They consist chiefly of addresses delivered during his years at Aberdeen University, and two themes run through them; the significance and importance of radioactivity, and the need of more and better facilities for teaching science. Dr. Soddy's papers are readable, and interesting to a wider audience than one of specialists.

UNTERSUCHUNGEN UBER DIE GESCHIEBEABLEITUNG BEI DER SPALTUNG VON WASSERLAUFEN.

By Hermann Bulle. Berlin, V. D. I. Verlag, 1926. (Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, heft 283). 34 pp., illus., diagrs., 10 x 7 in., paper. 5 marks.

This pamphlet reports the results of extensive investigations on models, undertaken at the Karlsruhe Hydraulic Laboratory, on the manner in which detritus is divided and deposited when a water course branches in various ways. The matters investigated include the explanation of the processes of flow; inquiry into the effect of the size of the branch angle upon the distribution of the water and detritus, and of the effect of the division of the detritus upon that of the water; a fundamental determination of the influence of a rounding off of the entrance into the branch channel and of the influence of various cross-sections of the branch channel below the separation.

The investigations showed that, when a water course branches from a straight channel, considerably the greater part of the detritus enters the branch and deposits just below the point of separation, forming a large bar. If the cross-sections of the two resulting channels and the amounts of water entering them are almost equal, the side branch receives from 90 to 95 per cent of the material deposited in both, a result that can not be explained by the law of transportation.

VERSTARKUNG, UMBAU UND AUSWECHSELUNG VON EISENBAHNBRUCKEN.

By K. Schaechterle. V. D. I. Verlag. 1926. 160 pp., illus., diagrs., tables, 12 x 9 in., cloth. 20 marks.

The increasing weight of locomotives and road vehicles has made it necessary to strengthen many railroad and highway bridges in recent years. Periodicals have frequently described such work, but the present book is apparently the first to collect the methods that have been used and examine them critically.

After some remarks on the historical development of the railroad bridge the author reviews the increase in moving loads,

axle pressures, etc. The calculation of the strength of old and new bridges is discussed as well as the effect of heavy service on existing bridges. Economic considerations concerning strengthening and general lines of procedure in planning such work are laid down.

A second section describes the various methods in use. A third section is devoted to methods for replacing iron bridges which cannot be strengthened with economy, and a fourth with the replacement of truss bridges by arches. The concluding section is devoted to the strengthening of piers and foundations.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Inspection Trip to the Plant of the Timken Roller Bearing Company in Canton. October 16. Attendance 75.

Boston

Cambridge Street Automatic Edison Station of The Edison Electric Illuminating Company of Boston, by W. H. Colburn, W. W. Edson and D. H. Hatheway. October 18. Attendance 175.

Cincinnati

Selectivity of Tuned Radio Frequency Circuits, by Kenneth Jarvis, Crosley Radio Corp. Joint meeting with Institute of Radio Engineers. September 9. Attendance 44.

Modern Laundry Machinery Methods, by J. E. McCarthy, American Laundry Machinery Co. October 14. Attendance 35.

Cleveland

The Application of Carbon Products to Industry, by P. D. Manbeck, National Carbon Co. Illustrated with motion pictures. October 21. Attendance 50.

Columbus

Interconnections in Ohio, by T. J. Williams, The Ohio Power Co. This was accompanied by a motion picture, entitled "Electrified Ohio," and

Cleveland Terminal and Data on Electrical Railways, by W. T. Schumaker, Chief Engineer of J. O. Mills. October 22. Attendance 38.

Connecticut

The History and Future Possibilities of Air Transportation, by T. O. Freeman, Colonial Air Transport Co. October 12. Attendance 60.

Denver

Engineering Education—Some of Its Problems, by H. S. Evans, University of Colorado. Illustrated with slides. October 22. Attendance 24.

Erie

Electrical Manufacturing in Europe, by James Burke, Burke Electric Co. October 19. Attendance 105.

Fort Wayne

Artificial Refrigeration, by A. R. Stevenson, Jr., General Electric Co. Illustrated with slides. A motion picture, entitled "Over the Bounding Main," was shown. November 4. Attendance 70.

Indianapolis-Lafayette

Transmission-Line Costs, by F. H. Miller, Hoosier Engineering Co. October 29. Attendance 27.

Ithaca

The Adirondack Power and Light System, by J. L. Harvey. October 29. Attendance 60.

Kansas City

Electric Welding, by W. M. B. Brady, General Electric Co. Illustrated with slides. October 25. Attendance 43.

Los Angeles

A New 220-Kv. Transmission Line, by H. Michener and C. B. Carlson, Southern California Edison Co., and

Vacuum Switching Experiments, by R. W. Sorensen and H. E. Mendenhall, California Institute of Technology. A dinner preceded the meeting. October 5. Attendance 105.

Present Tendencies in Motor Development, by David Hall, Westinghouse Elec. & Mfg. Co. Illustrated;

Application of Electric Motors to Oil-Well Drilling, by H. H. Anderson, Shell Oil Co. Illustrated with slides, and

Elevator Motors and Control, by H. E. Fuqua, General Electric Co. A dinner preceded the meeting. November 2. Attendance 102.

Lynn

Electricity in Paper Making, by R. G. Rogers, General Electric Co. Illustrated with motion pictures and slides. A buffet luncheon was served. October 20. Attendance 100.

Minnesota

Move it Electrically, by H. S. Greiner, Northern States Power Company;

Chicago Central Station Institute, by C. H. Burmeister and D. Malmgren, students, and

Nela School of Lighting, by Seth Witts, J. C. Brightfelt, N. Ronning, students, and Professor M. E. Todd. Illustrated. Joint meeting with Student Branch at the University of Minnesota. November 1. Attendance 80.

Nebraska

Magic of Communication, by M. T. Castor, Lincoln Telephone and Telegraph Co. November 2. Attendance 34.

Niagara Frontier

Generator Voltage-Regulator Developments, by J. H. Ashbaugh, Westinghouse Electric and Mfg. Co. September 23. Attendance 35.

Management and Standardization, by John Gaillard, American Engineering Standards Committee. Joint meeting with A. S. M. E., S. I. E., Chamber of Commerce, and E. S. B. October 26. Attendance 225.

Philadelphia

Refrigeration, by A. R. Stevenson, Jr., General Electric Co. October 11. Attendance 165.

Pittsfield

A Talk was given by C. C. Chesney, National President, A. I. E. E., who spoke on his trip to the Pacific Coast and Canada. Illustrated with slides. The Pittsfield Section Best Paper Prize was awarded to H. R. West for his paper entitled "The Cross-Field Theory." The Regional Prize was presented to Messrs. E. J. Wade and K. B. McEachron for their paper entitled "The Time Lag of the Needle Gap." November 2. Attendance 700.

Rectification of Alternating Current, by D. C. Prince, General Electric Co. Illustrated with slides. November 9. Attendance 86.

Rochester

Economic and Industrial Aspects of Recent Electrical Experiments, by Guiseppe Faccioli, General Electric Co. Illustrated with slides. Joint meeting with Rochester Engineering Society and Rochester Chamber of Commerce. October 1. Attendance 150.

St. Louis

Changing the Voltage Ratio of Transformers under Load, by L. H. Hill, Westinghouse Electric & Mfg. Co. October 20. Attendance 50.

Saskatchewan

Large Power Transformers, by C. C. Chesney, National President, A. I. E. E. Illustrated by a motion picture, and

Lightning Protection, by K. B. McEachron, General Electric Co. Illustrated by slides. October 4. Attendance 70.

Steam-Turbine Design and Performance, by H. L. King, W. W. Johnson and W. R. Vogel, General Electric Co. October 29. Attendance 18.

Schenectady

Smoker. October 15. Attendance 200.

Waste in Distribution, by H. G. Crockett, of Scobell, Wellington and Co. Joint meeting with Engineering Societies of Schenectady. October 25. Attendance 100.

Educational Opportunities for College Graduates. Symposium by M. L. Frederick, J. D. Harnden, E. E. Johnson, M. M. Boring, C. H. Linder, W. A. Sredenschek and R. E. Doherty, General Electric Co. November 5. Attendance 150.

Sharon

The Penn-Ohio Power System, by C. S. MacCalla, Andrew Carnegie, F. W. Funk, R. W. Graham and H. M. Wood. Illustrated with motion pictures. October 12. Attendance 208.

The Modern Trend in Large Generating Apparatus, by F. D. Newbury, Westinghouse Electric & Mfg. Co. November 9. Attendance 101.

Spokane

Electricity in the Manufacture of Paper, by C. W. Fick, General Electric Co. Illustrated with motion pictures. October 15. Attendance 30.

Springfield

Copper—From Mine to Consumer, by J. C. Bradley, The American Brass Co. Illustrated by moving picture. October 18. Attendance 134.

Toledo

Bond Issues, by F. B. DeFrees. A talk was also given by Mr. W. E. Richards on the Quebec Convention of the Edison Illuminating Society. The following officers were elected: Chairman, O. F. Rabbe; Vice-Chairman, T. J. Nolan; Secretary-Treasurer, Max Neuber. October 15. Attendance 22.

Toronto

Indicating Electrical Measuring Instruments, by J. B. Dowden, Weston Electrical Instrument Corp. October 8. Attendance 70.

The Testing of Thermionic Vacuum Tubes, by J. H. Miller, Jewell Electrical Instrument Co. Illustrated with slides. October 22. Attendance 118.

Urbana

Development of Transmission of Intelligence Since Early Times, by E. B. Paine, University of Illinois. October 14. Attendance 104.

A Report on the Annual Convention at White Sulphur Springs was given by C. A. Keener. October 19. Attendance 14.

Utah

Mexico, by A. W. Ivins. Dance and Banquet. October 19. Attendance 138.

Vancouver

Electricity in Paper Manufacture, by C. W. Fick, General Electric Co. November 2. Attendance 51.

Washington

The Construction of Dirigibles and Their Electrical Control, by Starr Truscott, Bureau of Aeronautics. A dinner preceded the meeting. November 9. Attendance 185.

BRANCH MEETINGS

Alabama Polytechnic Institute

Two films, entitled "The Wizardy of Wireless" and "Revelations by X-Rays," were shown. October 13. Attendance 47.

John A. Brashear—An Autobiography, by J. J. Wilmore. T. J. Lynch, student, gave an account of his last two Summers' work with an electrical contractor. October 20. Attendance 44.

Cable Splicing, by J. B. Davis, student;

Electric Refrigeration, by A. L. Cameron, student,

Summer Work with the Gulf Electric Company, by G. L. Kenny, student, and

The Virginian Railroad Electrification, by Harry Fulwiler, Jr. October 27. Attendance 37.

Electricity as Applied to the Modern Automobile, by C. L. Brown, and

Finance and Banking, by Prof. A. L. Thomas. November 3. Attendance 38.

The Wilson Dam, by R. E. Brown, and

Your Work after Graduation, by Prof. J. C. McKinnon. November 10. Attendance 32.

University of Arizona

Business Meeting. The following officers were elected: President, J. W. Cruse; Vice-President, Tom Davis; Secretary-Treasurer, Audley Sharpe. September 25.

Features of Electrification of Spanish Northern Railway, by Mr. Adkinson, and

Electrolytic Refining of Copper, by Mr. Antillon. October 2.

A New Type of Cold-Cathode Rectifier, by Mr. Collins;

Advantages of the Electric Type of Locomotive, by Mr. Ellicote; and

Facts about Some of the Early Experimenters, by Mr. Gehringer. October 9.

A motion picture, entitled "Bakelite—The Material of a Thousand Uses," was shown. October 16.

Diesel-Electric Power Plants, by Mr. Glascock;

Some Hints on Motor Winding, by Mr. Hopkins; and

Electric-Drive Gasoline Busses, by Mr. Humbert. October 23.

University of Arkansas

Importance of Student A. I. E. E. Membership, by Dean W. N. Gladson. October 12. Attendance 21.

High-Tension Engineering, by Prof. W. B. Stelzner;

Steam Power in Relation to Hydroelectric Power, by Lloyd Rebsman, and

Automatic Railway Signals. October 26. Attendance 20.

Armour Institute of Technology

Business Meeting. October 21. Attendance 60.

California Institute of Technology

Business Meeting. October 7. Attendance 24.

Vacuum Switching, by H. E. Mendenhall, California Institute of Technology. October 22. Attendance 32.

University of California

Engineering Opportunities in Large and Small Corporations, by Roy Phelan, and

Hydraulics, by Prof. H. W. King, University of Michigan. October 13. Attendance 60.

An Inspection Trip to the *U. S. S. Tennessee* was made. October 26. Attendance 360.

Carnegie Institute of Technology

Underground Power Cables, by D. M. Simons, Standard Underground Cable Co. He also spoke on the aims and activities of the A. I. E. E. and of the Relation of the Branch to the National Organization. October 20. Attendance 30.

Case School of Applied Science

Business Meeting. The following officers were elected: Chairman, C. J. Brumbaugh; Vice-Chairman, R. J. Kappanadze; Secretary, E. E. Samson; Treasurer, J. P. Ditchman. October 7. Attendance 20.

The Development and Future of the Electrical Industry in Cleveland, by J. North, Electrical League of Cleveland. November 3. Attendance 41.

University of Cincinnati

Business Meeting. The following officers were elected: President, C. W. Taylor; Vice-President, O. C. Schlemmer; Treasurer, B. J. Roof and Wm. Fife; Secretary, W. C. Osterbrock. October 14. Attendance 22.

Clemson College

Electric Suburban Service on The Illinois Central Railroad, by R. M. Marshall; *White-Way Street Lighting for Small Cities,* by H. L. Baldwin, and *Current Events,* by R. H. Mitchell. November 11. Attendance 25.

University of Colorado

The Importance of Fundamentals Such as Physics in Engineering Work, by Dr. O. C. Lester, University of Colorado, and *Productive Lighting in Industry,* by Lester Simpson. October 20. Attendance 60.

The Development and Use of the Telephone, by Mr. Ketterman, Mountain States Telephone Co. November 10. Attendance 40.

Cooper Union

Two motion pictures, entitled "The Audion" and "Electrical Transmission of Speech," were shown. The following officers were elected: Chairman, H. T. Wilhelm; Secretary, E. T. Reynolds. October 30. Attendance 36.

University of Florida

Superpower Systems in the United States, by Mr. Hearne, Tampa Electric Co. October 18. Attendance 30.

Iowa State College

Business Meeting. October 26. Attendance 20.

Business Meeting. November 2. Attendance 19.

Carnegie Institute of Technology

Behind the Pyramids, by J. T. Green, National Carbon Co. October 9. Attendance 16.

Kansas State College

Automatic Substations on the Pacific Electric Railways, by F. A. Decker, student; *Work with the Wabash Railway*, by J. O. Johnson, student, and *Work in the Signal Department of the Sante Fe Railway*, by E. W. Wichman, student. October 18. Attendance 65.

Experiences with the M. K. T. Railway, by L. K. Willis, student; *Meter-Testing Experiences*, by R. P. Aikman, student, and *Work in the Signal Department of the Frisco Railway*, by Mr. Bradehaft, student. November 8. Attendance 71.

University of Kansas

Short talks were given by seven students on their work during the past Summer with electrical companies. October 21. Attendance 54.

Electrification of the Illinois Central Railroad, by Mr. Dunkelberg, I. C. R. R. Illustrated. November 4. Attendance 68.

Lehigh University

Economics of Education, by O. W. Eshbach, A. T. & T. Co. A talk was also given by L. R. Schreiner, student, on his Summer Experience with The Niagara Falls Power Company. Illustrated. October 21. Attendance 55.

Lewis Institute

Business Meeting. The following officers were elected: President, J. S. Howe; Secretary and Treasurer, O. D. Westerberg. November 9. Attendance 32.

Louisiana State University

Business Meeting. The following officers were elected: President, K. J. Ozment; Vice-President, E. G. Kemp and Secretary-Treasurer, E. P. Athens. October 6. Attendance 21.

University of Maine

Business Meeting. The following officers were elected; President, P. E. Watson; Vice-President, P. D. Lamoreau; Secretary, R. F. Scott; Treasurer, B. T. Poor. October 28. Attendance 14.

Super Regeneration, by Dean Paul Cloke, College of Tech., and *Public Utilities*, by Arthur Davis and H. W. Coffin, Bangor Hydroelectric Co. November 4. Attendance 35.

Business Meeting. November 10. Attendance 14.

Marquette University

Industrial Power Control, by R. G. Lockett, Cutler-Hammer Co. Illustrated with slides. October 14. Attendance 36.

Massachusetts Institute of Technology

The Cambridge Street Station of the Edison Electric Illuminating Company, by three engineers of the Edison Company. An inspection trip was also made to this station. October 18. Attendance 250.

Inspection trip to the plant and high-voltage laboratory of the Simplex Wire and Cable Co. November 2. Attendance 60.

Milwaukee School of Engineering

Business Meeting. The following officers were elected: Chairman, L. H. LaFever; Vice-Chairman, R. J. Snyder; Secretary, W. H. Freisleben; Treasurer, M. W. Setzer. October 26. Attendance 20.

University of Minnesota

Move It Electrically, by H. S. Greiner, Northern States Power Co.;

Chicago Central-Station Institute, by C. H. Burmeister and R. V. Malmgrem, students; *The Nela School of Lighting*, by S. N. Witts, J. C. Brightfelt, N. A. Ronning, students, and Prof. M. E. Todd. A motion picture, entitled "Bringers of Light," was also shown. November 1. Attendance 110.

University of Missouri

The *Aims and Objects of A. I. E. E.*, by Prof. M. P. Weinbach. The following officers were elected: Chairman, V. L. Tiller; Vice-Chairman, C. E. Schooley; Student Secretary, J. L. Egbert; Treasurer, O. P. Minnick; Local Secretary, W. D. Johnson. November 1. Attendance 40.

Montana State College

Electricity to Keep Trains Safe, by R. M. Johnson, and *The New Empire of the Saguenay*, by Robert Harrison. October 7. Attendance 152.

Simple Traffic Signals in Minneapolis, by Melvin Barbour, and *Neon Tubes and the Radio Transmitter*, by E. A. Elge. October 21. Attendance 148.

University of Nebraska

Summer Jobs, by D. J. Fagan, L. A. Kilgore, A. A. Little and L. L. Smith. October 21. Attendance 52.

University of New Hampshire

The Generation of Electric Power, by L. B. Blum, student, and *Distribution and Uses of Electric Power*, by R. F. Burnham, student. October 18. Attendance 39.

Eddy Currents, by S. S. Appleton, and *High-Voltage Insulators*, by C. C. Connor. October 25. Attendance 39.

Automatic Motor Starters, by Mr. Balch, student and *Street Illumination*, by Mr. Dustin, student. November 1. Attendance 37.

College of the City of New York

Business Meeting. October 14. Attendance 14.

New York University

Business Meeting. October 1. Attendance 19.

The Purpose and Operation of Substations, by Henry Och. October 8. Attendance 20.

Effects of the "C" Battery on Amplification in a Radio Set, by Mr. Senanke. October 22. Attendance 18.

University of North Carolina

Business and Social Meeting. September 23. Attendance 68.

Transmission-Line Construction, by R. M. Farmer. October 7. Attendance 38.

Lightning Arresters, by G. M. Wilson, and *Light*, by Professor J. E. Lear. October 21. Attendance 33.

University of North Dakota

Insulated High-Tension Cable, by Ted Giese, and *The Business End of Engineering*, by R. L. Holt. October 4. Attendance 21.

Electricity and Refrigeration, by Mr. Augustodt; *Hydroelectric Development in the West*, by H. Ikelman, and *The Motion-Picture Machine*, by R. Sturtevant. October 18. Attendance 18.

Northeastern University

Business Meeting. October 5. Attendance 47.

The Safety Problem in Electrical Engineering, by T. Penard, Boston Edison Co. November 2. Attendance 51.

University of Notre Dame

Business Meeting. October 25. Attendance 60.

Ohio Northern University

Illumination, by Mr. Hartley. October 21. Attendance 35.

Oregon Agricultural College

Business Meeting. October 12. Attendance 41.

Oklahoma Agricultural and Mechanical College

A talk was given by Mr. Reicer on his Summer experience in the R. O. T. C. and on his visit to Mexico. November 10. Attendance 29.

Oregon State College

Smoker. October 21. Attendance 75.

Pennsylvania State College

Summer Experience Talks were given by M. E. King, R. W. Bauer, E. H. Basehorie, J. C. Fink and G. L. Haller. October 20. Attendance 60.

University of Pennsylvania

Business Meeting. October 8. Attendance 40.

University of Pittsburgh

Business Meeting. The following officers were elected: Chairman, M. G. Jarrett; Vice-Chairman, H. I. Metz; Secretary-Treasurer, D. P. Mitchell. October 1. Attendance 26.

The Engineer of the Future, by C. F. Scott, Yale University. October 8. Attendance 26.

Piezo Electricity, by M. G. Jarrett, student; *Current Transformers*, by D. P. Mitchell, student, and *An Engineer's Love*, by H. I. Metz, student. October 15. Attendance 26.

Purdue University

Development of the Telephone and the Talking Movie, by J. L. Wayne and W. W. Sturdy, American Telephone and Telegraph Co. October 25. Attendance 1100.

Rensselaer Polytechnic Institute

Interconnection and Superpower, by S. Q. Hayes, Westinghouse Electric & Mfg. Co. Illustrated. October 15. Attendance 125.

Rhode Island State College

Business Meeting. October 1. Attendance 19.

Business Meeting. October 6. Attendance 21.

The Power House in Newport, by G. A. Eddy. October 20. Attendance 15.

Enamelled Wire Testing, by H. V. Van Valkenburg, student. October 27. Attendance 17.

The New Turbo-Alternator Installation of the Commonwealth Edison Company, by J. E. Rolston. November 10. Attendance 12.

Rose Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, D. L. Fenner; Secretary, W. F. A. Hammerling. October 7. Attendance 15.

Rutgers University

Talks on experiences in their Summer work were given by Messrs. Erdelsley, White and Cortelyou, students. October 11. Attendance 32.

A motion picture, entitled "The Single Ridge," was shown. November 8. Attendance 25.

University of Southern California

Studies of Lightning Phenomena, by F. W. Peek, Jr., General Electric Co. October 12. Attendance 64.

South Dakota State School of Mines

Business Meeting. A letter from the General Electric Company was read, entitled "The Training of Men." October 21. Attendance 12.

University of South Dakota

The Slide Rule and It's Possibilities, by Professor Cosanday. October 20. Attendance 8.

Stanford University

Business Meeting. October 11. Attendance 16.

Stevens Institute of Technology

Waste Elimination, by J. O. G. Gibbons. A motion picture concerning the generation of electric power in steam and hydroelectric stations was shown. November 3. Attendance 48.

Syracuse University

Business Meeting. The following officers were elected: Chairman, G. F. Kern; Secretary-Treasurer, T. P. Hall. September 30. Attendance 25.

Hydraulic Power in Southern Appalachian Region, by A. F. Bagnato; *Hydraulic Power in Northern Appalachian Region*, by D. L. Bangs, and *Prospective Power in Appalachian Region*, by Professor Henderson. October 6. Attendance 24.

Possibilities of Hydraulic Power in New York State, by L. J. Bengamm, and *Power in St. Lawrence River Basin*, by B. Bladen. October 13. Attendance 25.

Present Power in St. Lawrence River Basin, by C. B. Clark, and *Power in Basin in 1950*, by C. W. Cushing. October 20. Attendance 23.

Texas Agricultural and Mechanical College

Methods of Resuscitation, by R. M. Moore. Texas Power and Light Co. October 26. Attendance 150.

University of Virginia

A motion picture on the process in the manufacture of the Okonite Cable was shown. November 2. Attendance 20.

State College of Washington

Business Meeting. October 14. Attendance 8.

Washington University

Business Meeting. October 14. Attendance 25.

Inspection Trip to the Bell Telephone Company. October 27. Attendance 45.

University of Washington

Rates of Electrical Power in Washington, by Professor G. L. Hoard. November 3. Attendance 20.

West Virginia University

Resuscitation from Electric Shock, by J. W. Schram; *Noiseless Construction of Steel Buildings*, by W. W. Williams; *Articles of Recent Development in Electricity*, by K. D. Stewart; *The Structure of the Atom*, by M. S. Diaz; *Failure of Arch Dams*, by S. J. Donley; *Hollow Pole Spans for Line Transmission*, by E. H. Braid; *Electrically Operated Bridges*, by C. L. Parks, and *Operation of Steam and Electric Bridges*, by R. O. Pletcher. October 18. Attendance 37.

Oil-Electric Power House on Wheels, by C. B. Binns; *D-C. Generator for Battery Charging*, by G. B. Pyles; *Power System of Penn. R. R. at Harrison, N. J.*, by W. H. Nuhfer; *Latest Planes Herald New Era of Safety*, by H. H. Hunter; *Cheat Haven Power Plant*, by I. L. Smith; *Protection of High-Tension Lines from Lightning*, by F. M. Farry; *Electro-Chemistry and Electro-Metallurgy*, by L. T. Kight, and *A Tidal Dam of Ice*, by G. E. Phillips. October 25. Attendance 37.

Cranes for Handling Freight on Railroads, by H. S. McGowan; *Automatic Train Control*, by E. R. Long; *Problems Confronting Young Engineers*, by A. Izzo; *Ultra-Violet Rays*, by W. W. Reed; *Vital Electrical Statistics*, by A. L. P. Schmeichel; *Principle of Electric Flow Meters*, by J. W. Schram; *Florida East Coast Railway*, by D. Carle; *Water-Quantity Measuring Instruments*, by P. E. Davis, and *Sail Trimming*, by P. J. Johnston. November 1. Attendance 37.

The Longest Railway Tunnel in America, by W. W. Williams; *Charles Steinmetz*, by W. E. Vellines; *A Pump-Propelled Boat*, by E. W. Conway; *Theory of the Planimeter*, by M. S. Diaz; *Electrical Maintenance in Steel Mills*, by W. T. Meyers; *Construction of Commutating Poles*, by C. L. Parks; *Cathode Rays*, by J. P. Paine; *The Most Costly Fuel is the Cheapest*, by S. C. Walsh, and *Can Welding Replace the Rivet?* by A. M. Kalo. November 8. Attendance 37.

University of Wyoming

Business Meeting. October 14. Attendance 21.

Yale University

Business Meeting. October 25. Attendance 38.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED NOVEMBER 19, 1926

AKERS, ROBERT EDWARD, Sales Manager & Engineer, Carrick Wedderspoon, Ltd., Christchurch, N. Z.

ANTHONY, PERCY ALEXANDER WILLIAM, Engineer in charge of Elec. Dept., A. E. Harding Frew, T. & C. Bldgs., Brisbane, Queensland, Aust.

BAGCHI, SUDHIR KUMAR, General Electrical Foreman, Tata Iron & Steel Co., 97 Q Road West, Jamshedpur, India.

BAILEY, GILBERT STEPHEN, Asst. Valuation Engineer, Great Western Power Co., 375 Sutter St., San Francisco; res., Oakland, Calif.

BAKER, MARTIN PHILIP, Asst. Meter & Testing Engineer, Electricity Dept., Shanghai Municipal Council, 30 Fearon Road, Shanghai, China.

BANKS, WILLIS HOLMES, Assistant Regulator, New York Edison Co., 680 First Ave., New York; res., Brooklyn, N. Y.

BAXENDALE, FRANK, Commercial Engineer, Export Dept., British-Thomson Co., Ltd., Rugby, Eng.

BELL, WATKIN, Electrical Supt., Pine Hill Coal Co., Minersville, Pa.

BERG, JOHN E., Electrical Engineer, Victor X-Ray Corp., 2012 W. Jackson Blvd., Chicago, Ill.

BERNT, ARVID CHRISTIAN, Draftsman-General Electric Co., 44 Waldo Ave., Bloomfield; res., Montclair, N. J.

BLYTHE, GEORGE E. K., Lecturer, Elec. Engg. Dept., Glamorgan County Council, Swansea, Glamorgan, South Wales.

BRYANT, ERNEST, Electrical Foreman, Te Awamutu Electric Power Board, Te Awamutu, Auckland, N. Z.

BUCKTIN, FRANK COLDBECK, Construction Foreman, Springs-Ellesmere Power Board, Templeton, Christchurch, N. Z.

BURBANK, JEROME DOUGLAS, Draftsman, Niagara, Lockport & Ontario Power Co., 605 Lafayette Bldg., Buffalo, N. Y.

*CHESNUT, FRANK T., Drafting & Design Dept., Gibbs & Hill, Pennsylvania Station, New York; res., Brooklyn, N. Y.

CORRIN, JOHN G., Pacific Coast Manager, Pittsburgh Transformer Co., 531 Call Bldg., San Francisco, Calif.

COWART, JAMES ESTUS, Electrical Designer, Thomas E. Murray & Co., 55 Duane St., New York; res., Brooklyn, N. Y.

CRANE, SYDNEY FREDERICK, District Engineer, Southland Electric Power Board, Invercargill, N. Z.

DART, SEELY CLARE, Chief Electrician, Oakland Motor Car Co., Pontiac, Mich.

DE CAMARGO, FLORIANO FERREIRA, Erecting Engineer, Substations, Companhia Paulista de Estrada de Ferro, Jundiahy, Sao Paula, Brazil, S. Amer.

DEMPSTER, JOHN H., Meter Engineer, Service Dept., Canadian Westinghouse Co., Ltd., Hamilton, Ont; res., Montreal, Que., Can.

DOBBS, LESLIE JOSEPH, Chief Inspector, Southland Electric Power Board, Tay St., Invercargill, N. Z.

DOXEY, FLOYD S., Student Engineer, General Electric Co., Schenectady, N. Y.; res., Salt Lake City, Utah.

ECKARDT, ERICH MAX, Electrical Engineer, New York Rapid Transit Corp., 58 Clinton St., Brooklyn, N. Y.

ERNST, JOHN PETER, Repair Foreman, Plant Dept., New York Telephone Co., 140 West St., New York; res., Hollis, N. Y.

EVANS, HECTOR C. H., Electrical Fitter, Newcastle City Council, Newcastle, N. S. Wales, Aust.

GLADSTONE, JAMES W. B., European Representative, R. Thomas & Sons Co., East Liverpool, Ohio; for mail, 70 Honor Oak Road, London, S. E., 23, Eng.

HAMMOND, THEODORE AUSTIN, Laboratory Engineer, General Electric Co., Pittsfield, Mass.

HASKELL, MOSES EDWARD, Superintending Engineer, Morarjee Goculdas & Co., Sudama House, Ballard Estate, Bombay 1, India.

*HOFFMANN, HARRY JOHN, Draftsman, Stone & Webster, Inc., 147 Milk St., Boston; res., Jamaica Plain, Mass.

HOLTMAN, JOHN EDWARD, Shop Supt., Westinghouse Elec. & Mfg. Co., 1909 Blake St., Denver, Colo.

HOOKER, JOHN FREDERICK, Electrical Tester, Municipal Electricity Dept., Christchurch, N. Z.

JACOBS, ERNEST, Asst. Meter & Testing Engineer, Electricity Dept., Shanghai Municipal Council, 30 Fearon Road, Shanghai, China.

JONES, ALMA LEE, Supt., Terminal Sub-Station, Utah Power & Light Co., Salt Lake City, Utah.

KEENAN, HENRY BRYANT, Resident Engineer, Wairarapa Electric Power Board, Carterton, N. Z.

KOOKEN, JAMES REX, Electric Repair Shop Foreman, Chile Exploration Co., Chuquicamata, Chile, So. Amer.

KUNDERT, ADOLPH, Plant Electrician, The New York Edison Co., New York, N. Y.

LIBECAP, ROSCOE EVANS, Electrician, Superior Electric Co., 409 S. Ervay St., Dallas, Texas.

LINDELL, SIGURD I., Electrical Draftsman, Schweitzer & Conrad, Inc., 4435 Ravenswood Ave., Chicago, Ill.

LOCKWOOD, EARLE LEWIS, Electrical Engineer, Power Dept., Newport News & Hampton Railway, Gas & Electric Co., Hampton, Va.

MASTER, JEHANGIR J., Maintenance Engineer, Tata Hydro & Andhra Valley Elec. Power Supply Co., Tulsi Pipe Line Road, De Lisle Road, Lower Parel, Bombay, India.

MASU, SUSUMU, Asst. Chief Engineer, Toho Electric Power Co., Kaijo Bldg., Tokio, Japan.

MOUNTAIN, CYRIL ELLIOTT, Distribution Engineer, Burma Electric Tramways & Lighting Co., Ltd., Mandalay, Burma, India.

NIEDERER, ERNST, Curtis Mfg. Co., Kienlen Ave., St. Louis, Mo.

NORRIS, WILLIAM J., Signal Man, New York Rapid Transit Co., New York; res., Brooklyn, N. Y.

ORINSKY, EMILE, Peerless Leather Goods Co., 19 High St., New York; res., Brooklyn, N. Y.

*OWENS, STANLEY, Electrical Engineer, Bureau of Safety, 1205-79 W. Monroe St., Chicago, Ill.

*PARKER, JOHN BRUCE, Traffic Engineer, Saskatchewan Government Telephones, Albert St., Regina, Sask., Can.

PECHA, ANTON F., Inspector, Electrical Testing Laboratories, 540 E. 80th St., New York, N. Y.

PERGLER, FRANK, Chief Engineer, City of Prague, Praha-VII Elektrarna, Prague, Czechoslovakia.

PHILLIPS, ALBERT, Lamp Research Inspector, Electrical Testing Laboratories, 80th St. & East End Ave., New York; res., Brooklyn, N. Y.

PONTIUS, PETER ANGELA, Electrical Engineer, Engg. Dept., Westinghouse Elec. & Mfg. Co., Homewood; res., Wilkinsburg, Pa.

REMSCHEID, EMIL JULIUS, Laboratory Assistant, General Electric Co., Schenectady, N. Y.

RIMSTIDT, JAMES WILLIAM, Field Man Southern Bell Tel. & Tel. Co., 1111 Republic Bldg., Louisville, Ky.

ROBINSON, J. PERCY, Pacific District Representative, Kerite Insulated Wire & Cable Co., 215 Market St., San Francisco, Calif.

SAVE, GEORGE ADAM, Draughtsman, N. Y. Edison Co., 130 E. 15th St., New York, N. Y.

SCURRAH, WILLIAM, Canadian Marconi Co., 173 William St., Montreal, Que., Can.

SEYLER, PAUL K., Transmission & Protection Engineer, Mountain States Tel. & Tel. Co., Salt Lake City, Utah.

SHARMA, SURAJ MAL., Asst. Engineer, Messrs. India Electric House, Church Road, Kashmere Gate, Delhi, India.

SHARP, SAMUEL MILES, Asst. Engineer, Minnesota Power & Light Co., Duluth, Minn.

SILVESTER, LEWIS THOMSON, Cable Supt. & Chief Station Electrician, "Italcable" Co., Anzio, Roma, Italy.

SIMPSON, JAMES CATANACH, Electrical Engineer, Bell Telephone Co. of Canada, Ontario St., Montreal, P. Q., Can.

SOGA, MASAO, Director & Chief Engineer, Keihin Electric Railway Co., Ltd., Kawasaki City, Kanagawaken, Japan.

STEINDORF, HERMAN ALFRED, Wireman, Riter Conley Construction Co., St. Louis, Mo.

SVARUP, ANAND, Lecturer, Thomason College, Roorkee, U. P., India.

SWANN, SAMUEL ARTHUR, Asst. Shift Engineer, Nottingham Electricity Dept., St. Anne's Well Road Power Station, Nottingham, Eng.

SZENES, ALEXANDER, Estimator, Elec. Constr. Dept., New York Edison Co., 130 E. 15th St., New York, N. Y.

TIMOFFEEFF, WOLDEMAR A., Chief Engr., Elec. Dept., Bureau of Electrification, Oramenbaum Rwy.; Asst. Prof. Elec. Rwy. Engg., Electrotechnical Inst. of Leningrad, Leningrad, Russia.

WEITMANN, OTTO, Engg. Dept., Sloan & Chace, Inc., 6th Ave. & 13th St., Newark, N. J.

WIACK, JOSEPH W., Sub-Foreman, Field Installation Dept., Western Electric Co., Inc., 268 W. 36th St., New York, N. Y.; res., Jersey City, N. J.

WILLS, FELIX PERCEVAL, Power Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

*YARLING, FRANK CLARK, Electrical Distribution Dept., Louisville Gas & Electric Co., Louisville, Ky.

YORK, FRANK JOSEPH, Electrical Contractor, 159 E. Elizabeth St., Detroit, Mich.

ZORN, FRED W., Supt., Engg. Dept., American Laundry Machinery Co., 134 W. 37th St., New York, N. Y.

Total 74.

*Formerly Enrolled Students.

ASSOCIATES RE-ELECTED NOVEMBER 19, 1926

GRONDAHL, LARS OLAI, Director of Research, Union Switch & Signal Co., Swissvale, Pa.

NEWILL, EDWARD B., Section Engineer, Control Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

SAND, J. HARVEY, Sales & Process Engineer, Zeller Lacquer Mfg. Co., 20 E. 49th St., New York; res., Brooklyn, N. Y.

WHITTAKER, CHARLES CLARENCE, Section Engineer, Rwy. Equipment Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

MEMBERS ELECTED NOVEMBER 19, 1926

ANDREE, JOHN W., Production Engineer, So. California Edison Co., 700 Edison Bldg. Los Angeles, Calif.

BLOIS, ROBIE KERR, Supt., Smoke Dept., Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C.

GREEN, DANIEL CRANDALL, Vice President & General Mgr., Utah Power & Light Co., Salt Lake City, Utah.

HALE, JUBAL ANDERSON, Chief Engineer, Utah Power & Light Co., Salt Lake City, Utah.

HALL, IRVING E., Asst. Works Manager, Roller-Smith Co., Bethlehem, Pa.

KEATH, HOWARD BASCOMB, Engineer-in-charge, Transformer Division, Wagner Electric Corp., 6400 Plymouth Ave., St. Louis, Mo.

MINTON, JOHN PRESTON, Consulting Engineer, New York; res., White Plains, N. Y.

TRANSFERRED TO GRADE OF MEMBER NOVEMBER 19, 1926

ENSTROM, AXEL F., Director, Royal Swedish Institute of Scientific Industrial Research, Stockholm, Sweden.

HALL, JACK H., Electrical Engineer, Ewa Plantation Co., Ewa, Oahu, T. H.

KORNER, A. J., Consulting Engineer, Stockholm, Sweden.

McDONALD, C. G. H., Acting Chief Electrical Engineer, Victorian Railways, Melbourne, Australia.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held November 16, 1926, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

DENTON, ALPHEUS P., President & Chief Engineer, Denton Engineering & Construction Co., Kansas City, Mo.

MILLER, KEMPSTER B., Consulting Engineer, Pasadena, Calif.

To Grade of Member

AHUJA, D. C., Asst. Chief Electrical Engineer, Tata Iron & Steel Co., Ltd., Jamshedpur, India.

ALLCOCK, HARRY, Export Manager, W. T. Glover & Co., Ltd., London, England.

BARROWS, WILLIAM E., Professor of Electrical Engineering, University of Maine' Orono, Me.
BASTON, CYRIL E., Engineer, Railway Equipment Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
BRENTLINGER, C. M., General Inspector, Western Union Telegraph Co., New York, N. Y.
CONNELL, EDWIN L., Chief Engineer, Van Dorn Electric Tool Co., Cleveland, Ohio.
COPELAND, CLEM A., Assistant Electrical Engineer, Bureau of Power & Light, Los Angeles, Calif.
COX, HERBERT H., Supt. Distributing Stations, Bureau of Power & Light, Los Angeles, Calif.
FREEMAN, WILLIAM E., Assistant Dean, College of Engineering, University of Kentucky, Lexington, Ky.
FURST, WALTER A., Manager, Engineering Dept., Westinghouse Elec. & Mfg. Co., Detroit, Mich.
GRIMES, WILLIAM F., Meter and Relay Engineer, Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
HARVEY, R. J., Consulting Engineer to New Zealand Government, London, England.
HENNINGER, G. ROSS, Engineering Editor, *Journal of Electricity*, San Francisco, Calif.
HICKERNELL, L. F., Assistant Investigations Engineer, Commonwealth Power Corp. of Michigan, Jackson, Mich.
HITCHCOCK, HARRY W., Transmission & Protection Engineer, Southern California Tel. Co., Los Angeles, Calif.
HOLMES, FREDERICK, Vice-President and Secretary, Duncan Electric Mfg. Co., Lafayette, Ind.
LUNSFORD, JESSE B., Technical Assistant, Design Division, Bureau of Engineering, Navy Department, Washington, D. C.
MACKNESS, CYRIL F., Consulting & Inspecting Engineer, London, England.
MOYER, HERBERT C., Chief Engineer, Standards Laboratory, Pennsylvania Power & Light Co., Hazleton, Pa.
NELSON, AARON L., Asst. Engineer, Railway Locomotive Engineering Dept., General Electric Co., Schenectady, N. Y.
PURDY, HENRY T., Consulting & Construction Engineer, San Jose, Costa Rica.
ROSS, JAMES HARVEY, Chief Electrician, Freeport Sulphur Co., Freeport, Tex.
SALBERG, JOHN, Representative, Westinghouse Electric & Mfg. Co., Salt Lake City, Utah.
SIEGMUND, HUMPHREYS O., Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.
SHUMAN, JESSE W., Secretary-Treasurer, Power Engineering Co., Minneapolis, Minn.
TANABE, STETFAN, Meter Design Engineer, Tokyo Electric Co., Kawasaki, Japan.
UNDERHILL, GEORGE H., Distribution Engineer, Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.
WRIGHT, C. H., President & Treasurer, Wright-Cason Electric Co., Knoxville, Tenn.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 31, 1926.

Allen, J. C., West Penn System, Butler, Pa.
Anderson, D. G., Puget Sound Power & Light Co., Chehalis, Wash.
Anderson, H. H., (Member), Shell Co. of California, Los Angeles, Calif.
Angermann, W. G., University of Southern California, Los Angeles, Calif.
Anissimoff, C. I., 656 S. Mentor Ave., Pasadena, Calif.
Archer, F. R., H. L. Doherty & Co., New York, N. Y.
Archer, F. W., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Armer, A. A., Magnavox Co., Oakland, Calif.
Ayer, R. B., General Electric Co., Schenectady, N. Y.
Babcock, Z. F., New York Edison Co., New York, N. Y.
Bardewyck, A. H., Public Service Gas & Elec. Co. of N. J., Newark, N. J.
Barker, E. H., The New York Edison Co., New York, N. Y.
Bennett, W. R., Bell Telephone Laboratories Inc., New York, N. Y.
Berger, F. J., Philadelphia Electric Co., Philadelphia, Pa.
Binkley, E. L., Brooklyn Edison Co., Brooklyn, N. Y.
Bleckley, S. C., Georgia Railway & Power Co., Atlanta, Ga.
Bloch, I., New York Edison Co., New York, N. Y.
Bocek, T., (Member), J. G. White Engineering Corp., New York, N. Y.
Bogan, L. B., Chesapeake & Potomac Telephone Co., Washington, D. C.
Bokum, W. H., The Philadelphia Electric Co., Philadelphia, Pa.
Borgers, R. W., Huron Portland Cement Co., Detroit, Mich.
Boudreau, J. J., United Electric Light & Power Co., New York, N. Y.
Boyer, G. C., Kansas City Light & Power Co., Kansas City, Mo.
Brandt, F. L., Ohio Insulator Co., Barberton, Ohio
Brightcliffe, N. J., Leeds & Northrup Co., Philadelphia, Pa.
Brown, E. H., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Brown, J. W., Brown Electric Co., Anderson, Ind.
Burnham, A. H., Jr., Locke Insulator Corp., Baltimore, Md.
Butler, T. H., General Electric Co., Schenectady, N. Y.
Byrd, R. H., Cornell University, Ithaca, N. Y.
Calvert, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Casey, E. A., Union Switch & Signal Co., Swissvale, Pa.
Cather, W. A., Barrett, Haentijens & Co., Hazleton, Pa.
Cerf, E. A., Jr., Yale University, New Haven, Conn.
Chromy, B. J., School of Engineering of Milwaukee, Milwaukee, Wis.
Cisneros, S. C., General Electric Co., Lynn, N. Y.
Cobb, N. M., Philadelphia Electric Co., Philadelphia, Pa.
Cohn, M., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Cosandey, C. J., University of South Dakota, Vermillion, So. Dakota
Courtright, A. V., Columbia Eng. & Management Corp., Cincinnati, Ohio
Craig, W. F., Westinghouse Elec. & Mfg. Co., Salt Lake City, Utah
Crawford, J. E., Duquesne Light Co., Pittsburgh, Pa.
Croco, C. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Curtis, L. B., Gibbs & Hill, Inc., New York, N. Y.
Daniels, C. E., Scranton Electric Co., Scranton, Pa.
D'Angelo, F. J., American Can Co., Brooklyn, N. Y.
Davies, P. J., 29 Quaker St., Granville, N. Y.
De Lellis, J., United Electric Light & Power Co., New York, N. Y.
De Shazo, J. S., Pennsylvania Power & Light Co., Hazleton, Pa.
Dewey, L. K., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Dixon, J.T., American Tel. & Tel. Co., New York, N. Y.
Dixon, W. R., Florida Public Service Co., Orlando, Fla.
Domenzain, S. F., (Member), Mexican Light & Power Co., Mexico, D. F., Mex.
Douglas, W. L., Electrical Inspector, City of Newark, Newark, N. J.
Dressel, P. H., Union Gas & Electric Co., Cincinnatio, Ohio
Eimers, H. O., Chesapeake & Potomac Telephone Co., Washington, D. C.
Ellison, C. E., The Milwaukee Elec. Railway & Light Co., Milwaukee, Wis.
Elwell, F., British Columbia Electric Railway Co., Vancouver, B. C.
(Applicant for re-election.)
Embree, J. N., Union Electric Light & Power Co., Webster Groves, Mo.
Engle, H. B., Chesapeake & Potomac Telephone Co., Washington, D. C.
Evans, C. W., San Antonio Public Service Co., San Antonio, Texas
Farnsworth, G. C., Public Service Co. of California, Denver, Colo.
Feldheim, F., Eagle Pencil Co., New York, N. Y.
Fischer, T. W., Gibbs & Hill, Brooklyn, N. Y.
Fischer, W. A., United Electric Light & Power Co., New York, N. Y.
Flatland, R. D., Robinson Sales Co., Seattle, Wash.
Folger, D. L., Columbia Engg. & Management Corp., Cincinnati, Ohio
Foulk, R. K., Home Gas & Electric Co., Greeley, Colo.
Fouse, R. W., General Electric Co., Erie, Pa.
Freeman, S., Jr., General Electric Co., Boston, Mass.
Gailing, H. A., Elias Nusbaum & Bros., Philadelphia, Pa.
Gaines, J. M., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Gamble, W. H., So. Dakota State College, Brookings, So. Dak.
Gaubatz, A. J., Radio Business, East St. Louis, Mo.
Gerber, H. L., Dept. of Electricity, City Hall, San Francisco, Calif.
Gerstein, E. N., Okonite-Callender Cable Co., Paterson, N. J.
Gibbs, C. T., (Member), Holmes & Sanborn, Los Angeles, Calif.
Glass, J. R., Georgia Railway & Power Co., Atlanta, Ga.
Glatzel, J. J., Public Service Electric & Gas Co., Paterson, N. J.
Gluck, E. J., Carolina States Elec. Co., Charlotte, N. C.
Grant, P. A., Jackson & Moreland, Boston, Mass.
Griffin, F. J., Brooklyn Edison Co., Brooklyn, N. Y.
Grimke, F. D., New York Edison Co., New York, N. Y.
Gross, E. S., New York Telephone Co., New York, N. Y.
Hammond, S., Jr., Public Service Elec. & Gas Co., Newark, N. J.
Haskell, F. V., New York Edison Co., New York, N. Y.
Applications for election Gal. 2 Bartels 11-16 G5
Hendricks, R. E., Fort Worth Power & Light Co., Fort Worth, Texas
Hershey, A. W., University of Illinois, Urbana, Ill.
Higginbottom, E. K., Kuhlman Electric Co., Atlanta, Ga.
Hildenbrand, H. L., The *Electric Journal*, Pittsburgh, Pa.
Hilshman, N. S., Lehigh University, Bethlehem, Pa.
Hobbs, H. G., Brooklyn Edison Co., Brooklyn, N. Y.
Hobson, J. R. A., Jr., Public Service Production Co., Newark, N. J.
Hoddy, G. L., General Electric Co., Schenectady, N. Y.

Holmes, C. B., Western Electric Co., New York, N. Y.
Horine, K., (Member), Commonwealth Edison Co., Chicago, Ill.
Houghton, H. W., Pennsylvania Power & Light Co., Allentown, Pa.
Houston, H. H., Jackson & Moreland, Boston, Mass.
Hovgaard, O. M., Acme Apparatus Co., Cambridge, Mass.
Hume, G. H., L. & N. R. R. Co., Louisville, Ky.
Hurowitz, S. W., Electrical Contractor, Bronx, New York, N. Y.
Inouye, I., Electrical Contractor, New York, N. Y.
Irish, C. V., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Johnson, B. P., Witherbee Sherman & Co., Mineville, N. Y.
Johnson, F. E., Jr., New Orleans Public Service, Inc., New Orleans, La.
Johnson, L. S., New York Central Railroad, New York, N. Y.
Johnson, M., 416, 4th Ave., N. W., Watertown, So. Dakota
Johnson, P. B., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio
Johnson, R., U. S. Patent Office, Washington, D. C.
Johnson, W. D., University of Missouri, Columbia, Mo.
Johnston, R. M., (Member), Jeffery-Dewitt Insulator Co., Kenova, West Va.
Journeaux, D., Electrical Testing Laboratories, New York, N. Y.
Jubien, E. B., General Electric Co., Thompson Research Lab., Lynn, Mass.
Karelitz, M. B., Pennsylvania Railroad Co., Altoona, Pa.
Keel, H. C., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Kehl, C. J., Electric Storage Battery Co., Wilkes-Barre, Pa.
Keller, F. R., United Electric Light & Power Co., New York, N. Y.
Kempf, M. B., The Milwaukee Elec. Railway & Light Co., Milwaukee, Wis.
Klingenschmidt, H. C., Southern Power Co., Salisbury, N. C.
Koenig, C. O., H. L. Doherty & Co., New York, N. Y.
Kollmeyer, C. A., Chesapeake & Potomac Telephone Co., Washington, D. C.
Korn, F. A., Bell Telephone Laboratories, Inc. New York, N. Y.
Kottman, H. W., H. W. Crowder, Jr. Co., Wilkes-Barre, Pa.
Krejci, E., N. Y. & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.
Krewatch, A. V., General Electric Co., Schenectady, N. Y.
Ku, Y. H., Mass. Inst. of Technology Cambridge, Mass.
Kurth, H. R., Edison Elec. Ill. Co. of Boston, S. Boston, Mass.
La Barr, C. S., Ohio Public Service Co., Lorain, Ohio
Landmesser, L. F., Pennsylvania Power & Light Co., Ashley, Pa.
Latham, J. W. L., (Member), Chesapeake & Potomac Tel. Co., Washington, D. C.
Laurence, R. G., Automatic Switch Co., New York, N. Y.
Lewis, W. A., Jr., California Inst. of Technology, Pasadena, Calif.
Liebrecht, E. F., Jr., Chesapeake & Potomac Telephone Co., Washington, D. C.
Locke, C. C., New York Edison Co., New York, N. Y.
MacLean, James B., The J. G. White Engineering Corp., New York, N. Y.
MacNeil, D. J., The New York Edison Co., New York, N. Y.
Maedel, G. F., New York Edison Co., New York, N. Y.
Mancini, F. G., Pennsylvania Railroad, Altoona, Pa.
Manuele, J., Jr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Mason, C. M., Cincinnati & Suburban Bell Tel. Co., Cincinnati, Ohio
Mawer, A. L., Ferguson, Pailin, Ltd., Toronto, Ont., Can.
McFarlane, M. L. D., *New York Daily News*, New York, N. Y.
Meadows, A. V., Toronto Hydro-Electric System, Toronto, Ont., Can.
Miller, G. B., Jr., Duquesne Light Co., Pittsburgh, Pa.
Miller, H. P., Georgia Railway & Power Co., Atlanta, Ga.
Mitchell, J. E. M., (Member) Jeffery-Dewitt Insulator Co., Atlanta, Ga.
Moore, W. H., New York Edison Co., New York, N. Y.
Moorhouse, A. H., Commonwealth Edison Co., Chicago, Ill.
Morris, H. C. B., New York Edison Co., New York, N. Y.
Morton, F. D., Philadelphia Electric Co., Philadelphia, Pa.
Morwood, J. E., General Electric Co., Schenectady, N. Y.
Mukerjee, H. P., International General Electric Co., Schenectady, N. Y.; (For mail, Chicago, Ill.)
Murtha, T. E., T. E. Murray, Inc., New York, N. Y.
Musseleck, W. F., New York Edison Co., New York, N. Y.
Nagamine, K., Mass. Institute of Technology, Cambridge, Mass.
Nally, T. E., General Electric Co., Pitttsfield, Mass.
Nelson, C. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Neubauer, J. P., New York Edison Co., New York, N. Y.
Newell, D. M., Duquesne Light Co., Pittsburgh, Pa.
Norell, L. W., Victor X-Ray Corp., San Francisco, Calif.
Oehm, F. A., Chesapeake & Potomac Telephone Co., Washington, D. C.
O'Meara, W. J., General Electric Co., Philadelphia, Pa.
Opp, G. C. A., The Detroit Edison Co., Detroit, Mich.
Parker, G. A., Jr., Chicago Pneumatic Tool Co., Detroit, Mich.
Parsons, D. E., Railway & Industrial Engineering Co., Philadelphia, Pa.
Peeling, C. U., (Member), Pennsylvania Power & Light Co., Bethlehem, Pa.
Peter, E., General Electric Co., Schenectady, N. Y.
Petho, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Pickard, R. W., Ohio Power Co., Canton, Ohio
Pitman, M. H., Georgia Railway & Power Co., Atlanta, Ga.
Poole, G. D., Gatun Locks, The Panama Canal, Gatun, C. Z.
Porter, E. Y., (Member), The Southern Sierras Power Co., Riverside, Calif.
Poteet, J. W., Jr., General Electric Co., Schenectady, N. Y.
Quinn, G. E., New York Edison Co., New York, N. Y.
Ratrie, H., Chesapeake & Potomac Telephone Co., Washington, D. C.
Rempe, P. J., El Paso Electric Co., El Paso, Texas
Rey, P., Brooklyn Edison Co., Brooklyn, N. Y.
Rhea, V. L. R., Scranton Electric Construction Co., Scranton, Pa.
Roberts, C. E., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Roberts, C. G., Duquesne Light Co., Pittsburgh, Pa.
Roberts, C. V., Erie Lighting Co., Erie, Pa. (Applicant for re-election.)
Rock, J. J., Great Western Power Co. of California, Oakland, Calif.
Roper, J. W., New York Telephone Co., New York, N. Y.
Ryan, T. R., Long Island Lighting Co., Mineola, L. I., N. Y.
Sah, A. P., 16 Elbridge St., Worcester, Mass.
Samer, H. A., Trumbull Electric Co., Ludlow, Ky.
Samuel, A. L., Mass. Institute of Technology, Cambridge, Mass.
Schmidt, C. G., New York Telephone Co., Albany, N. Y.
Schoening, W. F., Washington University, St. Louis, Mo.
Schoetker, R. W., Union Electric Light & Power Co., St. Louis, Mo.
Seaman, E. F., N. Y. & Queens Elec. Lt. & Pr. Co., Flushing, L. I., N. Y.
Serett, H., A. B. See Elevator Co., Jersey City, N. J.
Sharp, L. W., General Electric Co., New York, N. Y.
Sharpe, J. M., Shawinigan Falls Water & Power Co., Shawinigan Falls, P. Q., Can.
Sinclair, J. F., Jeffery Dewitt Insulator Co., Kenova, West Va.
Sinclair, W. L., Postal Telegraph-Cable Co., Louisville, Ky.
Sixtus, E. F., Pacific Electric Mfg. Co., San Francisco, Calif.
Skeats, W. F., nGeeral Electric Co., Schenectady, N. Y.
Sklar, S. B., (Member), Chem. Mech. & Elec. Inventor, Washington, D. C.
Smith, T. A., Radio Corp. of America, New York, N. Y.
Smythe, R. L., Line Material Co., S. Milwaukee, Wis.
Southworth, M. D., Mutual Tel. Co., Erie, Pa.
Speer, J. L. D., Jr., Chesapeake & Potomac Telephone Co., Washington, D. C.
Starks, F. C., Mutual Tel. Co., Erie, Pa.
Stevenson, P. J., Erie Lighting Co., Erie, Pa.
Stewart, H. E., Duquesne Light Co., Pittsburgh, Pa.
Stewart, W. F., Canadian General Electric Co., Peterboro, Ont., Can.
Stoddard, H. B., New York Edison Co., New York, N. Y.
Stoll, P. A., Commonwealth Power Corp., Jackson, Mich.
Swaim, J. V., Purdue University, W. Lafayette, Ind.
Taylor, H. S., (Member), Consulting Engineer, Dayton, Ohio
Teele, R. P., Jr., University of Michigan, Ann Arbor, Mich.
Tenzel, W. V., Memphis Power & Light Co., Memphis, Tenn.
Thimme, E. J., Public Service Electric & Gas Co., Paterson, N. J.
Tholstrup, H. L., University of Minnesota, Minneapolis, Minn.
Tompkins, W. A., Penn Public System, Erie, Pa.
Troutman, F. L., General Electric Co., Philadelphia, Pa.
Venturine, J. B., Cobbs & Mitchell Lbr. Co., Valsetz, Ore.
Wagoner, A. G., Foreman for Elec. Contractor, Brooklyn, N. Y.
Waldorf, S. K., Johns Hopkins University, Homewood, Baltimore, Md.
Walters, E., Cleveland Electric Illuminating Co., Cleveland, Ohio
Weaver, B. S., General Electric Co., Lynn, Mass.
Weaver, P. A., Electric Storage Battery Co., Wilkes-Barre, Pa.
Weber, L., Dept. of Trade & Commerce, Regina, Sask., Can.
Weilenmann, B. E. A., Metropolitan Mfg. Co., Long Island City, N. Y.
White, F. D., Mountain States Power Co., Albany, Ore.
Wilson, E. F., Houston Light & Power Co., Houston, Texas
Winckler, G., General Electric Co., Lynn, Mass.
Wright, C. E., International General Electric Co., Schenectady, N. Y.

Wright, M. V., Mutual Tel. Co., Erie, Pa.
Wu, P. M., Western Electric Co., Toledo, Ohio
Yankey, H. D., Michigan Bell Telephone Co., Detroit, Mich.
Zamzow, G. L., Chicago Surface Lines, Chicago, Ill.
Zinn, G. W., Brooklyn Edison Co., Brooklyn, N. Y.
Zubair, M., General Electric Co., Schenectady, N. Y.
Total 236

Foreign

Grey, J. B., Waitomo Electric Power Board, Te Kuite, N. Z.
King, H. J., (Member), King & Strut, E. Dulwich, London, S. E. 22, Eng.
Milne, J. A., Westport Coal Co., Granity, Westport, N. Z.
Rhodes, A. E., (Member), Electrical Engineer, Auckland, N. Z.
Sarda, P. M., The Surat Electricity Co., Ltd., Surat, India
Slater, J. M. L., The Electrical Apparatus Co., Ltd., London, S. W. 8, Eng.
Weeden, E. H., General Electric Co., Schenectady N. Y.; Mackenzie College, Sao Paulo, Brazil, S. A.
Withers, L. F., Lake Coleridge Power Schme, Addington, N. Z.
Total 8

STUDENTS ENROLLED

Abulafia, A., University of Pittsburgh
Alford, Edward L., Univ. of Missouri
Allen, Edwin J., Texas A. & M. College
Allen, Winthrop, Princeton Univ.
Allera, Joe, Univ. of Colo.
Altenbern, Carl A., Texas A. & M. College
Anderson, Lewis G., Ohio State Univ.
Andrews, Howard L., Brown University
Archibald, Carl G., Oregon Agr. College
Armfield, John S., Stanford Univ.
Asmus, Lester, Marquette University
Austin, George W., University of Ky.
Avery, Lloyd D., Northeastern Univ.
Babcock, Colton W., University of Colorado
Bagnato, Anthony F., Syracuse University
Bair, Frank B., University of No. Dak.
Baker, Robert V., University of Mo.
Baldwin, William G., Lafayette College
Bale, Townley W., Oregon Agr. College
Ballantine, Robert Wm., Princeton Univ.
Bangs, D. Leslie, Syracuse University
Bann, Gerald W., Marquette Univ.
Barber, Clarence D., Kansas State Agr. College
Barre, Benjamin A., Calif. Inst. of Tech.
Barris, Henry A., Cornell University
Beatty, Edwin H., University of Delaware
Bechberger, Paul F., Ohio State Univ.
Beck, Bjorn O., Purdue University
Becker, Lester J., So. Dak. State School of Mines
Begard, Karl, Case School of Applied Science
Benjamin, Louis J., Syracuse University
Bennett, Gordon W., Ohio State Univ.
Bent, Joseph G., Jr., Lehigh Univ.
Berg, Frederick T., University of Maine
Bering, Donald A., Stanford Univ.
Betkouski, Marcellian R., Univ. of Santa Clara
Biebel, Lawrence B., University of Pittsburgh
Bingham, Harvey C., Case School of Applied Science
Birge, Knowlton R., Calif. Inst. of Tech.
Black, Donald M., Univ. of Kansas
Blackburn, H. F., Kansas State Agr. College
Bladen, Bernard, Syracuse Univ.
Blascak, Stanley J., Ohio State Univ.
Block, Henry J., Purdue University
Blount, Frank, Oregon State Agr. College
Blugerman, Leonide N., University of Washington
Boardman, Albert D., Stanford Univ.
Bond, Marion E., Ohio State Univ.
Borgman, Theodore, University of Louisville
Bramble, John H., Lehigh Univ.
Brandt, Mulford M., Drexel Institute
Brooks, Hamilton, University of Pittsburgh
Brown, Byron B., Ohio State Univ.
Brown, John W., Northeastern University
Brown, Walter M., Drexel Institute
Brumbaugh, Kenneth D., Case School of Applied Science
Bryan, Arthur L., Ohio State Univ.
Bub, George L., Case School of Applied Science
Bullock, Edmund T., University of Ky.
Bullock, Menifee C., University of Mo.
Bunting, William L., University of Illinois
Burke, Francis L., Mass. Inst. of Tech.
Burke, Wm. E., Oregon Agr. College
Burris, Frank J., So. Dak. State School of Mines
Butt, Charles N., University of Washington
Cain, Walter W., Ohio State Univ.
Canfield, Wright, Kansas State Agr. College
Carter, Conway D., Oregon Agr. College
Caveney, Eldred J., Univ. of Santa Clara
Cerveny, James P., State College of Wash.
Chambers, Dudley E., Stanford Univ.
Chatten, Frank L., Rutgers College
Chidester, John T., Carnegie Inst. of Technology
Child, Joseph E., Iowa State College
Clark, Clifford B., Syracuse Univ.
Clark, Richard G., University of Maine
Clark, Will T., Texas A. & M. College
Clewell, Orlo E., Iowa State College
Coad, Jack F., Iowa State College
Colburn, Howard O., Oregon Agr. College
Cole, Burton R., Stanford Univ.
Connell, Glenn W., University of Pittsburgh
Conover, Joseph E., Rutgers University
Cooper, Victor E., Purdue University
Courtright, David S., Cornell Univ.
Cowen, Edward G., Mass. Inst. of Tech.
Cowhig, Walter W., Northeastern University
Coyner, John E., Purdue University
Cozzens, Bradley, Stanford Univ.
Crawford, Arthur B., Ohio State Univ.
Creveling, Robert, Calif. Inst. of Tech.
Crossno, V. O., University of Tennessee
Crout, Prescott D., Mass. Inst. of Technology
Crow, George L., University of Missouri
Cummings, Clifford C., So. Dak. State School of Mines
Cundiff, Robert M., University of Ky.
Cunningham, David, Univ. of Missouri
Cunningham, Walter, Oregon Agr. College
Curtiss, Arthur N., University of Pittsburgh
Cushing, Charles W., Syracuse Univ.
Dagon, John W., Lafayette College
Dalby, Harry W., Oregon Agr. College
Dalton, Wm. Robert, Rutgers College
da Roza, F. Gonzalez, Purdue Univ.
Darrah, Merle D., Iowa State College
D'Ascensio, Frank, Cornell University
Daugherty, C. S., University of Ky.
David, Amos R., University of Ky.
Davis, Norman D., Case School of Applied Science
Davis, Samuel W., Okla. A. & M. College
Decker, Floyd A., Kansas State Agr. College
DeLean, Louis H., Washington State College
Dempsey, Edward F., Ohio State Univ.
Demsko, William J., Pennsylvania State College
Dettmer, Herman W., Rutgers University
Dice, Robert F., Kansas State Agr. College
Dietel, E. A., Texas A. & M. College
Disher, Isaac C., Univ. of Ky.
Dixon, James E., Univ. of Missouri
Doehne, Robert, Lehigh Univ.
Dohr, Joseph N., Marquette University
Donohue, John W., Marquette University
Doty, Irwin T., Ohio State Univ.
Douglass, Dale D., Purdue Univ.
Dow, Orville E., University of Colo.
Driscoll, Leslie B., University of No. Dak.
Driskill, William C., So. Dak. State School of Mines
Duncan, Thomas C., Cornell Univ.
Dunlap, Norton T., Kansas State Agr. College
Earnheart, Richard L., Oregon Agr. College
Eckhouse, Robert H., Lehigh Univ.
Edelstein, H. E., Cornell Univ.
Edmonds, Edward C., University of Tennessee
Edwards, Julian M., Univ. of Arkansas
Egbert, Jerry L., Univ. of Missouri
Eisenmann, Samuel B., Rutgers College
Ellis, William T., Case School of Applied Science
Elsea, Harold D., Univ. of Missouri
Epley, Frederic I., University of Ky.
Erb, Harry A., Cornell Univ.
Ernst, M. Leslie, Syracuse Univ.
Everts, William J., Northeastern University
Evitts, William E., University of Iowa
Ewertz, Gordon E., Lehigh Univ.
Ewing, Maxwell S., Syracuse Univ.
Fairhurst, John A., Rose Polytechnic Institute
Falkenberg, Roy T., Texas A. & M. College
Fathauer, Walter F., Mass. Inst. of Tech.
Fayram, Burtis L., Iowa State College
Fenn, G. Titus, Univ. of Ky.
Field, Kenneth S., University of Maine
Fields, Eugene, University of Louisville
Fisher, William P., Univ. of Santa Clara
Fishman, Sam, Case School of Applied Science
Fleck, Hayden A., Kansas State Agr. College
Flynn, Francis, Armour Inst. of Tech.
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Foote, Cecil D., Kansas State Agr. College
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Fouts, Ben S., Okla. A. & M. College
Francis, Arthur D., University of Wash.
Frank, Charles W., Mass. Inst. of Tech.
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Frazier, Walter B., Purdue Univ.
Freundt, Gerhard L., Armour Inst. of Tech.
Frey, J. C., Lehigh Univ.
Friend, Robert E., Marquette University
Frink, James C., Syracuse Univ.
Fuller, Robert L., Univ. of Utah.
Furniss, George A., University of Calif.
Gamage, F. T., Purdue Univ.
Garey, Hollis W., University of Maine
Garnhart, Gordon E., Syracuse Univ.
Garretson, William A., Iowa State College
Gates, Lester C., Kansas State Agr. College
Gear, Robert B., Cornell University
Ghous, Shah G., Purdue Univ.
Gillham, James B., Univ. of Calif.
Goldstein, Maurice, Armour Inst. of Technology
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Gove, Harold E., Univ. of Missouri
Grasser, Marvin H., Ohio State Univ.
Greenwood, Walter S., Northeastern University
Gross, Malvern J., Oregon Agr. College
Grove, John V. T., Syracuse Univ.
Gum, William A., Univ. of Missouri
Gussow, Phillip M., Univ. of Missouri
Habicht, Carl E., Iowa State College
Hahn, Raymond E., Marquette University
Hall, Charles R., Ohio State Univ.
Hall, Henry D., Northeastern University
Hall, Theodore P., Syracuse Univ.
Hall, William M., Mass. Inst. of Tech.
Hamilton, Alvin W., Kansas State Agr. College
Hansen, Theodore, Iowa State College
Hansen, Verner H., Iowa State College
Hardin, William B., Cornell Univ.
Harrington, Paul, Purdue Univ.
Harrison, Charles I., Univ. of Calif.
Hart, Wesley T., Kansas State Agr. College
Hartley, Harry A., Purdue Univ.
Harvey, R. L., University of Tennessee
Hase, Raymond C., Univ. of Missouri
Hatch, William H., University of Illinois
Hayden, George E., Rhode Island State College
Hayes, Thomas H., Kansas State Agr. College
Haynes, Raymond W., University of Illinois
Hensarling, Phil H., Jr., Texas A. & M. College
Hertz, John D., Ore. Agr. College
Hescock, Lee F., University of Maine
Heye, Gus D., Texas A. & M. College
Hicks, George E., University of Ky.
Hilarov, Victor A., Syracuse Univ.
Hilkey, Harold R., Kansas University
Hill, Edward T., Bucknell Univ.
Hill, Ezra C., Purdue Univ.
Hill, Ole A., Jr., Iowa State College
Hinnrichs, Herbert, Marquette University
Hippler, F. R., Case School of Applied Science
Hobson, Henry M., Rutgers University
Hoeke, William W., Jr., Lehigh Univ.
Hoffman, Howard A., Lafayette College

Hoffman, Kermit B., Lehigh Univ.
Holmes, William R., Univ. of Missouri
Holt, Roy L., University of No. Dak.
Hoppe, Paul R., University of Oregon
Horn, Leonard, Armour Inst. of Tech.
Hornby, Fred B., Texas A. & M. College
Hossie, Walter W., Mass. Inst. of Tech.
Howard, Arthur W., Univ. of Colorado
Howell, Louis O., Stanford Univ.
Hudson, Otis B., Syracuse Univ.
Hunt, John H., Jr., Lafayette College
Hutton, Donald G., University of Colorado
Ikehara, Shikao, Mass. Inst. of Tech.
Israel, John O., Lafayette College
Ittin, David, Armour Inst. of Tech.
Jack, Carl R., Purdue Univ.
Jacobs, Paul M., Marquette University
Jarrett, Marcus G., University of Pittsburgh
Jennings, Louis A., Northeastern Univ.
Jeppesen, Ernest, Oregon Agr. College
Jesse, Louis R., University of Ky.
Johnson, Claude L., Jr., Louisiana State Univ.
Johnson, Ernest O., Rose Polytechnic Inst.
Johnson, Erval W., University of Idaho
Johnson, George S., University of Colorado
Johnson, Theodore R., Ohio State Univ.
Johnson, William H., University of Florida
Jones, C. Sidney, Armour Inst. of Technology
Jones, Lloyd, University of No. Dak.
Jordan, Charles O., Kansas University
Karnik, Vashwant G., University of Illinois
Kelham, Merl G., Purdue Univ.
Kelley, Warren T., University of Washington
Kellogg, Frank L., Oregon Agr. College
Kendall, George A., Iowa State College
Kennedy, Wesley M., University of Washington
Kenny, Greg L., Jr., Alabama Polytechnic Inst.
Kern, George F., Syracuse Univ.
Ketel, Carl G., University of Illinois
Kieb, Nelson A., Rutgers University
Kirn, Fairfax D., University of Colo.
Klienert, George, Jr., Armour Inst. of Tech.
Klinestiver, Gordon H., The Pennsylvania State College
Knight, Arthur R., Ohio State Univ.
Konkle, Phil, Iowa State College
Koopman, Richard W., Univ. of Missouri
Korsznick, John, Lehigh Univ.
Kossiakoff, Ivan T., University of Washington
Kramer, Norman J., Lehigh Univ.
Krantz, Herman F., Mass. Inst. of Tech.
Kratochvil, Frank M., Armour Inst. of Tech.
Kratosky, Fred F., Iowa State College
Krause, August L., University of Washington
Krawcek, A. E., Syracuse Univ.
Krieckhause, Glenn, Kansas University
Kroeger, William J., Carnegie Inst. of Tech.
Kronmiller, Charles W., Purdue Univ.
Kuan, Tung, Mass. Inst. of Tech.
Kuehn, Frederick W., Cornell Univ.
Kuehne, Herbert A., Iowa State College
Kuhn, Jackson G., Calif. Inst. of Tech.
Kurtinaitis, John V., University of Illinois
Lake, Maurice E., Northeastern University
Landenslager, Richard L., Lehigh Univ.
Landon, Lester L., Jr., Univ. of New Hampshire
Lantz, Lawrence L., University of Illinois
Larson, H. Eugene, University of Utah
Larson, Hilmer E., Calif. Inst. of Tech.
Lavorgna, Michael L., University of Maine
Leaverton, Lowell D., Kansas University
Leavitt, Charles F., Brooklyn Polytechnic Inst.
Leeka, Warren C., Ohio State Univ.
Lewis, Donald A., Ohio State Univ.
Libeck, Melvin C., Washington State College
Lober, Charles N., Univ. of Missouri
Lockshin, Samuel, Ohio State Univ.
Lockwood, Mason G., Rice Institute
Loggan, Harry J., Oregon Agr. College
Lome, Julius B., University of Ill.
Love, Russell J., Calif. Inst. of Tech.
Low, Harold R., Washington State College
Lowe, Victor A., Case School of Applied Science
Lueth, Irving B., Armour Inst. of Tech.
Lukens, Alan F., Princeton Univ.
Luthropp, Arthur, Marquette Univ.
MacGregor, Robert W., Jr., Princeton Univ.
Mackey, Harry S., Cornell Univ.
MacNutt, Raymond D., Syracuse Univ.
Madsen, August M., Iowa State College
Markey, Milton L., Cornell Univ.
Markwald, James, University of Colo.
Marples, Robert, Stevens Inst. of Tech.
Marshall, Thomas C., University of Ky.
Martin, Devereaux, Mass. Inst. of Tech.
Martin, Everett E., State College of Washington
Martin, Ken, Oregon Agr. College
Massa, Frank, Mass. Inst. of Tech.
Mathews, John T., University of British Columbia
Matthews, Douglas W., Case School of Applied Science
May, Montgomery, University of Tennessee
McClanahan, Charles D., University of Ky.
McCord, William P., University of Tennessee
McElroy, Richard H., University of Washington
McGinty, Edward J., Marquette University
McGowan, Harry S., West Virginia Univ.
McKay, Robert, Ohio State Univ.
McKie, Robert B., Carnegie Inst. of Tech.
McKown, Henry M., Northeastern Univ.
McMakin, William H., Drexel Inst.
McNally, Francis P., Syracuse Univ.
Mentzer, Paul K., Case School of Applied Science
Mercer, Aaron L., Oregon Agr. College
Merchant, Leland A., The University of Maine
Mesenkop, Louis H., Calif. Inst. of Tech.
Metz, Henry I., University of Pittsburgh
Metzger, Daniel C., Mass. Inst. of Tech.
Meurer, Erwin E., University of Pittsburgh
Meuth, Rome M., University of Ky.
Meyers, George J., Marquette University
Mikelberg, Samuel, Mass. Inst. of Technology
Miles, Harold L., Cornell Univ.
Miles, Irving B., Lehigh Univ.
Miller, George H., University of Colorado
Miller, Ira W., Ohio State Univ.
Millspaugh, Frederick W., Drexel Institute
Minnick, Oley P., Univ. of Missouri
Mino, T. Joseph, State College of Wash.
Minocha, Kanshi R., Mass. Inst. of Tech.
Mitchell, D. P., University of Pittsburgh
Mitchell, Standish R., So. Dak. State School of Mines
Moccia, Carmen, Mass. Inst. of Tech.
Moon, Monroe E., University of Maine
Moore, Hudson, Jr., University of Colorado
Morehodoff, John A., University of Washington
Morgan, Nathaniel R., Stanford Univ.
Morris, Rayson, University of Idaho
Morton, George R., University of Ill.
Mosier, George, Univ. of Colorado
Mount, Mark L., Purdue Univ.
Muench, Roland, Univ. of Missouri
Muldoon, James, Rensselaer Poly. Inst.
Murphy, Laran A., Kansas State Agr. College
Murray, Donald A., Stanford Univ.
Myers, J. M., Princeton Univ.
Nader, Joseph, Purdue Univ.
Neath, Walter A., Armour Inst. of Technology
Nelson, Harry O., Oregon Agr. College
Nelson, Loyd B., University of Colorado
Nelson, Paul E., University of Colorado
Neumann, Philip C., Marquette University
Newton, C. Elmer, Univ. of Santa Clara
Newton, Stanley H., Northeastern Univ.
Noel, Edward B., University of Illinois
Nolte, Theodore C., Univ. of Missouri
Novak, John M., Oregon Agr. College
Noyes, Warren F., Northeastern Univ.
O'Brien, Robert P., Univ. of Santa Clara
Oelkers, Albert L., Stevens Inst. of Tech.
Ogan, John K., Purdue Univ.
Olehy, James H., University of Colorado
Olmstead, Noel C., Mass. Inst. of Tech.
Olson, Kermit, University of Washington
Orr, Norman, University of Pittsburgh
Osborne, George, Oregon Agr. College
Osenbaugh, Chester L., Purdue Univ.
Osterholm, R. W., Case School of Applied Science
Papieski, Lucien E., University of Pittsburgh
Park, Howard, University of Washington
Parker, Lewis C., University of Colo.
Paul, Daniel, Lafayette College
Payne, Herbert M., Ohio State University
Penn, L. R., University of Ky.
Perrine, Robert O., Carnegie Inst. of Tech.
Perry, Paul G., Rice Institute
Peters, Ervin G., State College of Washington
Peters, R. E., Texas A. & M. College
Petersen, R. Lee, Mass. Inst. of Tech.
Peterson, Arthur C., Jr., Univ. of Washington
Peterson, Fritz B., University of Idaho
Pierson, Theodore G., Lehigh Univ.
Pietschmann, Gustav M., Rutgers University
Poliak, Hyman A., University of Colorado
Pollard, Ernest I., University of Nebraska
Pollock, Sam H., Univ. of Missouri
Poor, Bernard T., University of Maine
Porter, James C., University of No. Dak.
Povey, Edmund H., Northeastern University
Prather, Virgil L., Purdue Univ.
Pratt, Charles R., Columbia Univ.
Preble, Herbert P., University of Maine
Priest, William F., Washington State College
Prokop, Edmund W., Marquette University
Quinn, John L., Univ. of Santa Clara
Raymer, William F., Jr., University of Ky.
Reber, Elwood E., Kansas State Agr. College
Rector, Lawrence, Kansas State Agr. College
Reifsynder, Guy C., Lafayette College
Reigler, Hartman, Univ. of Arkansas
Reitsch, Charles W., Montana State College
Reynolds, Barton C., Univ. of Kansas
Riat, Mehar C., Purdue Univ.
Riechel, Darrel A., Oregon Agr. College
Riggs, Harold C., Princeton Univ.
Robb, Harry C., Jr., Syracuse Univ.
Robbins, Clyde F., University of Illinois
Robertson, J. D., Oklahoma A. & M. College
Rochells, Jerome J., University of Ill.
Rochholz, Curtis A., Iowa State College
Rockwell, Ronald J., Iowa State College
Rosenberg, Marks, Brooklyn Polytechnic Inst.
Roush, Guy F., Bucknell Univ.
Rowland, James, Rutgers Univ.
Rubin, Milton M., Rose Polytechnic Institute
Ruus, Earl, Iowa State College
Sanders, Robert B., Iowa State College
Sasser, Ralph E., Purdue Univ.
Sato, Robert K., Rose Polytechnic Inst.
Sax, Eli J., Mass. Inst. of Tech.
Saxe, William R., Cornell Univ.
Schell, Paul, University of So. Dak.
Scherner, Hermann, Oregon Agr. College
Schmelling, Christian E., Syracuse Univ.
Schmidt, Oliver D., Kansas State Agr. College
Schnur, Raymond C., University of Louisville
Scholz, Walter E., Iowa State College
Scholz, William, Armour Inst. of Tech.
Schonvizner, Michael, Case School of Applied Science
Schooley, Charles E., Univ. of Missouri
Schott, Lionel, Univ. of Missouri
Scott, Robert F., University of Maine
Scoville, Ray R., University of Washington
Seiter, Norman W., Syracuse Univ.
Sennett, Harold E., University of Maine
Setterstrom, R. C., Oregon Agr. College
Shawhan, Sam F., University of Ky.
Sherman, Kenneth S., Case School of Applied Science
Sherman, Robert E., University of Ky.
Sherwood, William E., University of Ky.
Simokat, Robert F., Case School of Applied Science
Slocum, Adelbert I., Northeastern University
Slocum, Richard M., Purdue Univ.
Slone, Horace, Syracuse Univ.
Smith, Charles F., Kansas State Agr. College
Smith, Edgar H., Lafayette College
Smith, Emerson C., Ohio Northern University
Smith, Finley W., Pennsylvania State College
Smith, Rollo A., Okla. A. & M. College
Smith, W. Paul, Alabama Poly. Institute
Smoot, Charles B., University of Ky.
Snelling, Will D., Texas A. & M. College
Snook, Starr K., So. Dak. State School of Mines
Snow, Hewitt A., Alabama Poly. Institute
Sparks, William J., Jr., University of Ky.
Spittle, Samuel E., Oregon Agr. College

Sprague, Clarence A., Washington State College
Stage, Joseph H., Marquette University
Staggs, Russell W., Rose Polytechnic Institute
Stanat, Arthur E., Cornell University
Stanley, Wilbur G., Mass. Inst. of Tech.
Starr, Frank, Jr., University of Colorado
St. Clair, Elgar L., University of New Hampshire
Steinert, Paul W., Armour Inst. of Technology
Stigers, Orren K., Univ. of Utah
Stocker, Arthur C., Ohio State Univ.
Stonefelt, Elmer G., So. Dak. State School of Mines
Stotler, Charles L., Pennsylvania State College
St. Pierre, Stowell, Northeastern University
Strobel, Horace R., Marquette University
Strodthoff, Geo. P., Marquette University
Swenson, Carl R., University of Washington
Swingle, William M., Mass. Inst. of Tech.
Syner, Truman L., University of Idaho
Tanner, Arnold F., Case School of Applied Science
Tanner, Carl C., Kansas State Agr. College
Tarr, James E., University of Maine
Taylor, Paul G., University of Colorado
Taylor, Paul H., Stevens Inst. of Tech.
Taylor, Roland C., Case School of Applied Science
Tenenbaum, Murray I., Columbia Univ.
Ter Maat, Edward, Armour Inst. of Tech.
Thaeler, Charles S., Lehigh Univ.
Thakur, Manohar L., Mass. Inst. of Tech.
Thatcher, John W., Calif. Inst. of Tech.
Thomson, Wilfrid R., University of Toronto
Thrall, Leon D., Ohio State Univ.
Tiller, Vernon L., Univ. of Missouri
Tobey, Raymond E., University of Maine
Tomkinson, Albert E., Northeastern University
Tomlinson, George W., Univ. of Kansas
Towle, Howard C., Jr., Lehigh Univ.
Tracy, Maurice B., Armour Inst. of Tech.
Tracy, Stephen J., Stevens Inst. of Tech.
Treweek, James, Lafayette College
Trice, Thomas W., Carnegie Inst. of Tech.
Troy, Constantine T., Cornell Univ.
Tsai, H. L., University of Illinois
Tsui, J. H. H., University of Pittsburgh
Tucker, Stanley W., Lewis Institute
Turner, Earl N., Oregon Agr. College
Turrell, Robert M., Univ. of Cincinnati
Tweeddale, Elwood L., Mass. Inst. of Tech.
Ulmer, Alfred R., Bucknell Univ.
Uyeda, Tokujiro, Mass. Inst. of Tech.
Valentine, Francis B., Ohio State Univ.
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Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

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MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th day of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

GRADUATE ENGINEER, with approximately five years' general experience in engineering work, preferably distribution experience in eastern public utility. Experience handling men desirable. Salary $3000 a year to start. Opportunity. Apply by letter stating age, education, and complete experience in detail, and enclose photograph. Location, New York City. X-1089.

CERAMIC ENGINEER, with one to two years' experience, for chemical company. Apply by letter. Location, New York. X-1117.

AN ESTABLISHED AND SUCCESSFUL CONSULTING ENGINEERING BUSINESS in New York City desires to add to its staff with an early chance of partnership, a graduate engineer having broad engineering experience, including sales, to take charge of a new extension of their business. No investment necessary, but prefer if applicant could carry himself financially for six months, although latter condition not absolutely necessary. Give detailed account of experience, when available, etc. X-1312.

MEN AVAILABLE

COLLEGE GRADUATE, '25 in E. E., desires position where he can acquire experience either in appraisal or construction work. Available two weeks. Location, New York. C-512.

1925 GRADUATE ELECTRICAL ENGINEER, desires position with public utility. One year's experience in overhead distribution. Available on reasonable notice. C-294.

ELECTRICAL ENGINEER, Lehigh graduate, 36, thoroughly experienced in coal mining, steel mill and allied industrial operations, invites correspondence with view toward connection with responsible firm. Now employed satisfactorily, but future limited by conditions beyond personal control. Available within month. B-4905.

ELECTRICAL ENGINEER, technical graduate, G. E. test and six years' experience with large public utilities including engineering, operation and commercial work; specialized in

cost and rate work. Desires position in valuation and rate work with public utility company or with firm of consulting engineers. B-9782.

ELECTRICAL DESIGNER, thoroughly experienced in substation and power-plant layout; six years European, two and one-half years' American experience with public utility and consulting company. 32 years old, and of Swedish origin. Would consider position as translator from German and the Scandinavian languages. Available immediately. C-2088.

UTILITY ENGINEER, 38, married, technical graduate. Fourteen years' experience testing, manufacture, installation, design and operation. Last six years spent in operation and management of a small utility. Desires position of responsibility with a utility or holding company in or near New York. A-2018.

ENGINEER, with public utility experience, including industrial power sales work; experience with a large industrial covering steam and power production, maintenance, rehabilitation, etc., also test floor and erecting experience with large electrical manufacturer. Cornell graduate, M. E. E. E. Only prospect of reasonably permanent employment considered. B-6764.

ELECTRICAL ENGINEER, 40, married, designer and manufacturer of small interchangeable electric equipment and parts, automatic machinery, power plants, transmission lines, catenaries and high tension systems, layout, costs and details. Accustomed to purchasing all material needed. Corporation executive work organizing and handling men in field and office and drafting room. Available now. Location preferred, New York, or within commuting area. B-8863.

GRADUATE IN ELECTRICAL ENGINEERING, desires a position in which there are possibilities of a future. Experienced in radio broadcasting and experimental amateur work, eight years. Has had experience in civil engineering and drafting. Location, Philadelphia or vicinity. Available in about two weeks. C-2129.

ASSISTANT ENGINEER, 29, single, technical graduate, with four years' power plant experience, including installation, material, estimating and valuation experience, desires a connection with consulting engineer or firm offering position of similar status on staff. Salary open. Available immediately. Location, East. C-1183.

RECENT GRADUATE IN E. E., with a year of varied experience in utility work, desires a position with construction or holding company. C-2147.

ENGINEER, 33, married, no encumbrance, desires change. Experience; five years apprentice mechanical engineer, designing and complete installation telephony and telegraphy (high speed cable and wireless), offices and plant, factory and plant management, automotive machinery. Able to handle men. Used to Tropics. Location, any part of World. C-2151.

PROFESSOR OF ELECTRICAL ENGINEERING, desires change, holds degrees from two large American universities. Has twice risen to be head of E. E. departments in State College. Fine administrator and teacher. Age 41, married, Protestant, member of A. I. E. E. and S. P. E. E. Correspondence invited. C-2155.

DISTRIBUTION ENGINEER, technical graduate, 33, married, several years' electrical and mechanical test experience in power stations. Five years' distribution experience with large public utility in East. Desires position in distribution engineering, or sales engineering in distribution field. Location, East. Available one month. Salary $280.00. B-1410.

DESIGN ENGINEER, age 31, technical man with nine years' experience on electrical design of modern power plants and indoor and outdoor substations. Thoroughly familiar with up to date practises and equipment and capable of supervising and checking work. Location, New York City. C-292.

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Rensselaer Polytechnic Institute, Troy, N. Y	F. M. Sebast	W. C. Michels	F. M. Sebast
Rhode Island State College, Kingston, R. I	G. A. Eddy	C. Easterbrooks	Wm. Anderson
Rose Polytechnic Institute, Terre Haute, Ind	J. H. Utt	E. Letsinger	C. C. Knipmeyer
Rutgers University, New Brunswick, N. J	E. C. Siddons	W. H. Bohlke	F. F. Thompson
Santa Clara, University of, Santa Clara, Calif	F. Whitwam	W. P. Fisher	D. W. Griswold
South Dakota State School of Mines, Rapid City, S. D	C. Allen	Harold Eade	J. O. Kammerman
South Dakota, University of, Vermillion, S. D	Maurice Nelles	Stanley Boegler	B. B. Brackett
Southern California, University of, Los Angeles, Calif	Karl Raife	E. E. Smith	C. E. Guse
Stanford University, Stanford University, Calif	A. V. Pering	J. G. Sharp	H. H. Henline
Stevens Institute of Technology, Hoboken, N. J	D. B. Wesstrom	G. E. Witham	Frank C. Stockwell
Swarthmore College, Swarthmore, Pa	J. S. Donal, Jr.	R. W. Lafore	Lewis Fussell
Syracuse University, Syracuse, N. Y	G. F. Kern	T. P. Hall	C. W. Henderson
Tennessee, University of, Knoxville, Tenn	F. N. Green	B. M. Gallaher	Charles A. Perkins
Texas A. & M. College, College Station, Texas	C. A. Altenbern	J. L. Pratt	F. C. Bolton
Texas, University of, Austin, Tex	F. W. Langner	H. W. Zuch	J. A. Correll
Utah, University of, Salt Lake City, Utah	F. C. Bates	C. E. Hoffman	J. F. Merrill
Virginia Military Institute, Lexington, Va	R. P. Williamson	M. L. Waring	S. W. Anderson
Virginia Polytechnic Institute, Blacksburg, Va	R. M. Hutcheson	M. B. Cogbill	Claudius Lee
Virginia, University of, University, Va	R. C. Small	H. M. Roth	W. S. Rodman
Washington, State College of, Pullman, Wash	S. H. White	H. R. Meahl	H. V. Carpenter
Washington University, St. Louis, Mo	E. B. Kempster, Jr.	R. L. Belshe	H. G. Hake
Washington, University of, Seattle, Wash	C. M. Murray, Jr.	Roy H. Crosby	George S. Smith
Washington and Lee University, Lexington, Va	C. M. Wood	R. E. Kepler	R. W. Dickey
West Virginia University, Morgantown, W. Va	I. L. Smith	P. E. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis	Benj. Teare	N. B. Thayer	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyo	John Hicks	J. O. Yates	G. H. Sechrist
Yale University, New Haven, Conn	W. W. Parker	J. W. Hinkley	Charles F. Scott
Total 93			

JOURNAL

OF THE

American Institute of Electrical Engineers

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Transformers.—Bulletin 20133-A, 4 pp. Describes Westinghouse SK steel clad distribution transformers. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Generator Voltage Regulators.—Bulletin 702, 12 pp. Describes quick acting automatic generator voltage regulators. American Brown Boveri Electric Corporation, 165 Broadway, New York.

Graphic Meters. Bulletin 1026, 4 pp. on New Uses for Graphic Meters. Describes the recording of automatic stations performance. The Esterline-Angus Company. Indianapolis, Ind.

Theater Switchboards.—Bulletin 1702-A, 20 pp. Describes various types of switchboards for theater lighting control. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Battery Charging Control Equipment.—Bulletin GEA 484, 4 pp. Describes a new line of unit control sections for battery charging service. General Electric Company, Schenectady, N. Y.

Electricity in Lumber Industry.—Bulletin GEA-106, 32 pp., entitled "Electric Drive in the Lumber Industry," describes and illustrates the application of electricity to the lumber industry. The General Electric Company, Schenectady, N. Y.

Meggers.—Catalog 1145, 48 pp. Describes Megger insulation testing instruments. The application of the complete line of these devices for the rapid and convenient testing of electrical insulation and measurement of resistance is illustrated by photographs. James G. Biddle, 1211 Arch Street, Philadelphia, Pa.

Supervisory Control.—Bulletin C-1694-B, 12 pp. Describes supervisory control systems, treating on the synchronous visual type of equipment, code visual type and the audible type. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Edison Hour Radio Programs.—The New York Edison Company, 130 E. 15th St., New York, has issued an attractive pamphlet of thirty-two pages outlining the radio programs to be broadcast from WRNY during Edison hour each Tuesday for the coming winter months. The title of this publication is "Twenty-one Adventurous Nights."

Radio and Electrical Laboratory Apparatus.—Bulletins enclosed in loose leaf binder. Among the apparatus described are decade and variable air condensers, standards of resistance and decade resistance boxes, audibility meters, standards of inductance, decade and capacity bridges, vacuum tube bridges, precision condensers, precision wavemeters, amplification test sets, station frequency meters, miscellaneous transformers and power amplifiers and plate supply. General Radio Company, 30 State Street, Cambridge (39) Mass.

NOTES OF THE INDUSTRY

G-E Reduces Prices of Motors and Transformers.—A reduction in prices on its general purpose motors, amounting to five per cent on most lines and ten per cent on commonly used sizes of squirrel cage induction motors, has been announced by the General Electric Company, effective December 1, 1926. The motors affected by the new price levels include both a-c. and d-c., constant and variable speed general purpose motors, from one to 200 horse power. Prices of standard squirrel cage induction motors have now been brought by the company to a level within about 10 per cent of that in 1914.

Effective November 8, a reduction averaging five per cent was made in the prices of distribution and small power transformers, 500 kv-a. and less, 73,000 volts and below. This is the fifth reduction that has been made by the General Electric Company on this class of material since 1920.

The Simplex Wire and Cable Company, Boston, announces the removal of its St. Augustine office to the Barnett National Bank Building, Jacksonville, Fla. Miss F. H. Pettee continues as Florida manager.

Air Filters.—Midwest Air Filters, Inc., Bradford, Pa., have placed on the market a "Self Clean" air filter which consists of an endless chain of standard Midwest filter units arranged so that they pass through a tank at the bottom of the device for constantly maintaining a fresh Viscosine surface. The operation is continuous or intermittent, as desired. These "self clean" air filters are supplied in standard units with capacities from 10,000 to 25,000 C. F. M.

The Ohio Brass Company, Mansfield, Ohio, has established new quarters for its San Francisco and Los Angeles branch offices. The address of the San Francisco office is Rooms 531-533 Matson Building, 215 Market Street. The Los Angeles office is located in Room 508 Subway Terminal Building, 417 So. Hill Street. In both of these cities the company will continue to carry ample stock of its various products for the convenience of the Western trade.

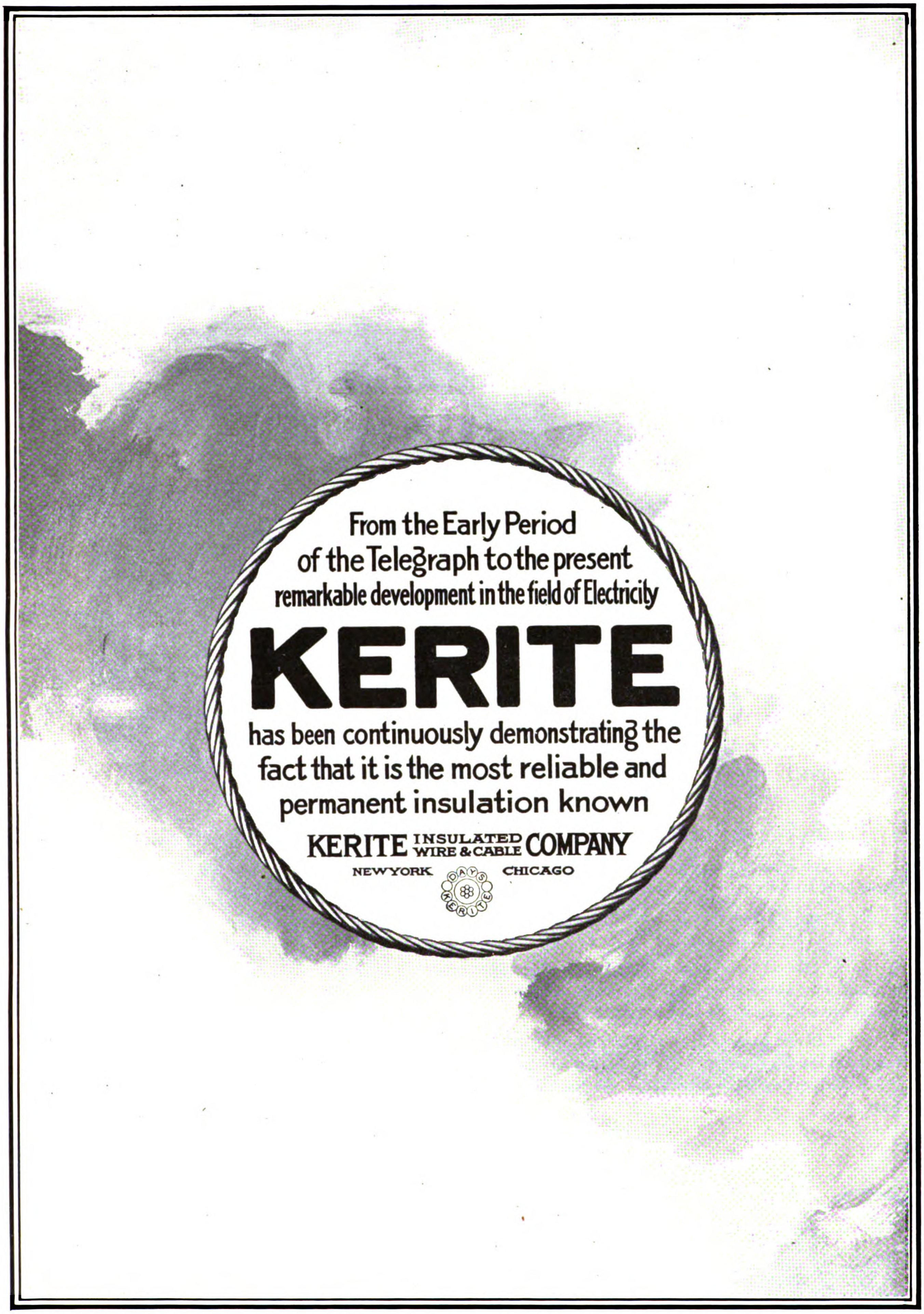
Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has opened a branch office in Jackson, Michigan, with L. F. Berry as resident representative. This office is located at 512 Reynolds Building, Jackson, and is a branch office of the company's office in Detroit, which is under the direction of F. S. Schuyler.

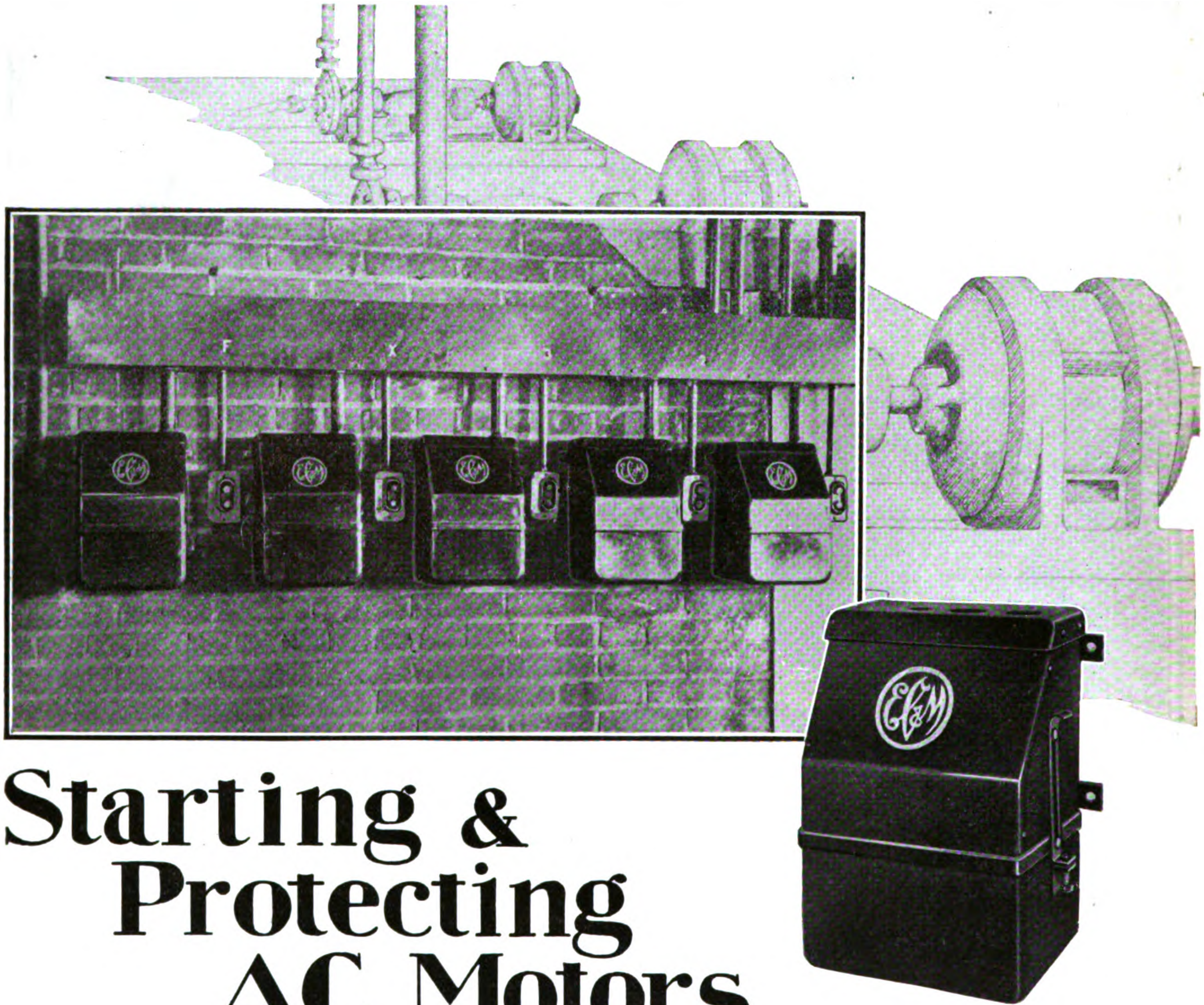
The company also announces the appointment of Ernest Smith as sales engineer in the Oruro, Bolivia office. This is a branch of the district office at Santiago, Chile.

The James R. Kearney Corporation, St. Louis, manufacturers of overhead and underground utility equipment, announces that the following have recently joined the sales organization: Herb Keller and Arthur Miller, of Power Machinery Company, Kansas City, Missouri, as special representatives in the Kansas City territory. W. M. Watters, formerly a representative of W. N. Matthews Corporation, in the Kansas City Territory, as special representative in the St. Louis territory. J. J. Costello, as representative in the New England States territory with headquarters in Boston.

A New Improved Mica Insulation.—Phthalic anhydride, a few years ago a chemical curiosity produced from naphthaline or moth balls and quoted at $5 a pound, and today an important heavy organic chemical used in the manufacture of dyestuffs and selling at 25 cents a pound, has been combined with glycerine, a by-product of the soap industry, to produce a synthetic resin which has succeeded shellac as a binding material in the manufacture of pasted mica insulation or micanite. The resin, developed in the research laboratory of the General Electric Company, is known as Glyptal. It has been standardized by the company for all rigid mica insulation used in its apparatus, including segments, cones and backs for commutators, tubes, washers, plates, blocks, molded shapes, etc.

Highest Voltage Transmission System in Canada.—A 187,000-volt transmission line 140 miles long, operating at a much higher voltage than any other system in Canada, is being constructed by the Shawinigan Engineering Company as a duplicate transmission line between the Isle Maligne generating station of the Duke Price Power Company and the City of Quebec. The oil circuit breakers will be the largest, both electrically and physically, in Canada. The height over the bushings is approximately 20 feet, and the floor space nine by thirty-one feet. The high tension neutrals will be solidly grounded throughout the system. The oil tanks are cylindrical in form, 84 inches in diameter, and are of steel plate with welded joints. Explosion chambers of the C. G. E. design are used. The F-5 bushings will withstand a high potential test of 450,000 volts dry for one minute, equal to four times the line-to-neutral voltage, and provide an ample factor of safety for a system with solidly grounded neutrals.


From the Early Period
of the Telegraph to the present
remarkable development in the field of Electricity
KERITE
has been continuously demonstrating the
fact that it is the most reliable and
permanent insulation known
KERITE INSULATED WIRE & CABLE COMPANY
NEW YORK CHICAGO



Starting & Protecting A.C. Motors

Place your AC motors under push-button control by installing EC&M Type ZO Switches.

Type ZO Switches are built for across-the-line starting of squirrel cage motors up to 10 H.P. When these switches are in service, your operators have only to press a push button to start or stop their machines.

Type ZO Switches have their contacts immersed in oil so they can be safely used in corrosive atmospheres and where inflammable dusts and gases are present.

In case of overloads, lost phase or other abnormal conditions, your motors are completely protected without any blowing of fuses and costly delays. This protection is provided by an expansion wire trip which is 100% accurate and dependable.

It is not necessary to mount the ZO Switch so that it is accessible to the machine operator. After the overload trip has opened the motor power circuit, the operator has only to wait a few seconds and then press his starting button to again put his machine in operation. He has complete control from his push button.

Write for Bulletin 1048.

THE ELECTRIC CONTROLLER & MFG. CO.

CLEVELAND, OHIO

BIRMINGHAM - BROWN-MARX BLDG.
CHICAGO - CONWAY BLDG.
CINCINNATI - 1ST NATIONAL BANK BLDG.
DETROIT - DIME BANK BLDG.
NEW YORK - 50 CHURCH ST.
LOS ANGELES - THOMAS MACHINERY CO. AMERICAN BANK BLDG.
PHILADELPHIA - WITHERSPOON BLDG.
PITTSBURGH - OLIVER BLDG.
SAN FRANCISCO - CALL BUILDING
SEATTLE - 570 COLMAN BLDG.
TORONTO - TRADERS BANK BLDG.

Let's Get Down to Fundamentals

Push a book along the table. Note the drag due to the friction of sliding one surface over the other.

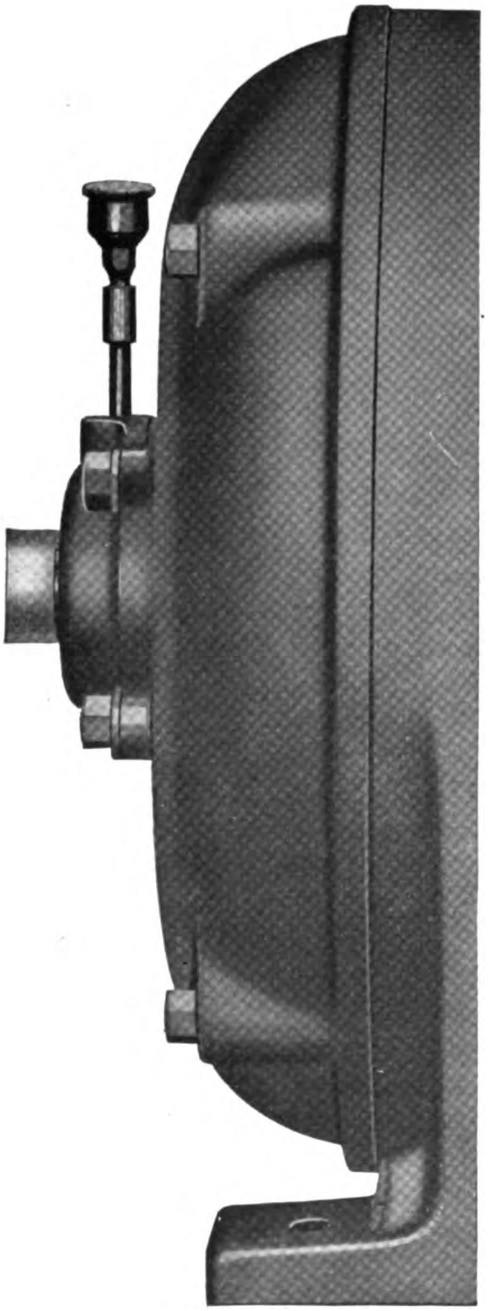
Place the book on pencils. It moves easier because *rolling* contact is substituted for sliding friction. But note the tendency of the rollers to change direction—and then to resist movement in the original direction.

Place the book on balls. The slightest touch starts the book across the table. And note particularly that the balls show no tendency to change the direction in which you are moving the book. Nothing rolls so easily, so true, so free of friction as a ball. *So it is with the New Departure Ball Bearing.*

New Departure Quality Ball Bearings

CONT. 427

Input and Output Brought Nearer Together



The margin between power input and power output has been steadily narrowed by Allis-Chalmers advancements. And the economy curve is kept flat year after year by Allis-Chalmers electrical and mechanical advantages.

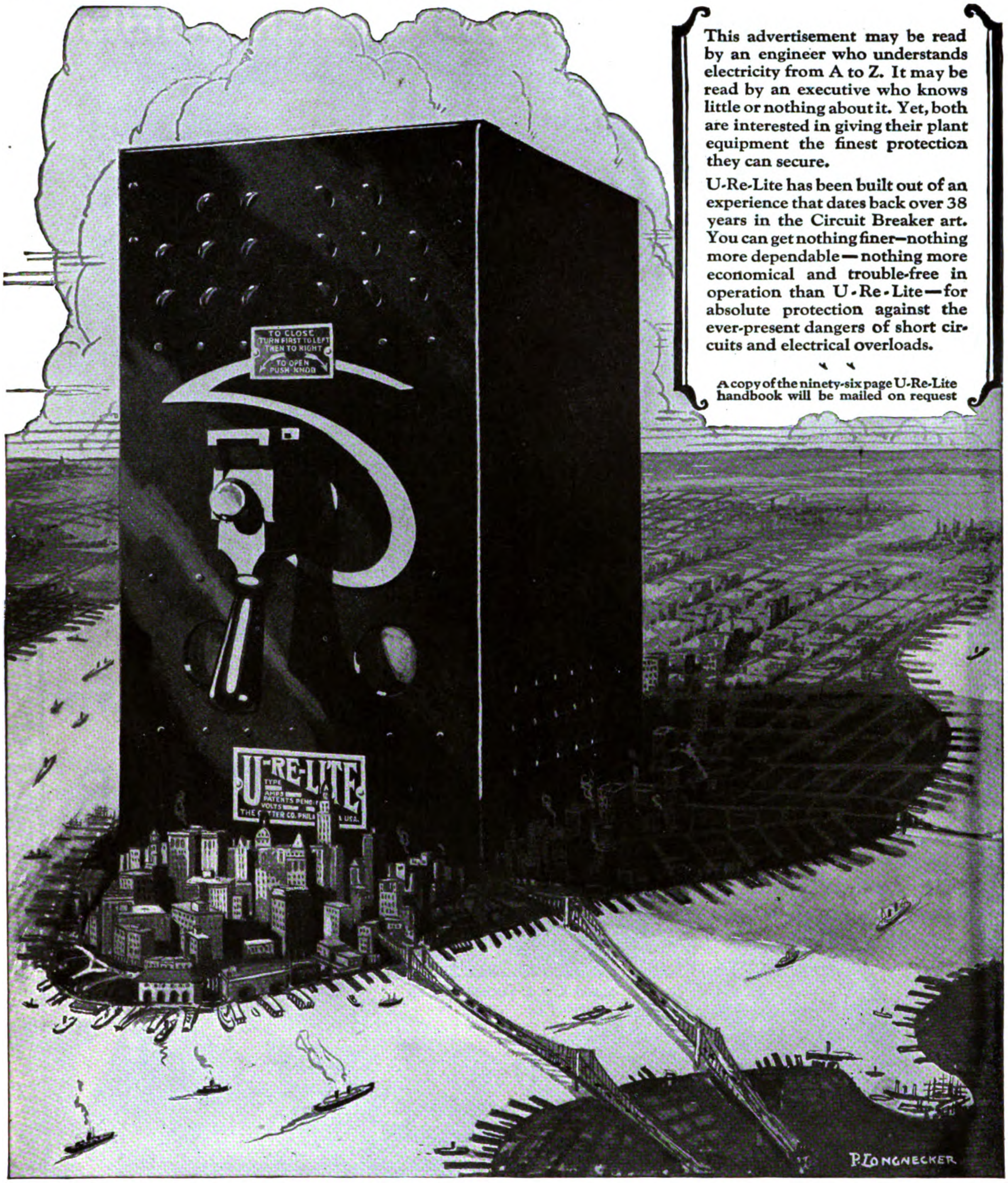
The frames of electric steel are shock-proof, rigid and clean. The special core construction produces an actual unit effect. Allis-Chalmers silver brazing has eliminated the rotor bar assembly as a critical factor. Allis-Chalmers Volume Ventilation is a positive cooling method under any conditions. The smooth, baked-on extra insulation is almost impenetrable.

The permanent wear resistance of the stationary parts is matched by the bearings themselves in Timken-equipped Allis-Chalmers motors! The higher load capacity of Timken Bearings, and their great freedom from friction means refined design, power-saving, and a continuously uniform gap, with no more than two or three greasings a year!

Anti-friction types and all other Allis-Chalmers motors are backed by authentic operating data, available at the Allis-Chalmers office nearest you—or by mail.

ALLIS-CHALMERS MFG. CO.
Milwaukee
District Sales Offices
in all Principal Cities

ALLIS-CHALMERS MOTORS



This advertisement may be read by an engineer who understands electricity from A to Z. It may be read by an executive who knows little or nothing about it. Yet, both are interested in giving their plant equipment the finest protection they can secure.

U-Re-Lite has been built out of an experience that dates back over 38 years in the Circuit Breaker art. You can get nothing finer—nothing more dependable—nothing more economical and trouble-free in operation than U-Re-Lite—for absolute protection against the ever-present dangers of short circuits and electrical overloads.

A copy of the ninety-six page U-Re-Lite handbook will be mailed on request

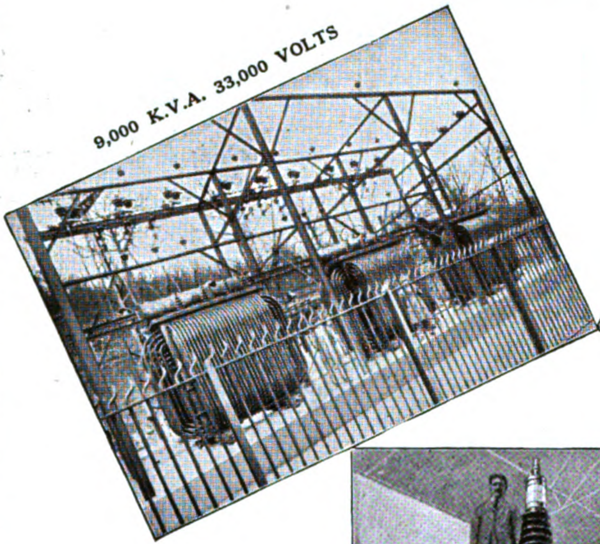
CUTTER

U-RE-LITE I-T-E CIRCUIT BREAKERS

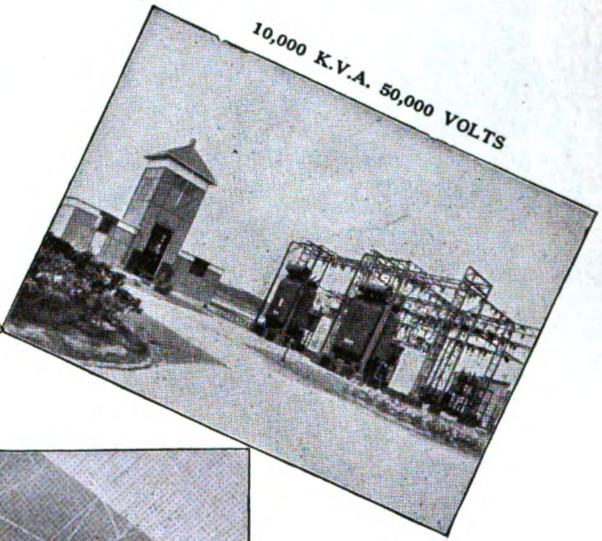
THE CUTTER COMPANY — *Established in 1888* — PHILADELPHIA, PENNSYLVANIA

FERRANTI

TRANSFORMERS

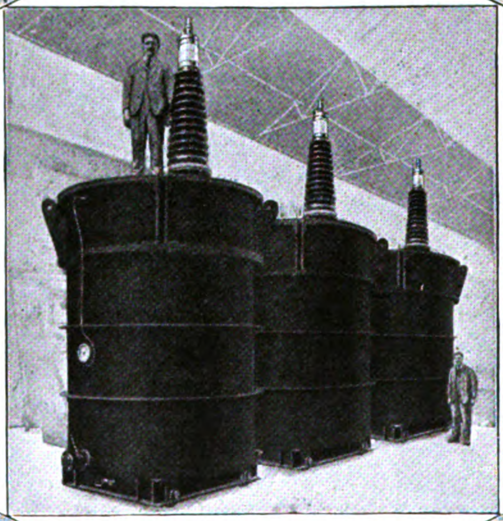


9,000 K.V.A. 33,000 VOLTS



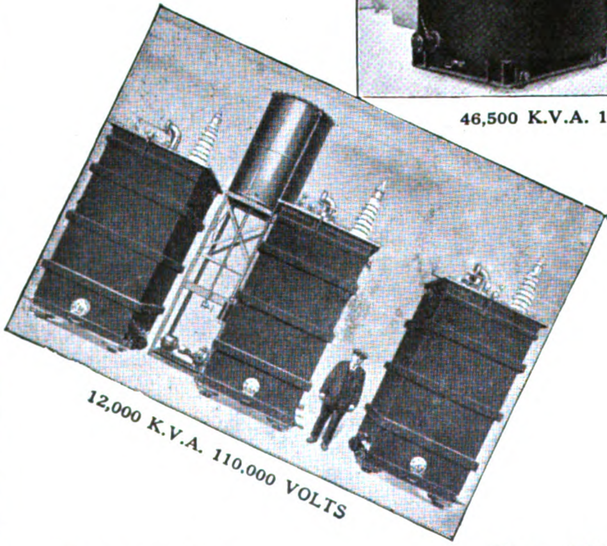
10,000 K.V.A. 50,000 VOLTS

FOR BIG

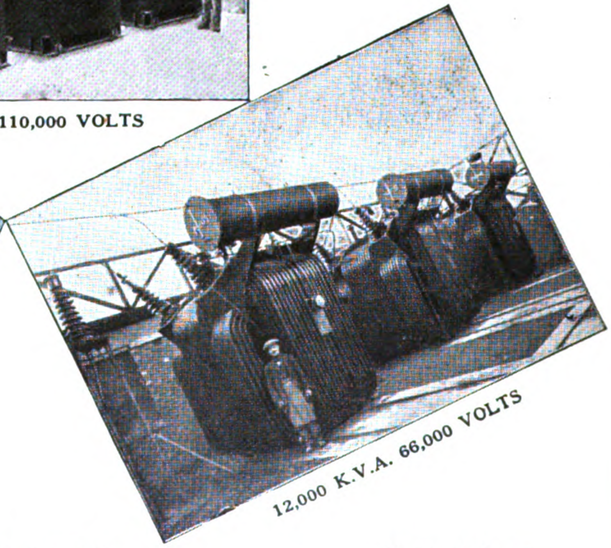


46,500 K.V.A. 110,000 VOLTS

POWER



12,000 K.V.A. 110,000 VOLTS



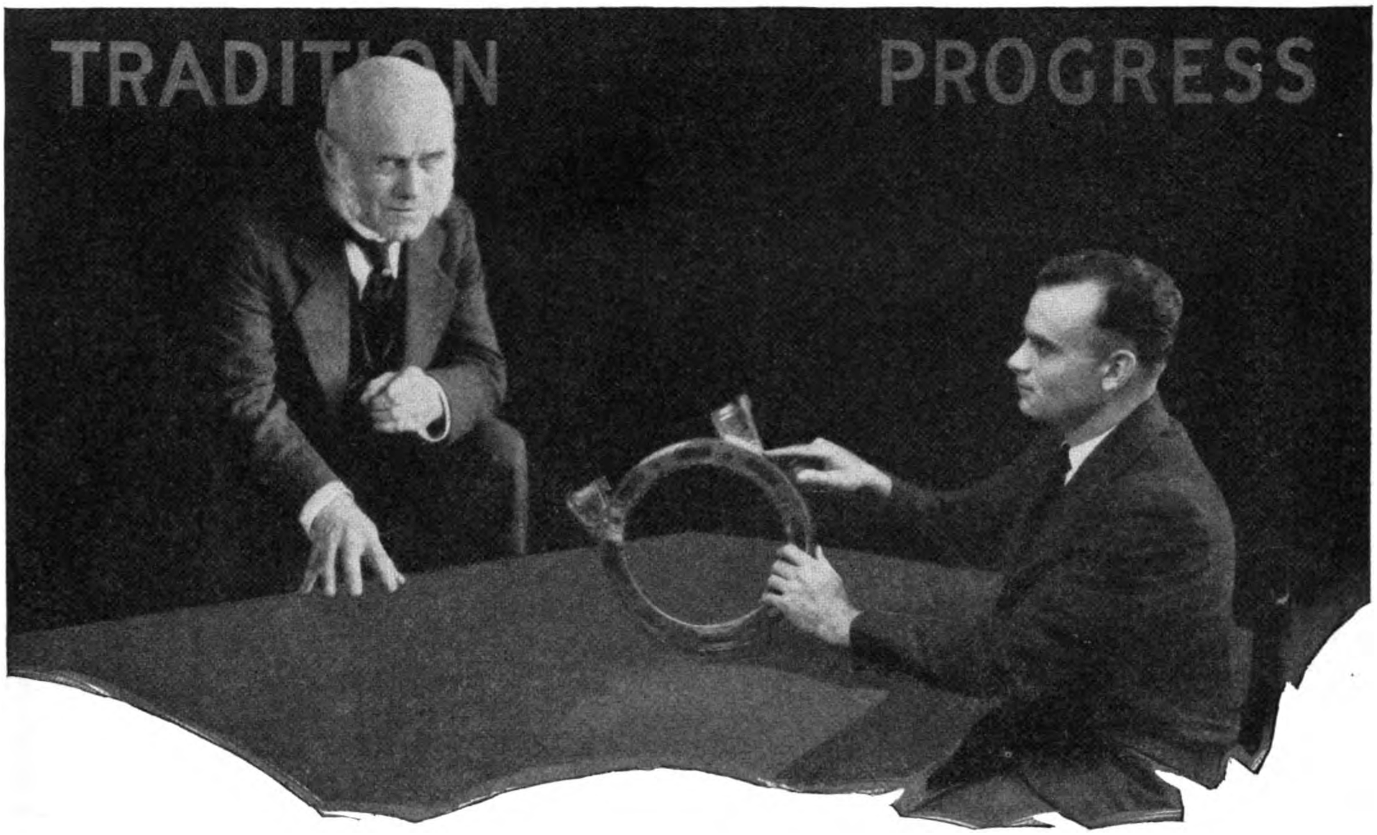
12,000 K.V.A. 66,000 VOLTS

Ferranti, Ltd.,
HOLLINWOOD, ENGLAND

Ferranti Electric, Ltd.,
26 Noble Street,
Toronto, Canada

Ferranti, Inc.,
130 West 42nd Street,
New York, U. S. A.

Pop Decides Not to Fire the Sweeper



"Here, Lad—

fire that sweeper in the lower plant—he's too careless! Last night he ran his rubbish truck against a motor and broke a foot off it—so we lose that machine's production until they get a new motor on the job."

"No, Pop—

you can't buy common sense in a sweeper, but you'd at least *expect* it in a motor maker.

There's always something sideswiping motors—and yet your gang of stiff-back motor assemblers stick to cast-iron feet. If they themselves didn't have clay feet they would weld drop-forged feet to a steel frame—just as in the Linc-Weld Motor.

Then your sweeper could do calesthenics with a sixteen-pound sledge and he couldn't "drop" a motor.

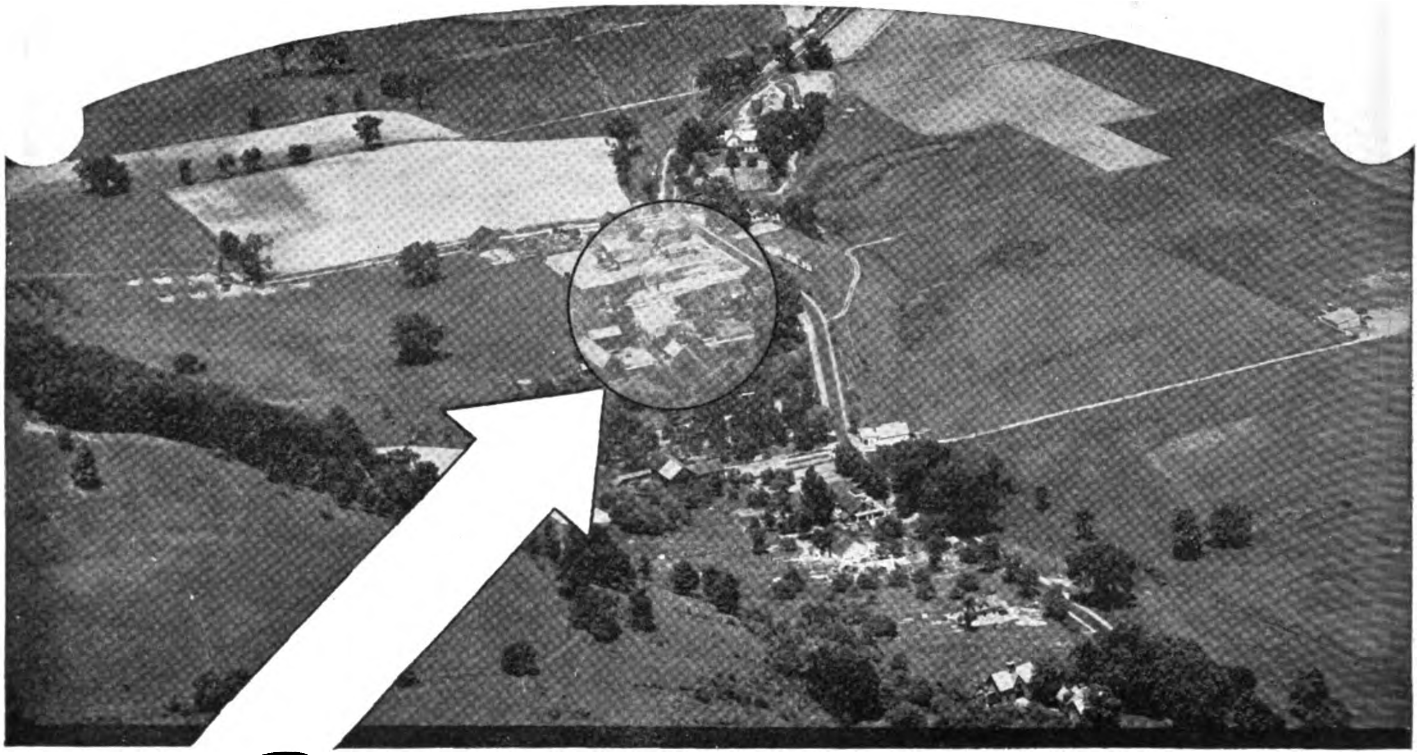
See Page 7 of the Motor Book. Better get yourself a copy from—
Department No. 21-12.

The Lincoln Electric Company, Cleveland, Ohio

MA-2

"Linc-Weld"

LINCOLN MOTOR



Out where trouble may begin

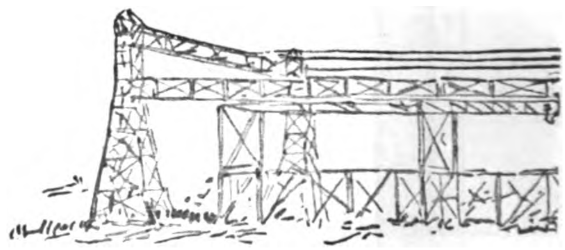
Troubles out on the line are none the less frequent in rural sections.

Lightning there, in season, is a potential source of trouble.

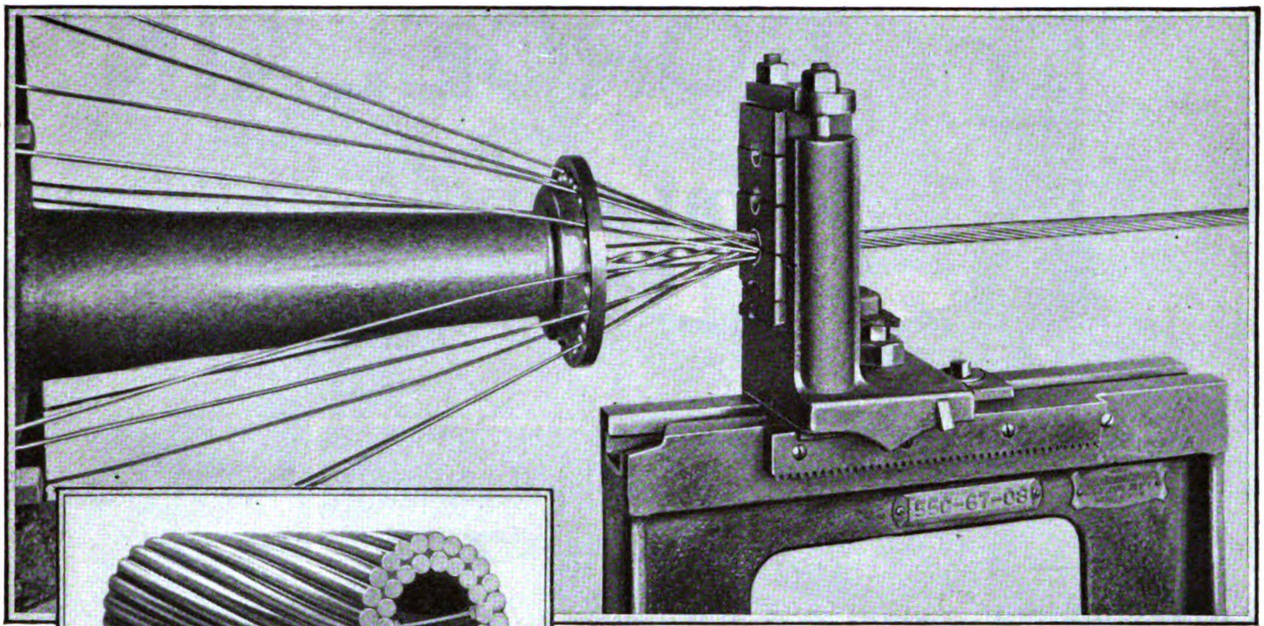
A wet tree can start as much trouble as a jammed motor.

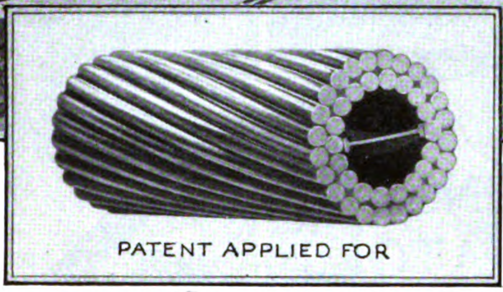
But this trouble need not get beyond the nearest station. If you have G-E Explosion-Chamber Breakers, it will not.

The rating of G-E Oil Circuit Breakers is always based on data obtained from actual tests. In this the special G-E testing facilities at Schenectady are an important factor. That G-E Breakers are rated well below the power they are able to handle is constantly being demonstrated by their successful operation under exacting conditions.



GENERAL





The illustration above shows how Anaconda Hollow Conductors are made by stranding copper wire over a spiral copper core.

Made entirely of Copper, and adapted to every transmission need

ANACONDA HOLLOW CONDUCTORS

IT IS possible to reduce corona and resistance losses in transmission lines by using Anaconda Hollow Conductors which are made entirely of copper—the most logical transmission material.

Anaconda Hollow Conductors can be designed with the diameters best adapted to cut down corona loss effectively, one, two, or three layers of strands being used as required. The twisted copper core, I-beam in shape, adds strength to the hollow construction without the addition of dead weight, or the sacrifice of conductivity or durability.

Where additional strength is required, the conductor may be reinforced with bronze strands, since bronze has the same temperature coefficient of expansion as copper.

Electrical engineers are invited to investigate the adaptability of Anaconda Hollow Conductors to their power transmission problems. Write for Research Bulletin C-6.

ANACONDA COPPER MINING CO.
THE AMERICAN BRASS COMPANY
Rod, Wire and Cable Products
General Offices: 25 Broadway, New York
Chicago Office: 111 W. Washington St.

ANACONDA COPPER

BRASS ANACONDA from mine to consumer BRONZE

LIKE the ski-jumper, the Condit Type FO-40 attains enormous acceleration at the "take-off". Multiple breaks in series accentuate its high speed of circuit interruption—one reason why the Type FO-40 is the outstanding breaker for higher voltage service.

CONDIT ELECTRICAL MFG. CORP.
Manufacturers of Electrical Protective Devices
Boston, Mass.

Northern Electric Company
LIMITED
Sole distributor for the Dominion of Canada

Specifications: 800 Amperes or less; 73,000 Volts; 50,000 Volts; 37,000 Volts. Interrupting Capacity 1,000,000 Kv-a or less. Breaker illustrated is 37,000 Volt B size.

CONDIT

New-

Type TA-1 Horn Gap Switch
15,000 to 73,000 volts
for outdoor service

Single-pole element of a Type TA-1 Triple-pole, Group-operated Horn Gap Switch with direct-manual operating mechanism.

Features

Sturdy construction.

Self-aligning contacts and blades.

Chopping action of blade removes sleet.

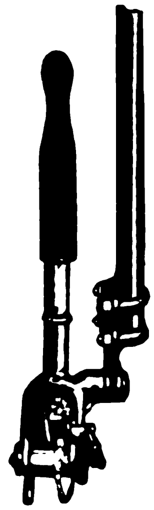
Malleable iron castings.

Hot-dipped galvanized malleable iron and steel parts.

Brass-bushed main bearings.

Shock-absorbing buffer springs.

Removable wooden handle.



General Electric supplies all equipment for outdoor stations, from transformers and oil circuit breakers to connectors and fittings, either individually or as a complete station "co-ordinated by G-E".

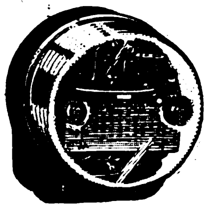
500-1

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES


"Steam Cured crack-proof"
CONTINUOUS EXPERIENCE DEVELOPMENT PROGRESS
THE SYMBOL of SERVICE
Where two or more porcelain parts are cemented together, as in the higher voltage pin type insulators, some means must be provided to safeguard the top and second section from expansion and contraction dangers due to the unequal rate of thermal change of these parts and their reaction on each other. The Locke "Steam Cured" process has become recognized as the only positive remedy for cracked tops in multi-part pin type construction Insist upon having only insulators which are "Steam Cured"– your best insurance for low maintenance and service satisfaction.
Process Patented.
LOCKE INSULATOR CORPORATION
Baltimore, Md.
Factories at Victor, N.Y. and Baltimore, Md.
Established LOCKE PORCELAIN 1894

Can a fault on one line of your distribution system cause interruptions on other lines?



The simple, sturdy, construction of G-E Induction Relays insures high, long-lived accuracy and permanent operating characteristics.

As DISTRIBUTION systems are always in danger of an occasional fault, they should be protected in such a way that the fault will be isolated before it can cause unnecessary interruptions on the rest of the system.

Relays, their operation depending *only* upon system conditions, operate promptly to take care of trouble by disconnecting the faulty line and keeping the rest of the system in operation even though it may carry for a short time a considerable overload due to the fault.

To establish and maintain a co-ordinated relay installation that will disconnect a line only when it should be disconnected requires a thorough knowledge of the distribution system and of relays—knowledge that many power companies have centralized to their best advantage in a department under the Protection Engineer.

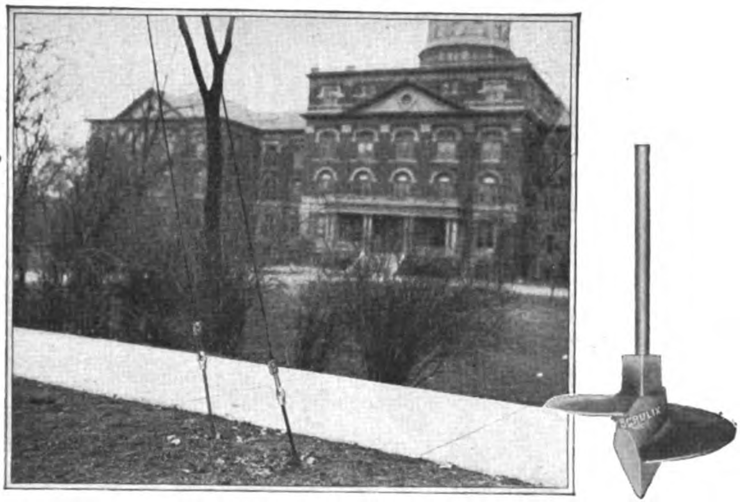
When new problems in the isolation of faults confront the Protection Engineer, valuable assistance in selecting the best method of relay protection can be obtained from G-E Relay Specialists, men who have the benefit of experience with relay installations on distribution systems all over the country.

Relays are an increasingly important factor in the generation, distribution, and utilization of electric power and the protection of electrical apparatus. Hence the Protection Engineer, who thoroughly knows relays and their applications, can be of service to every operating department.

501-3

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES



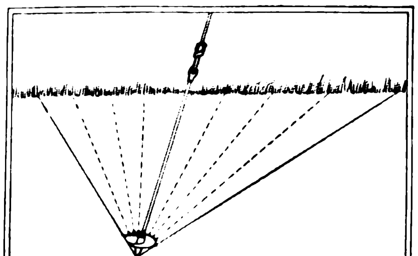
Time Proves

The difference between apparent and real holding power of Matthews Scrulix Anchors

More than one user has written us that his first impression of the probable effectiveness of Matthews Scrulix Anchors was that these comparatively small, easily handled anchors would undoubtedly fall short of the claims made for them. Their ease and low cost of installation, their neatness, and other advantages were definitely and decidedly favorable. But how could such anchors with only six to twelve inch helix possibly perform miracles of holding power in places where formerly it had been necessary to use costly and temporarily satisfactory devices? The secret lies in the design of the helix.

Tons of Resistance

The helix of the Scrulix Anchors is so designed that instead of depending merely upon the column of earth close to the shaft for holding power, it brings into play the tremendous weight of hundreds of cubic feet of earth around it. Under strain the lines of force radiate from the helix at a forty-five degree angle. For all ordinary purposes the use of comparatively small sizes is adequate.



In 5 to 15 Minutes

In less time than it takes to get a hole well started, two men can turn a Matthews Scrulix Anchor deep down under tons of earth without loosening the ground above. They come completely assembled, all in one piece, ready to install by simply screwing them into place. No moving parts to become lost or be buried unadjusted. One of the simplest and quickest operations in erection work.

No Creepage

Under water, in hard pan, loam, shale—wherever unusual anchorage problems occur—Scrulix Anchors demonstrate their advantages. No take-up in guys due to creepage is required. They hold fast permanently. Made in seven different sizes, Matthews Scrulix Anchors present an easy solution for any anchorage problem.

Learn More About Them Now

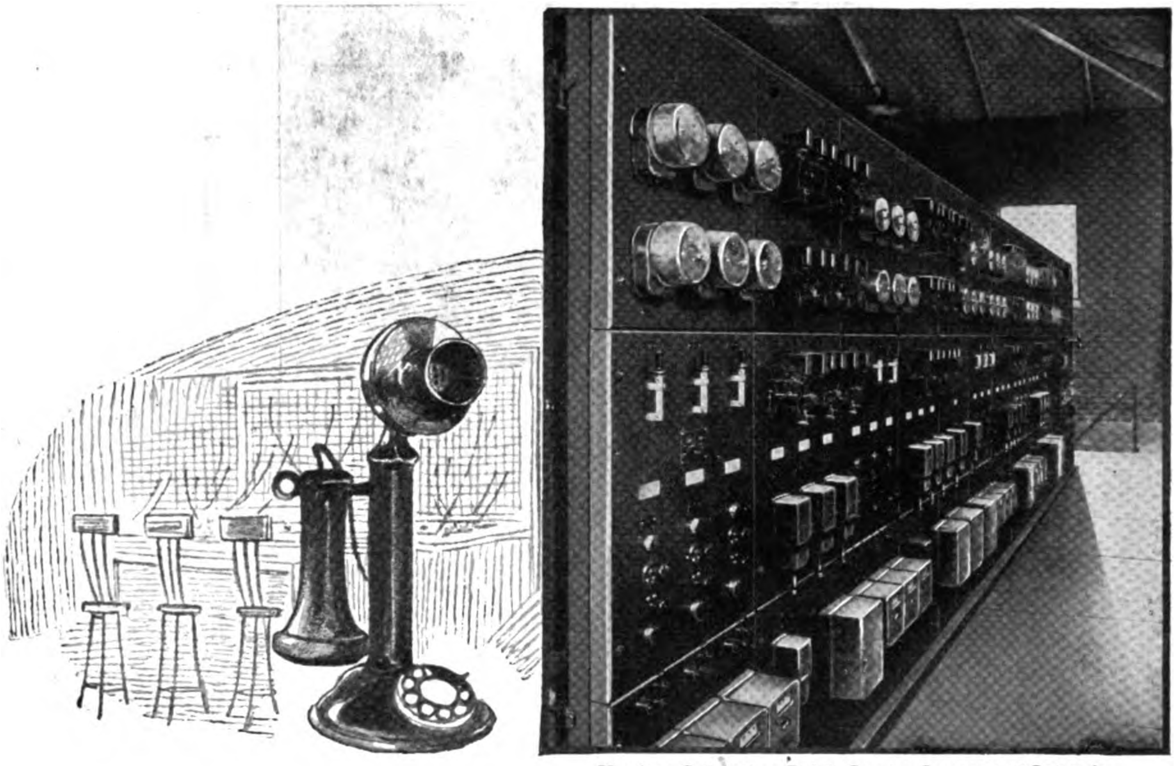
Write for Bulletin 800 covering in detail the interesting variety of applications of this anchorage principle. It will reveal to you complete mastery of anchorage problems as met by many companies during the last twenty years.

W. N. MATTHEWS CORPORATION
3706 Forest Park Blvd., St. Louis, U. S. A.

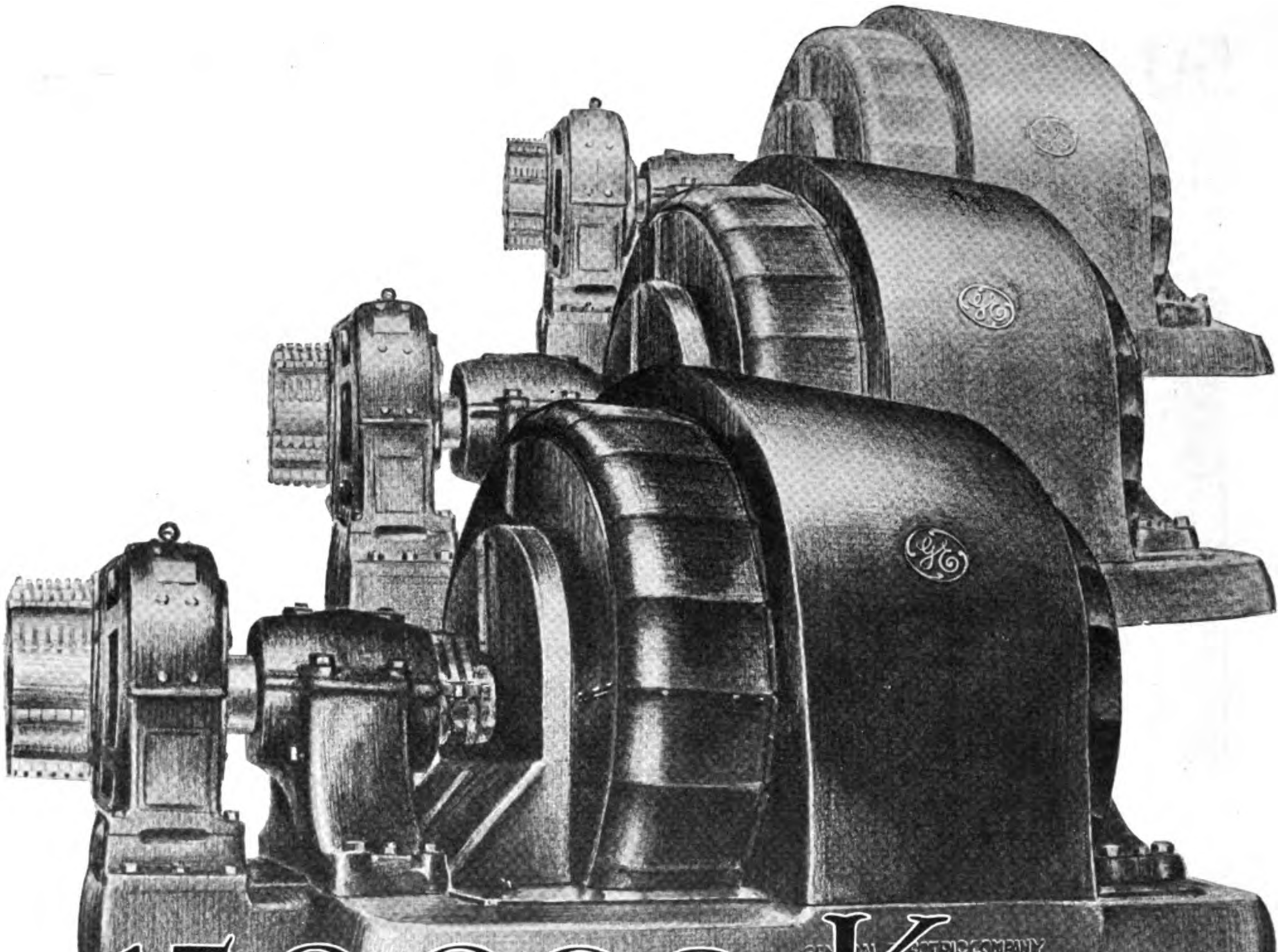
Ask about these Matthews Fuswitches · Matthews Disconnecting Switches
Matthews Scrulix Anchors · Matthews Adjustable Reel · Matthews Guy Clamps
Matthews Slack Puller · Matthews Cable Clamps · Matthews Lamp Guards
Matthews Telefault · Matthews Teleheight · *Distributors in all Principal Cities.*

60

MATTHEWS
SCRULIX ANCHORS



Harrison Substation, Public Service Company of Colorado



150,000 Kv-a.

of Synchronous Condensers

Three 50,000-kv-a. G-E Synchronous Condensers now under construction for the Southern California Edison Company are of much greater capacity than any previously built.

These machines will be used for regulating the voltage of the 220,000-volt transmission lines of that company, which carry power from the Big Creek hydro-electric development into Los Angeles. Two are for installation in the new Lighthipe Substation and the third will be placed in the Eagle Rock Substation.

Other G-E Synchronous Condensers on the lines of the Southern California Edison Company include two 30,000-kv-a. machines, which are installed in the Laguna Bell and Eagle Rock Substations.

With a standard line of Synchronous Condensers ranging from 500 to 50,000 kv-a., 60 cycles, for voltage control and power-factor improvement, General Electric can meet any demand for machines of this class. Where conditions make automatic operation desirable, installations can be equipped with G-E Automatic Control so as to require no attention other than occasional inspection.

108-4

GENERAL ELECTRIC

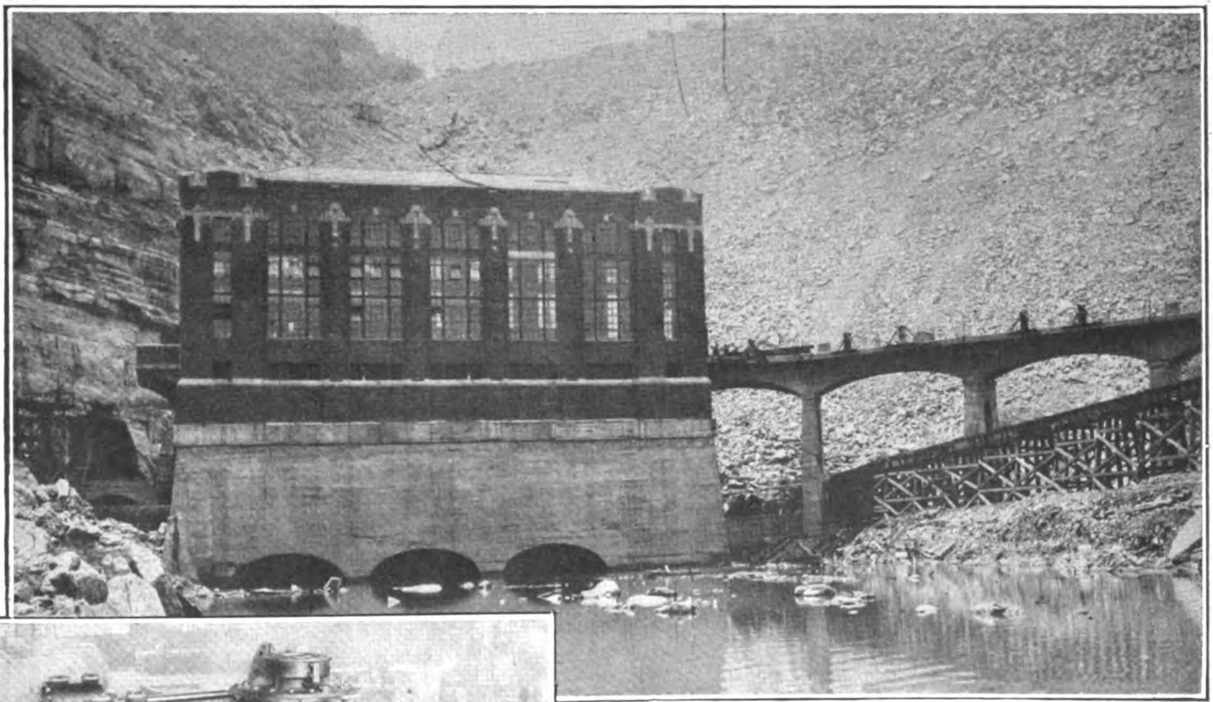
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES

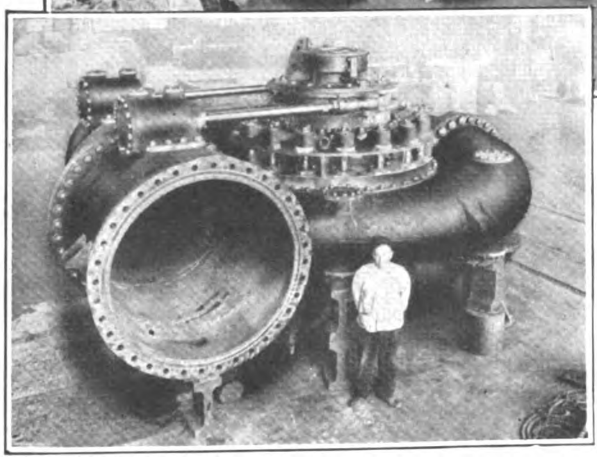
I. P. Morris Hydraulic Turbines

The Wm. Cramp & Sons Ship & Engine Building Co.

Richmond and Norris Streets, Philadelphia

New York Office: 100 Broadway **Birmingham Office: American Trust Building**





Shop Assembly of Turbine

DIX RIVER PLANT
of the
Kentucky Hydro-Electric Company

Installed capacity of 33,000 h. p. developed by

Three I. P. Morris Turbines

Head 235 Feet **Speed 300 R.P.M.**

These units are noteworthy in that they are designed for operation under a wide range in heads varying from 165 to 235 feet.

With each unit a 102″ x 66″ type "B" Johnson Hydraulic Valve is installed to control the quantity of water utilized by each turbine.

This project which includes the World's Highest Rockfill Dam, was designed and constructed by L. F. Harza, Hydro-Electric & Hydraulic Engineer, Chicago.

Designers and builders of the Johnson Hydraulic Valve and the Moody Spiral Pump

ASSOCIATED COMPANIES
THE PELTON WATER WHEEL CO., San Francisco and New York
DOMINION ENGINEERING WORKS, LTD., Montreal, Canadian Licensees

check up

Oil in

transformers

circuit breakers

oil switches

with the

American Transformer TS-6 Portable Oil testing outfit

Bulletin 1025 fully describes this unit and many other types of testing apparatus. Copy sent on request.

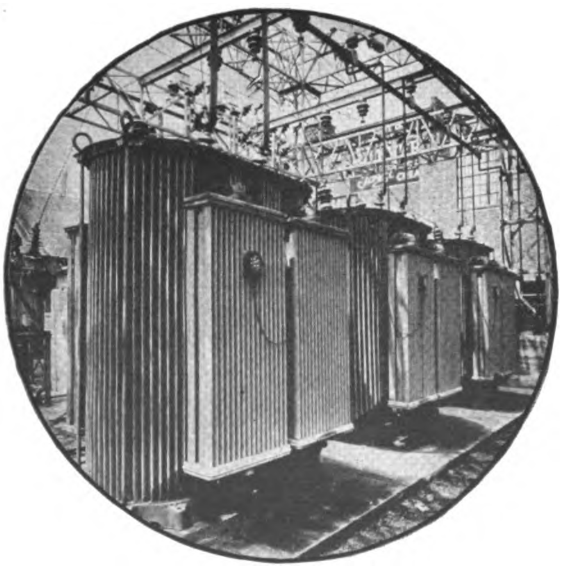
"Oil is often found in bad condition in above named equipment by the electrical inspectors of The Hartford Steam Boiler Inspection and Insurance Company, whose business it is to insure electrical machinery."

Guard against this on your property by using the American Transformer TS-6 testing set.

This transformer, complete with potentiometer regulator, primary main line switch, voltmeter, circuit breaker, pilot lamp and oil testing cup, is mounted in a heavy oak case with angle iron protecting pieces on the corners. It can be loaded on a truck or flivver and readily transported to wherever the insulating oil is to be tested.

AMERICAN TRANSFORMER COMPANY, 176 Emmet St., NEWARK, N. J.

Moloney Transformers



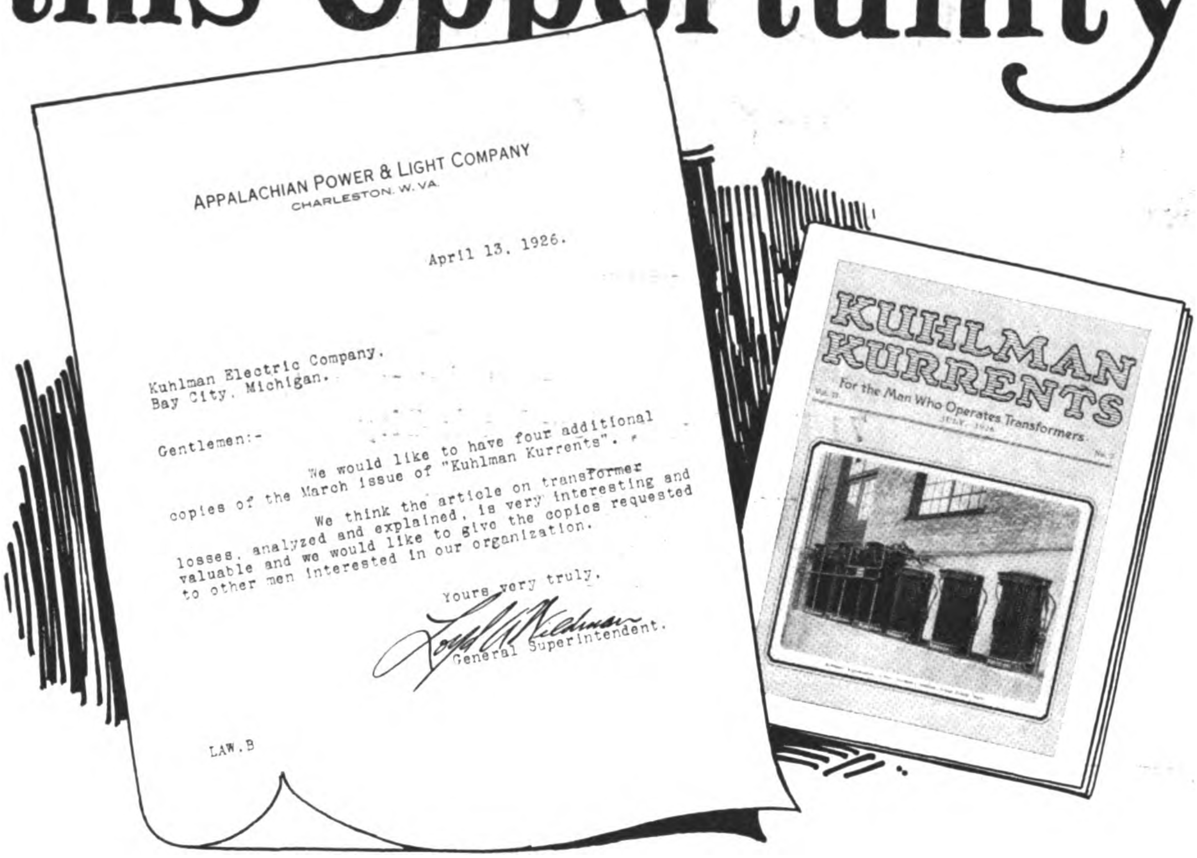
Every Installation Fully Demonstrates Moloney Quality

High quality performance has been identified with the name Moloney over a period of thirty years. During this time we have applied our complete efforts, time and experience to giving industry better transformers.

Complete information furnished upon requets

Moloney Electric Company
St. Louis, Mo.

Are You overlooking this Opportunity?



More than 6200 utilities and industrial concerns and individuals in their organizations are now taking advantage of the opportunity offered them by *KUHLMAN KURRENTS*—the opportunity to secure a better knowledge of transformers.

KUHLMAN KURRENTS report new developments in transformer design, construction, and application. They contain comprehensive discussions of the principles of transformer connections; they give interesting information regarding transformer operation. The letter reproduced here is typical of many requests for back numbers and duplicate copies—evidence of the value of *KUHLMAN KURRENTS*.

If a better knowledge of transformers will be helpful to you or others in your organization, take advantage of this opportunity by writing on your Company letterhead to our nearest office. There is no obligation.

KUHLMAN ELECTRIC CO., Bay City, Michigan

Atlanta........... 411 Glenn Bldg.	Dallas........Unit 2, Santa Fe Bldg.	Minneapolis..1004 Marquette Ave.	Salt Lake City..134 West 2d South St.
Boston............69-71 High St.	Denver.............1843 Wazee St.	New York......300 Madison Ave.	San Francisco............Call Bldg.
Buffalo............280 Carolina St.	Detroit......3-260 Gen. Motors Bldg.	Omaha........727 W. O. W. Bldg.	Seattle................314 Seneca St.
Chicago..............844 Rush St.	Indianapolis.202 Indiana Term'l Whse.	Philadelphia......1700 Walnut St.	Toledo..............421 Spitzer Bldg.
Cincinnati...1308 Union Trust Bldg.	Los Angeles.316 American Bank Bldg.	Pittsburgh.........839 Oliver Bldg.	Tulsa............318 So. Boulder St.
Cleveland........500 East 102d St.	Milwaukee........1031 Clybourn St.	Saint Paul, Minn.......1479 Blair St.	York, Pa...........335 W. Market St.

KUHLMAN TRANSFORMERS

POWER-DISTRIBUTION-STREET LIGHTING

STEEL

TOWERS

and component parts

FOR ELECTRIC TRANSMISSION

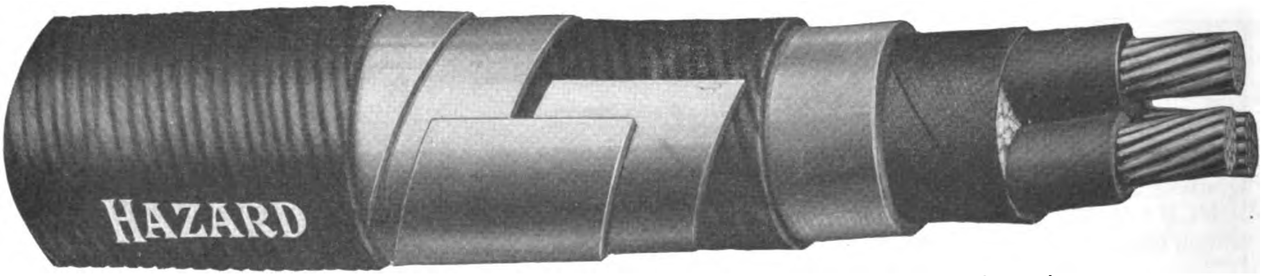
AMERICAN BRIDGE COMPANY

71 Broadway, New York City

TOWER DEPARTMENT

Frick Building, Pittsburgh, Pa.

Offices in Principal Cities



Three-phase Hazard Parkway Power Cable Conductors 0000 B & S 2300 volt service

FOR POWER TRANSMISSION

Consider the advantage of having your power cables safely underground—away from storm hazards and winter ice and snow—without the expense of installing conduits.

Hazard Parkway Cable with lead sheath, double layer of flat steel armor and asphalted jute covering, offers this advantage. By using this trouble-proof cable you can eliminate not only the expense and unsightliness of poles, cross-arms, insulators, etc., but the cost of laying and maintaining conduits.

Installation is simple. Dig a narrow trench, 18 in. to 24 in. deep, lay in the cable and cover up. The lead sheath, double steel tape armor and asphalted jute give permanent protection. No separate conduits are necessary.

This type of cable is especially advantageous for localized power distribution up to 25,000 volts.

ORNAMENTAL STREET LIGHTING

Parkway Cable is now used more than any other type of cable for street lighting, because of its low cost, easy installation and permanent high efficiency.

PUBLIC PARKS and COUNTRY ESTATES can be best lighted through the use of Parkway Cable, as it may be laid practically without disturbance to lawns, walks or roadways.

Let us send full particulars.

Hazard Manufacturing Company, Wilkes-Barre, Pa.

New York Philadelphia Pittsburgh Chicago Denver Birmingham

Maydwell & Hartzell, Agents, 158 11th St., San Francisco

HAZARD Parkway Cable

Minerallac Insulating Compound

"stands the gaff." In the winter months, when ice, sleet and snow combine to create hard operating conditions, Minerallac *"stands up."* It is generally specified on high-voltage lines in filling Cable Joints, Potheads and similar electrical equipment.

Write for Bulletin 100.

MINERALLAC ELECTRIC COMPANY

1043-1045 Washington Blvd.
CHICAGO

ATLANTIC

INSULATED WIRES

DOLPHIN ATLANTIC — NEPTUNE ATLANTIC — TRITON ATLANTIC

Including all types of rubber covered, and rubber covered lead encased wires and cables, bare wire, magnet wire, and flexible cords.

ATLANTIC INSULATED WIRE & CABLE COMPANY
Rome, N. Y.

WIRE PRODUCTS
For Varied Applications

We manufacture many types of wires, cords and cables for specific uses. Among them are:

Rubber Covered Wire—Solid Conductor, Stranded Conductor, Flexible Conductor, Extra Flexible Conductor. Lamp Cords, Reinforced Cords, Heater Cord, Brewery Cord, Canvasite Cord, Packinghouse Cord, Deck Cable, Stage Cable, Border Light Cable, Flexible Armored Cable, Elevator Lighting Cable, Elevator Operating Cable, Elevator Annunciator Cable. Switchboard Cables, Telephone Wire, Flameproof Wires and Cables, Railway Signal Wires, High Voltage Wires and Cables. Automobile Ignition Cables, Automobile Lighting Cables, Automobile Starting Cables, Automobile Charging Cables. Moving Picture Machine Cable.

Boston Insulated Wire & Cable Co.

Main Office and Factory:
Dorchester District Boston, Mass.
Canadian Branch, Office and Factory, Hamilton, Ont.

"COPPERWELD"
GUY AND MESSENGER WIRE
Does Not Rust

Consequently, the purchase of "oversize" Copperweld is not necessary. The size may always be based solely on the strength needed in the design. No allowance is needed for loss of strength due to rusting.

For example, where 10,000-lb. and 6000-lb. strengths are standard for galvanized strand, 8400-lb. and 5600-lb. strengths may be safely used with Copperweld, its non-rusting properties preserving its original strength.

Copperweld Steel Company

MAIN OFFICE & MILLS:-BRADDOCK P. O., RANKIN, PA.
30 CHURCH ST. NEW YORK. 129 S JEFFERSON ST. CHICAGO
403 RIALTO BLDG. SAN FRANCISCO
In Canada: Northern Electric Co., Ltd.

Roebling

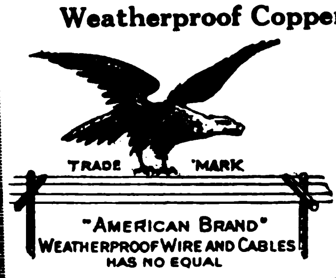
Electrical Wires and Cables. High in Conductivity and Reliability.

John A. Roebling's Sons Co.
Trenton, New Jersey

ROEBLING

"AMERICAN BRAND"

Weatherproof Copper Wire and Cables



COST

You can buy weatherproof wire cheap, but is it worth what it costs?

"American Brand" gives you more mileage per dollars with a longer life on the line.

Get a sample and satisfy yourself.

American Insulated Wire & Cable Co.
954 West 21st Street, Chicago

Cable Insurance

secured through effective terminal devices represents the best engineering practise of today. When such devices are properly applied to the ends of lead sheathed cables they protect the insulation from moisture and electrostatic discharges and prevent loss of time and money through cable breakdowns.

STANDARD

Outdoor (DOA) and Indoor (DS) Terminals

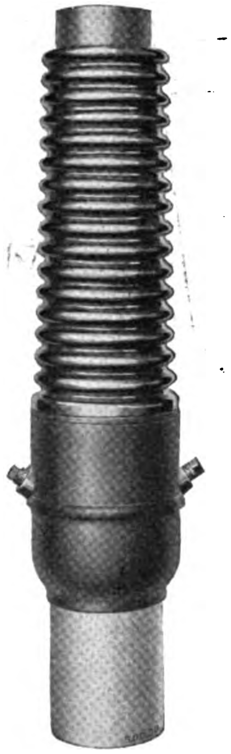
have their protective features developed and perfected beyond any other terminals on the market. The effectiveness of these features has been demonstrated by many years of service under all sorts of climatic conditions. STANDARD Terminals are also convenient to install, cheap to maintain, and have disconnecting features which make for flexibility in operation.

If interested in cable insurance write our nearest office.

Standard Underground Cable Co.

BOSTON WASHINGTON CHICAGO KANSAS CITY NEW YORK ATLANTA DETROIT
SEATTLE PHILADELPHIA PITTSBURGH ST. LOUIS LOS ANGELES SAN FRANCISCO

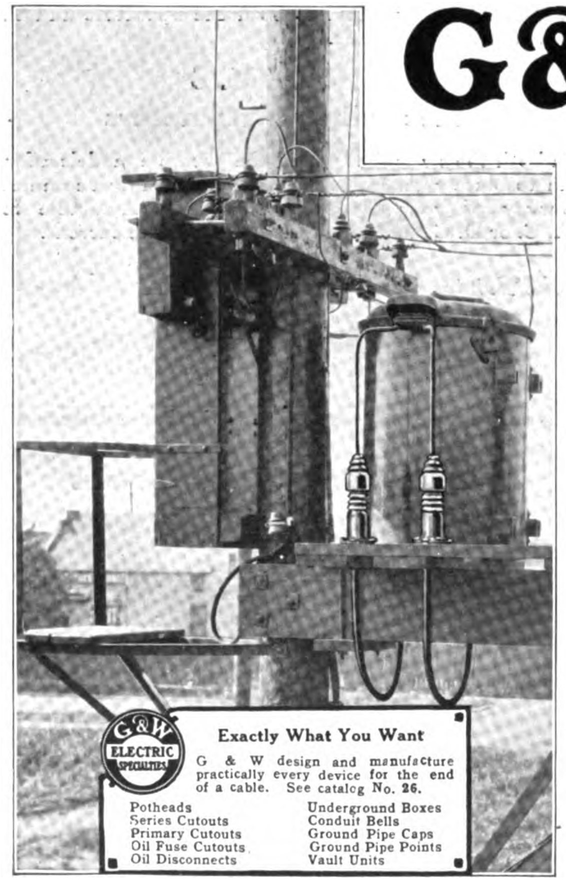
FOR CANADA: STANDARD UNDERGROUND CABLE CO., OF CANADA, LIMITED, HAMILTON, ONT.



35 KV. DS Terminal

G&W POTHEADS

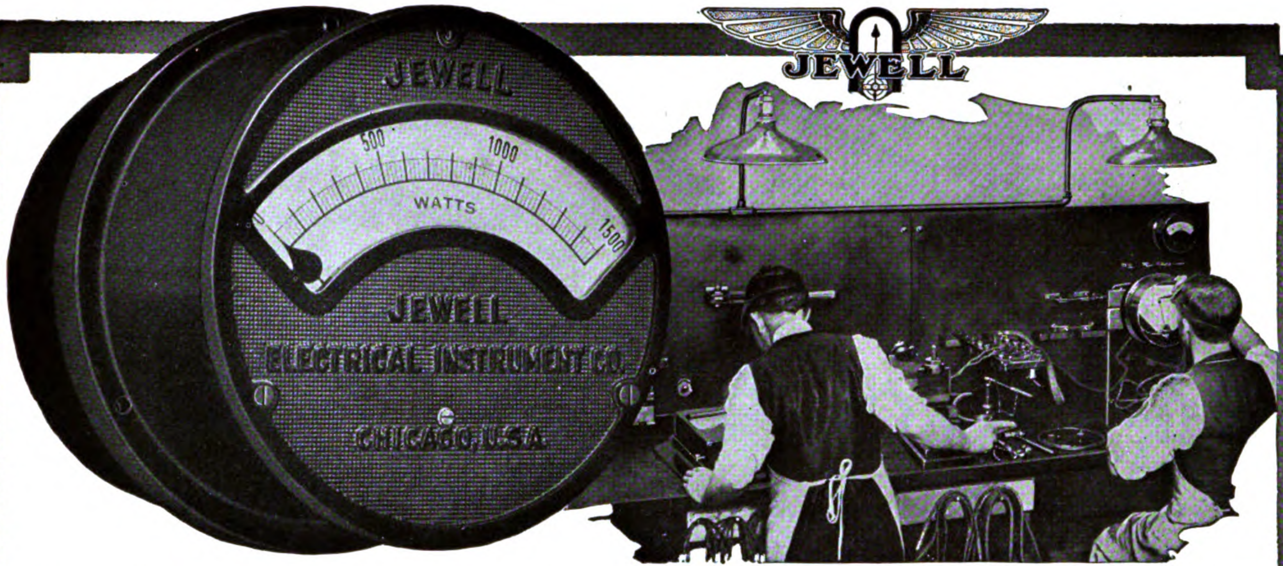
MORE THAN PROTECTION FOR CABLE ENDS



G&W DISCONNECTING POTHEADS— ADAPTABLE TO ANY CONDITION

THIS street lighting control platform shows the neat and simple arrangement possible when G & W Disconnecting Potheads are used. The adaptability of G & W Disconnecting Potheads to any condition and the resultant space economy and safety is fully demonstrated wherever they are a part of the installation. The disconnecting potheads here are mounted on both the platform base and the cross arm. G & W Disconnecting Potheads seal the cable insulation. Ease of transformer removal and of control of street lighting is made possible in this installation which is all automatic. You will find G & W Disconnecting Potheads most advantageous whatever your particular needs may be.

G & W ELECTRIC SPECIALTY CO.
7780 DANTE AVE. CHICAGO, ILL.



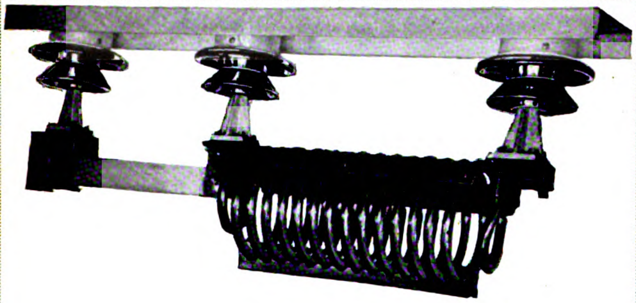
The Jewell Polyphase Wattmeter is of the dynamometer type and employs two full size movements on a single shaft. The separate movements are accurately calibrated and the movements are balanced as a whole so the indications are accurate under all conditions.

Accuracy of indication by calibration

The calibration of switchboard instruments as well as portable instruments is best done by comparing with an accurate standard, stepping the points and drawing the scale on fine bristol board.

The accuracy of Jewell instruments is as much due to the care taken in stepping and calibrating as to the proper use of materials and design. With every detail we go to extremes to make accuracy possible always. For example, the two experts shown in illustration are both giving attention to the same operation.

JEWELL ELECTRICAL INSTRUMENT CO. 1650 Walnut Street, CHICAGO, ILL.



The New

THONER & MARTENS

underslung outdoor disconnecting switch

THE standard T & M underslung outdoor disconnecting switch, 800 amp., is now equipped with choke coil.

Working pressure is 22,000 volts, dry flush is over 88,000 volts and wet flush over 55,000 volts.

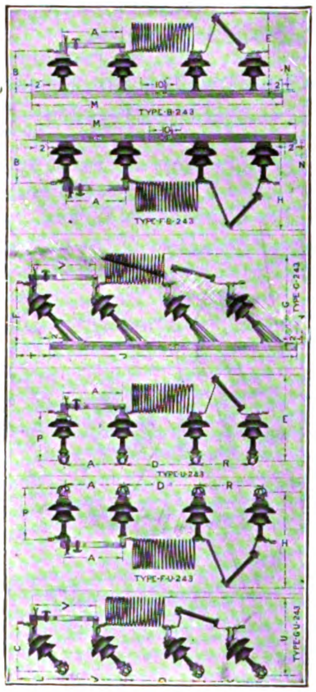
Other T & M features are the Bolt type lock and new sleet cover.

Write for further details

THONER & MARTENS

463 Commercial St., Boston, Mass., U. S. A.

OUTDOOR TYPE EQUIPMENT



Every Insulator is a Unit Type and is Interchangeable

You Should have Our Bulletins on File

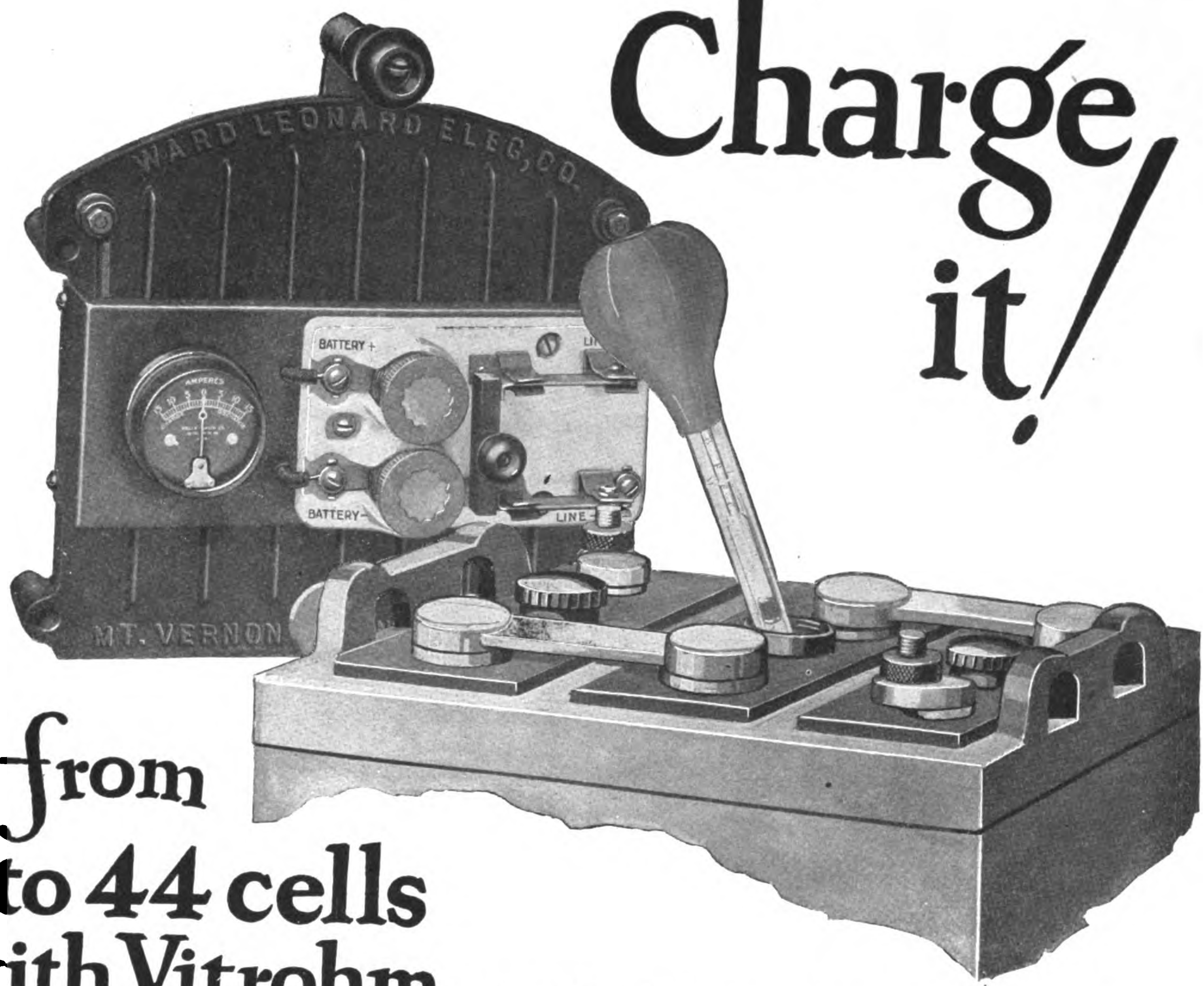
Would You Like a Picture of Our 750 K. V. Laboratory?

Why Not Get On Our Mailing List?

Delta-Star Electric Co

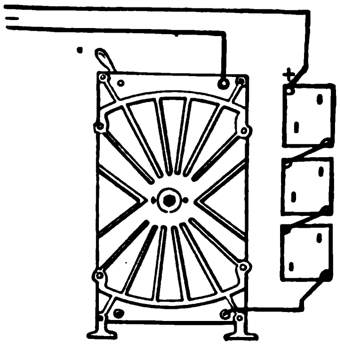
2400 Block, Fulton St. Chicago, Illinois

Charge it!



from 1 to 44 cells with Vitrohm Type 73000 Charging Rheostat

+ *Direct Current Line*



HERE is a battery charging rheostat that eliminates all fussing with controls and work with pencil and pad every time you add a battery to the charging line.

There's no worry about the charging rate—no worry about the number or type of cells in the connection—this new Vitrohm Type 73,000 Charging Rheostat takes from 1 cell to 44 and charges at the exact rate you wish.

Money is being made in the battery charging business, but you can't fuss away half your time in getting run down batteries into the line and then spend the balance of the time worrying about the rate at which the batteries are being charged.

This rheostat makes battery charging on 100-120 volt direct current lines simple as A B C. Put any number of cells, from 1 to 44 in series with the Universal Charging Rheostat, place the control handle to the extreme left, and turn on the current. The charging rate can then be regulated to any current you wish. Putting a low battery in the line, or taking a charged cell out, means only a change in the position of the current control handle. All guesswork and worry is gone.

The Charging Rate Range

With Cat. No. 73403—15 Amperes Max. 1.5 Amperes Min.
With Cat. No. 73402—10 Amperes Max. 1 Amperes Min.

Many other sizes, with or without switches—fuses, circuit breakers, etc.
SEE BULLETIN NO. 69—SENT ON REQUEST

6635-2

Ward Leonard Electric Company

37-41 South Street Mount Vernon, N. Y.

THE PACIFIC ELECTRIC MANUFACTURING COMPANY

"The Oldest Exclusive Manufacturers of High Voltage Switches and Circuit Breakers"

Have opened an office at 419 Chemical Building, St. Louis, Missouri, purchased three acres of land on the Terminal Railroad Association Belt Line at St. Louis Avenue, and will proceed at once with the construction of a factory building to meet the growing demand for the service, design and economy which have made Pacific Switchgear pre-eminent throughout the Pacific Coast.

PACIFIC ELECTRIC MANUFACTURING COMPANY

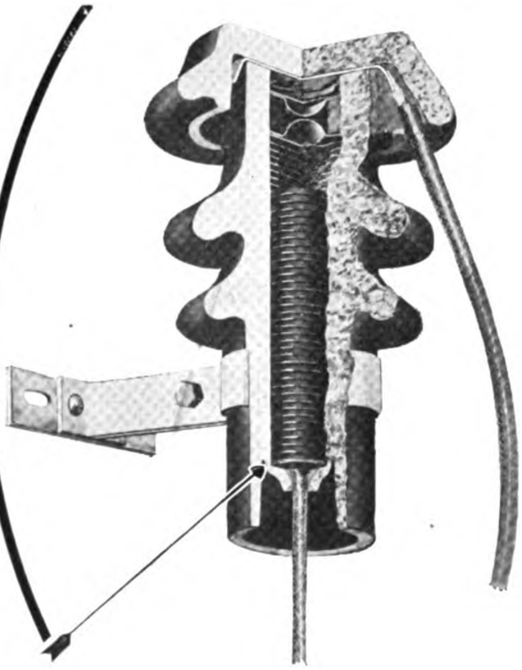
Manufacturers of Oil Circuit Breakers and High Voltage Switchgear

5815 Third Street, SAN FRANCISCO

30 Church St., New York
1001 McCormick Bldg., Chicago
Symes Bldg., Denver, Colo.
135 High St., Boston, Mass.
Hoge Bldg., Seattle, Wash.
Pioneer Bldg., St. Paul, Minn.
H. W. Hellman Bldg., Los Angeles
Interurban Bldg., Dallas, Tex.
930 Wyandotte St., Kansas City, Mo.
American Trust & Savings Bldg., Birmingham, Ala.

When Superintendents Meet "Speaking of Lightning Arresters"

IT was during one of those confidential chats that the talk turned to lightning arresters. · "Yes", the central station superintendent was saying, "I am strong for the LV Autovalve Arrester because of its maintained leadership in new and constructive ideas about distribution circuit protection.



The decreased portion of porcelain which fractures when the 'drop out' functions because of a sustained over-voltage, or a direct stroke.

"It was the first to give us the valve principle of operation for distribution circuit protection.

"The separate mounting bracket was a desirable innovation.

"We can now install arresters with one principle of operation on all our distribution circuits, up to 50 kw.

"Prior to the LV, the high cost of high-quality, higher-voltage arresters prohibited the adequate protection of all our distribution systems.

"The small size and light weight of the higher-voltage LV arresters minimize our installation costs.

"The 'drop out' feature of the latest LV is a definite tell-tale of the arrester condition that an inspector can see readily from the ground.

"Should a sustained over-voltage, or direct stroke, cause the failure of one of these arresters, the 'drop out' functions and our line does not become permanently grounded."

Talks of this character are common wherever central station superintendents meet.

Leaflet 20013 and Circular 1737 describe this trail-blazer in the art of distribution circuit protection.

Westinghouse Electric & Manufacturing Company
East Pittsburgh Pennsylvania
Sales Offices in All Principal Cities of the United States and Foreign Countries

Westinghouse

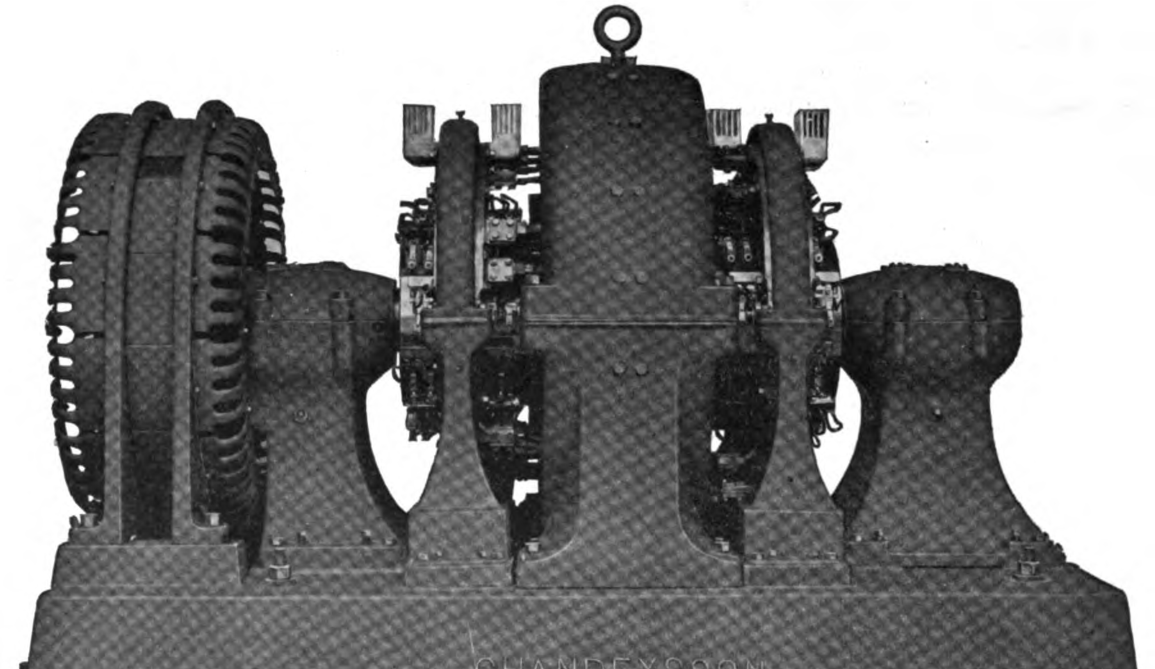
X90186

Chandeysson

Generators
25 to 25,000 Amperes

Direct Connected to

G-E Motors



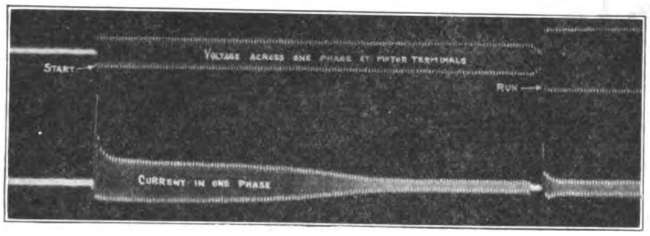
50-h.p., 300-r.p.m.
G-E Synchronous Motor

5000-amp., 6-volt;
2500-amp., 12-volt Generator

CHANDEYSSON ELECTRIC CO., ST. LOUIS, U. S. A.

Compression Resistance Starters Are Superior to Compensators

The upper wavy line is the oscillographic record of motor voltage during starting and running positions of a compensator. Notice the abrupt change from the starting to running voltage, and also the momentary drop of voltage during switch-over.



The lower wavy line is the oscillographic record of starting and running current of a squirrel-cage motor started with a compensator. Notice the two current inrushes which are characteristic of motor starting with a compensator.

The Compensator May Look Innocent

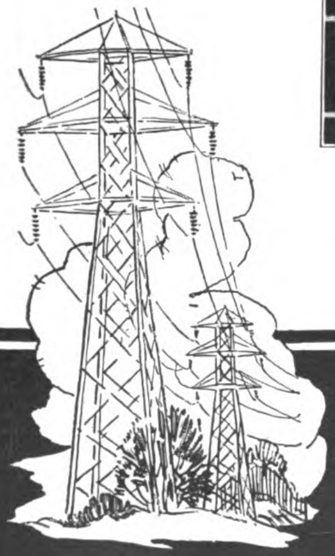
But It Gives the Line Some Awful Wallops

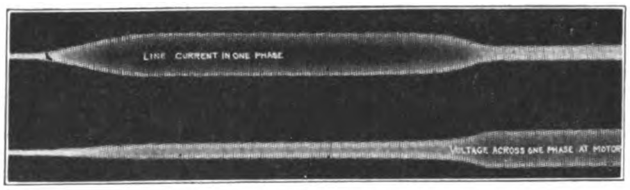
No one ordinarily suspects the starting compensator of doing harm to the line voltage, the motor, or the connected machinery.

However, the oscillograph, with its unerring photographic film, records the evidence that explains why power lines are seriously affected when squirrel-cage motors are started with compensators. It is found that the compensator is actually responsible for two severe current inrushes, both of which disturb the voltage stability of a power circuit.

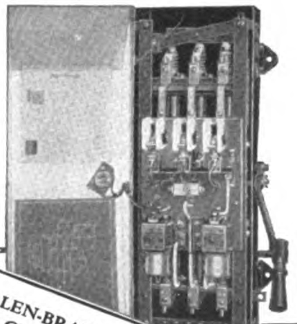
The auto-transformer of the compensator draws a heavy inrush of magnetizing current when it is first connected to the line. This, added to the motor starting current, produces the first wallop or current inrush shown in the above oscillogram. Then, when the motor is disconnected from the auto-transformer of the compensator and switched to full line voltage, the line receives another wallop. The second inrush occurs because the motor cannot be switched from the auto-transformer to the line without opening the motor circuit.

The Allen-Bradley hand-operated Type H-1852 Compression Resistance Starter, entirely eliminates these wallops to the line voltage, as shown by the lower oscillogram. The motor is started gradually and steplessly from standstill, and brought to line voltage without a jerk or sudden current inrush. No other squirrel-cage motor starter offers such advantages to power companies or motor users.





Use the handy coupon below, for full information, catalog and technical report on the advantages of Allen-Bradley Compression Resistance Starters for Squirrel-Cage Motors.



Allen-Bradley
Graphite Compression
RESISTANCE STARTERS
for Squirrel-Cage Motors

ALLEN-BRADLEY CO.,
494 Clinton St., Milwaukee, Wis.
Please send me engineering bulletin with oscillograph test of squirrel-cage motor starters.
Name............................
Company............................
Address............................
....

Will It Profit You

to pay for Precision in the Bearings of the machines you build to sell?

Yes!

Any slight difference in cost is repaid many hundred fold by their longer life and improved service. Your greater profit lies in the increasing demand for your better product.

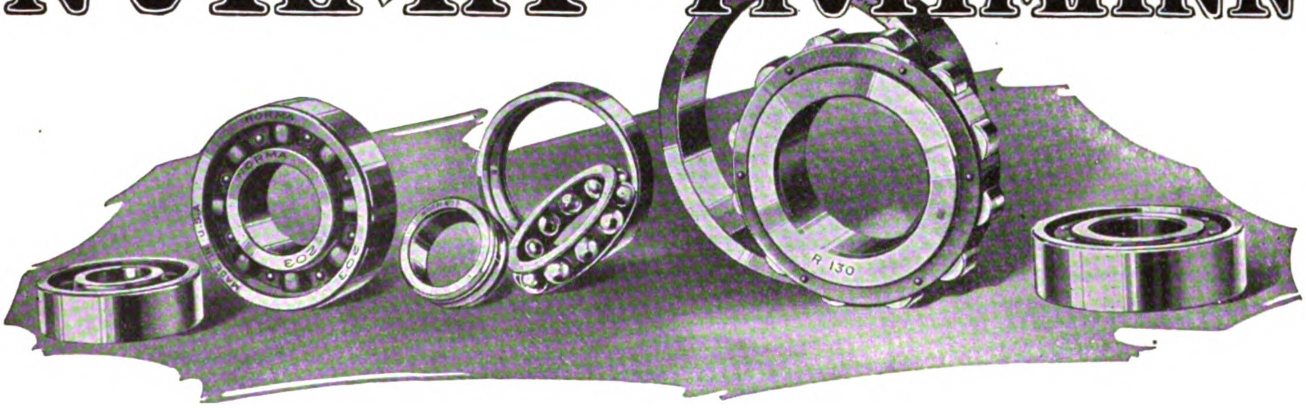
"**Norma**" Precision Ball Bearings, in both open and closed types, for the smaller powers and the highest speeds.

"**Hoffmann**" Precision Roller Bearings for the heaviest loads, hardest service, and all speeds.

Our engineers will welcome an opportunity to work with yours. Write for catalogs 904, 905 and 915.

NORMA-HOFFMANN BEARINGS CORPORATION
Stamford—Connecticut
PRECISION BALL, ROLLER AND THRUST BEARINGS

NORMA—HOFFMANN



Thickness	Code No.	Weight per Sq. Yds., Lbs	See Page 2	
.005"	2000	32	900-1100	Ca
.006"	2001	36	900-1100	Can
.006"	2022	36	900-1100	Cam
.007"	2002	40	900-1100	Cambr
.007"	2003	40	900-1100	Cambric
.008"	2004	45	900-1100	Cambric
.009"	2005	50	900-1100	Cambric
.010"	2006	54	900-1100	Cambric
.012"	2007	66	900-1100	Cambric
.012"	2020	67	900-1100	Cambric
.015"	2008	82	900-1100	Cambric
.015"	2012	85	800- 900	Canvas
.016"	2009	87	800- 900	Canvas
.022"	2010	112	400- 500	Duck
.025"	2013	118	400- 500	Duck
.030"	2011	145	400- 500	

ECIFY CODE N

What These Code Numbers Mean To You In ACTUAL YARDAGE

As varnished insulations are bought by the pound, the gauge governs the yardage. Over in thickness, under in length. Sometimes short measure is not important, but more often it runs into a loss that counts. At any rate, you are not getting what you expect.

Acme Varnished Products are accurate in weave and gauge, and your guide is our Code Number. This Code is always the same. Take Code No. 2000, for instance, as shown above. This number will always bring you Acme black varnished cambric .005" thick, running 32 pounds per 100 sq. yds., and having a dielectric strength of 900-1100 volts per Mil. A similar Code governs every Acme Varnished Product, and we take pride in adhering strictly to it.

May we send you our catalog of Acme Varnished insulations? We are sure you will be interested in our system of "Yardage insurance." Ask for Catalog No. 3A.

ACME WIRE PRODUCTS

The Acme Wire Co., New Haven, Conn.

Branches at

New York, 52 Vanderbilt Ave. **Chicago, 427 West Erie St.**
Boston, 80 Federal St. **Cleveland, Guardian Bldg.**

West Virginia
Fibre Board
I-N BOARD

For Electrical Insulation

I-N Board has been tested and approved by the Underwriters' Laboratories for electrical insulation.

This board has a very high tensile and dielectric strength and is being used successfully by many electrical manufacturers who are finding it a decided factor for economy.

Pulp Products Department

West Virginia Pulp & Paper Company

200 Fifth Avenue, New York, N. Y.

503 Dime Bank Bldg. Detroit, Mich. **732 Sherman Street Chicago, Ill.**

503 Market Street, San Francisco, Cal.

Y-26 High-Heat Mica Plate

For High Temperature Insulation

Possesses all the advantages of natural mica for insulating heating appliances. Is more economical, particularly when used in the larger units.

Supplied in sheets up to 30" x 42", in thicknesses of ten mils or over. Can be cut or punched to any form.

Send for samples and prices.

Y-26 STANDARDIZED NEMCO MICA PRODUCTS HIGH-HEAT MICA PLATE

NEW ENGLAND MICA CO.
Waltham 54, Mass.
New York Office — 220 Broadway

ALL FORMS OF MICA FOR ELECTRICAL PURPOSES

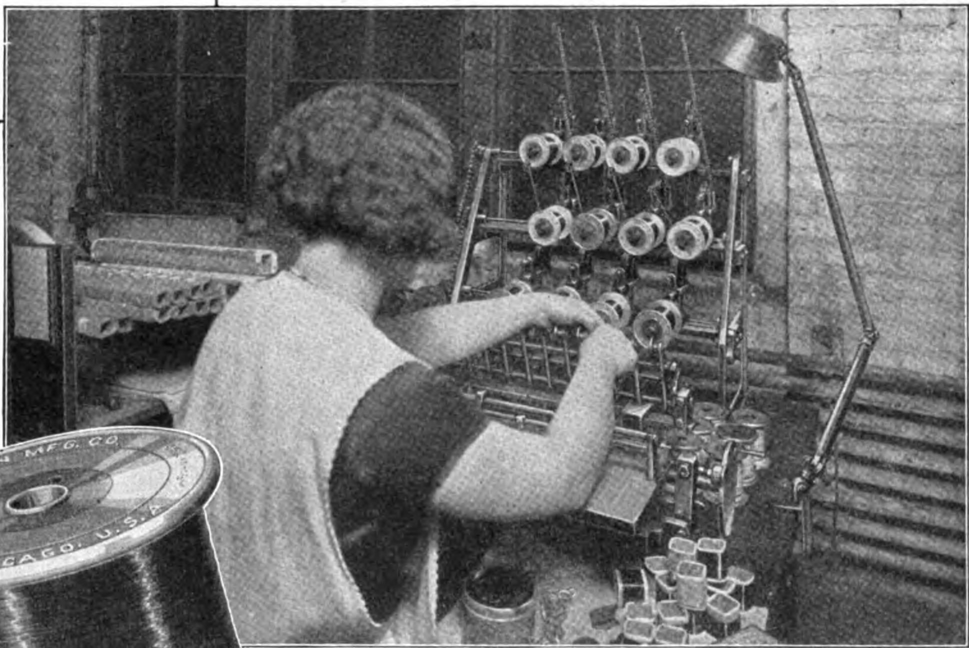
"IRVINGTON" PRODUCTS

Black and Yellow

Varnished Cambric Varnished Paper
Varnished Silk
Flexible Varnished Tubing
Insulating Varnishes and Compounds
"Cellulak" Tubes and Sheets

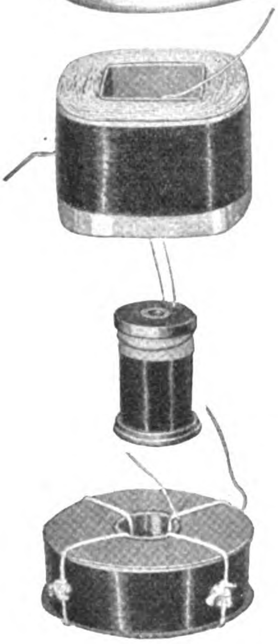
IRVINGTON VARNISH & INSULATOR Co.
Irvington, New Jersey.

Sales Representatives in all principal cities



Winding High Tension Coils
Demonstrates Beldenamel Superiority

High speed winding of small coils requires a uniform wire with tough and flexible insulation.



RELIABLE insulation for fine wire coils with thousands of turns is no longer a problem. Thanks to the painstaking efforts of Belden Engineers, Beldenamel meets every requirement of this difficult service perfectly. It is flexible and smooth, working from winding machines without trouble. Pliable and tough—it does not crack or break under sharp turns. Its uniformity of size assures a uniform number of turns in a given space. Its smallness of bulk permits many turns in small space—far more turns than are possible with other forms of insulation.

BUT, most important of all, is the utter dependability of Beldenamel insulation. Automatically controlled conditions guard the perfection of Beldenamel through every step in its manufacture. Extensive laboratory and service tests have perfected the formula under which it is made. The liquid enamel is made in the Belden factory under the closest supervision. Dipping and baking treatments are performed with utmost care. The result is a product so uniformly perfect that it is ideal for the exacting service of winding small coils. Investigate the unusual possibilities of Beldenamel magnet wire.

Leading coil manufacturers are using Beldenamel wire extensively for high tension coils. Try Beldenamel on your next winding job.

Specify Belden

USE THE COUPON

Belden Manufacturing Company
2316B So. Western Ave., Chicago

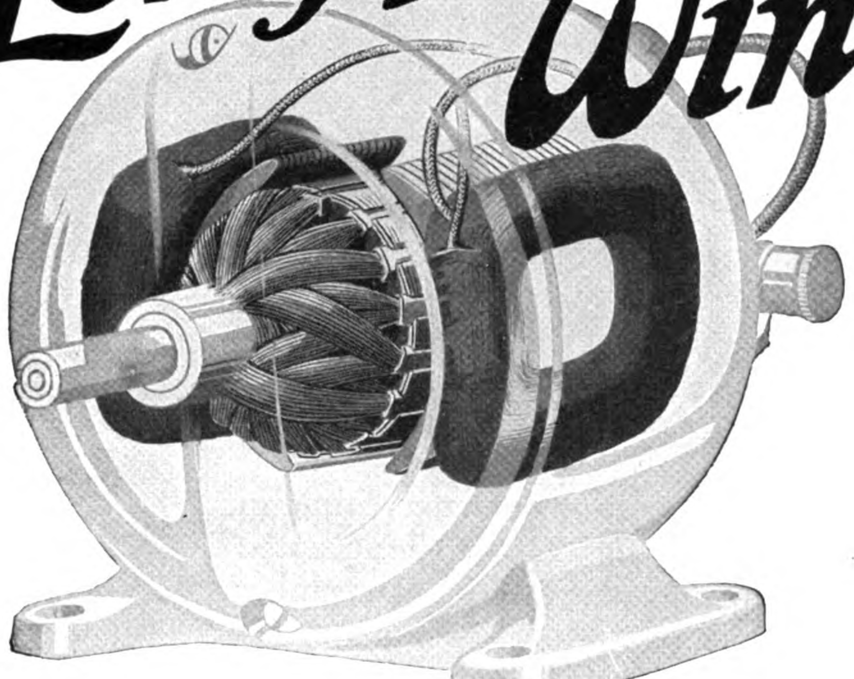
Please send us your booklet on Beldenamel Wire including winding data.

Name..............................

Address............................

....

Long-Lived Windings



make Long-Lived Motors

DUDLO

The life of any motor is measured by the durability of its windings. The life of DUDLO Windings is insured through the durability of the wire, particularly the insulation, upon which winding efficiency depends. Manufacturers of fractional horse power motors for all kinds of domestic and industrial equipment will insure the longest possible life for their motors through the use of Dudlo Magnet Wire and Field Coils.

The Dudlo experimental and engineering departments are at the service of any manufacturer, fully and freely, without obligation of any kind.

DUDLO

DUDLO MANUFACTURING CORPORATION, FORT WAYNE, INDIANA

412 Chamber of Commerce Bldg.	160 North La Salle Street	4153 Bingham Ave.	274 Brannan St.
NEWARK, N. J.	CHICAGO, ILL.	ST. LOUIS MO.	SAN FRANCISCO, CALIFORNIA

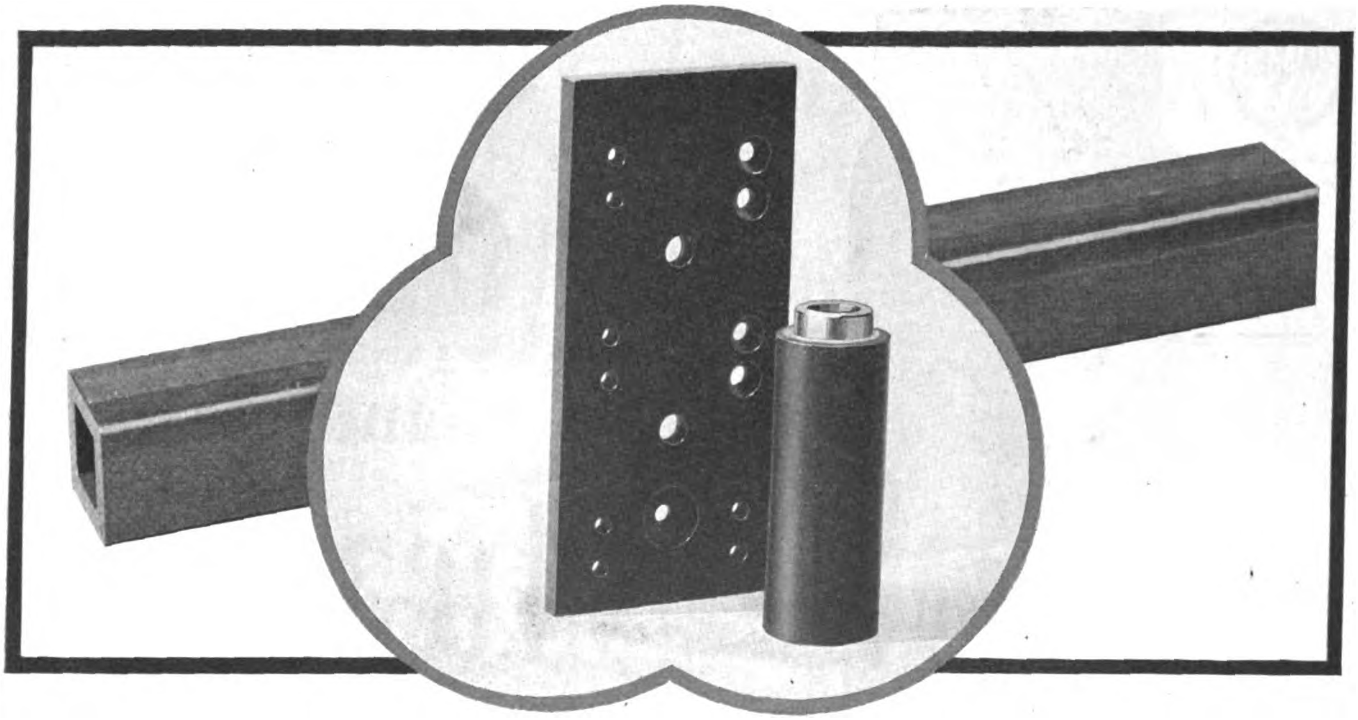
Announcement

The advertising rates of the JOURNAL of the A. I. E. E. have been increased, effective January 1, 1927.

Orders covering insertions of advertising in this publication during 1927 will be accepted on the existing rate basis up to December 31, 1926.

The advance in space costs is due to the greatly enlarged circulation of the JOURNAL.

The circulation has increased 75% since the present rates were established, averaging over 23,000 copies per issue during 1926—the largest of any technical periodical in the electrical field.



Important parts of Allen-Bradley apparatus are Bakelite Insulated

Over the heavy, square steel shaft of the Allen-Bradley A. C. Contactor is drawn an insulation sleeve of square Bakelite laminated tubing, to which each contactor is rigidly clamped.

The core of the Overload Relay made by this same manufacturer, is of Bakelite molded, with a steel end plug solidly embedded during the molding operation.

All Allen-Bradley push-button stations, used on voltages above 440, are assembled on a Bakelite laminated contact base.

With this manufacturer, as with many others, the success of Bakelite insulation for one part, led to its adoption for several additional devices.

Bakelite engineers and laboratories are constantly cooperating with electrical manufacturers in adapting Bakelite to the betterment of their own products. This consulting service involves no obligation on your part.

Write for Booklet 3

BAKELITE CORPORATION

247 Park Ave., New York, N. Y. Chicago Office: 636 West 22nd St.

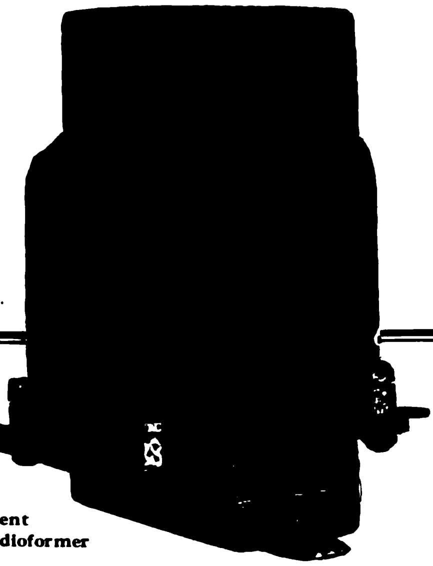
BAKELITE CORPORATION OF CANADA, LTD., 163 Dufferin Street, Toronto - - Ontario, Canada

BAKELITE

REGISTERED U. S. PAT. OFF.

THE MATERIAL OF A THOUSAND USES

"The registered Trade Mark and Symbol shown above may be used only on products made from materials manufactured by Bakelite Corporation. Under the capital "B" is the numerical sign for infinity, or unlimited quantity It symbolizes the infinite number of present and future uses of Bakelite Corporation's products."



The Pacent Superaudioformer

Audio Frequency Transformers

EXTREMELY successful transformers developed by the Pacent Engineers, who are primarily specialists in Audio Frequency parts. Handsomely finished in dull bronze, made in two types.

Superaudioformers

INPUT TYPE No. 27A, Ratio 3 to 1, Primary Inductance 124 henrys, designed for use between any vacuum tubes, and also with power amplification requirements in mind.

Shielded $7.50 Unshielded $6.00

OUTPUT TYPE No. 27B, Ratio 1 to 1, Inductance 15 henrys.

Shielded $7.50 Unshielded $6.00

Pacent Audio Choke

A type of Super audioformer developed for use in filter circuits of power amplifiers and battery eliminators. Unusually sturdy for long usage.

CHOKE TYPE No. 29, Inductance 50 henrys (with no superimposed D. C.); Inductance 32 henrys (with 60 m. a. superimposed D. C.).

Shielded $6.50 Unshielded $5.00

Full information on request.

PACENT ELECTRIC CO., INC.
91 SEVENTH AVENUE NEW YORK CITY
Canadian Licensed Manufacturer:
White Radio Limited, Hamilton, Ont.
Manufacturing Licensees for Great Britain and Ireland:
Igranic Electric Co., Ltd., London and Bedford, England

Pacent
RADIO ESSENTIALS

Merry Christmas and a Healthy New Year

·BUY· ·CHRISTMAS· ·SEALS·

THE NATIONAL, STATE AND LOCAL TUBERCULOSIS ASSOCIATIONS OF THE UNITED STATES

Piezo Electric Oscillator

The Type 275 oscillator is a vacuum tube oscillator the frequency of which is held constant by the Piezo electric action of a quartz plate.

This type of oscillator provides an instrument of great reliability for transmitter adjustment, or as a primary standard for wavemeter calibration. Licensed under Pierce and Cady patents.

Bulletin 723E on request.

PRICE	Type 275 oscillator		$85.00
	Type 276B plate	25%	30.00
	Type 276C plate	5%	40.00
	Type 276D plate	0.1%	60.00

GENERAL RADIO COMPANY
30 State Street Cambridge, Massachusetts

Popular Research Narratives

are proving excellent means for introducing *Engineering Foundation* and engineering research to new friends and keeping the name before them.

If you have read these two little books, we suggest that you have copies sent to friends whom you would like to interest. Teachers and young persons in secondary schools and colleges, also, are finding them useful. The price is only $1.50 for the set, sent post-paid to any address.

These short stories of research, invention and discovery were contributed by eminent scientists, engineers and inventors. They are worth reading and are entertaining.

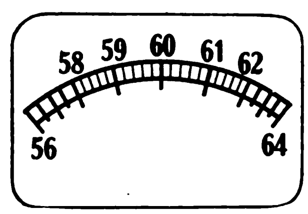
Requests and remittances may be sent to Engineering Foundation, at 29 West 39th Street, New York.

High Sensitivity Frequency Meters

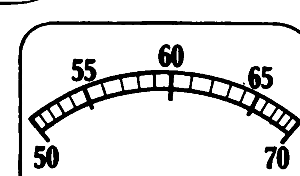
WESTON RECTANGULAR INSTRUMENTS

ENGINEERS know the Weston Rectangulars as the most modern type of switchboard instruments. Weston does not stop at a thoroughly modernized line but goes further whenever the need arises. The new high sensitivity frequency meters just added to the rectangular group constitute a refinement well worthy of the engineer's consideration. ¶The scales for these new instruments, examples of which are here shown, make possible a much closer frequency control because the scales are much more open and a cycle difference in the center or critical part of the scale covers a considerable longer arc, (up to 13/16" in length). ¶The scales also present a better appearance because they are now substantially the same length for the entire rectangular group. It should be remembered that the rectangular frequency meters possess the characteristic advantages of this group of being unusually readable, standardized as to mounting, economical in use of panel space, unusually handsome in appearance, but now with higher sensitivity they are even more desirable. ¶The new scaled frequency meter is but one of the Weston rectangular group which consists of A. C. Ammeters and Wattmeters, Reactive Component Meters, Power Factor Meters, Triplex Meters and D. C. Voltmeters and Ammeters. ¶Compare the three scales illustrated here — see the obvious advantages. For complete information address—

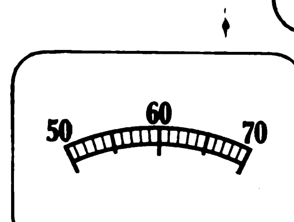
WESTON ELECTRICAL INSTRUMENT CORPORATION
48 Weston Avenue, Newark, N. J.



New expanded type of frequency scale



New normal type of frequency scale



Old type of frequency scale

STANDARD THE WORLD OVER
WESTON
Pioneers since 1888

PROFESSIONAL ENGINEERING DIRECTORY

For Consultants in the Fields of Engineering and Related Arts and Sciences

Established 1857
ALEXANDER & DOWELL
Attorneys at Law
PATENT, TRADEMARK AND COPYRIGHT CASES
902 F Street, N. W. Washington, D. C.

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Consulting Engineer
Electrical, Mining and Industrial Reports
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Electrical and Mechanical Engineers
MONADNOCK BUILDING CHICAGO

AMBURSEN DAMS
Hydroelectric Developments
Water Supply and Irrigation Dams
DAMS ON DIFFICULT FOUNDATIONS
AMBURSEN CONSTRUCTION CO.
Incorporated
Grand Central Terminal, New York
Kansas City, Mo. Atlanta, Ga.

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Fellow A. I. E. E.
Attorney and Expert in Patent Causes
Soliciting, Consultation, Reports, Opinions
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FREYN ENGINEERING COMPANY
Industrial Electric Power
Generation—Application—Purchase
Combustion Engineering
Electric Furnace Installations
CHICAGO 310 South Michigan Ave. PHILADELPHIA 1500 Chestnut St.

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Valuations and Reports of Public utility, industrial and all other properties
Rate Cases, Reorganizations — Condemnation Suits, Liquidations
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And Principal Cities

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Factory and Office Lighting
3400 Walnut Street Philadelphia, Pa.

M. H. GERRY, JR.
Consulting Engineer
Electrical Transmission of Power
Hydroelectric Developments
Steam and Diesel Plants
Industrial Applications
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Mutual Building KANSAS CITY, MO.

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FORD, BACON & DAVIS
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ENGINEERS
115 Broadway, New York
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HOOSIER ENGINEERING CO.
Erectors of Transmission Lines and Substations
325 South New Jersey Street
INDIANAPOLIS INDIANA

MAKE your name and specialized service well known to the electrical industry through a card in the ENGINEERING DIRECTORY

Classified Advertiser's Index for Buyers

Manufacturers and agents for machinery and supplies used in the electrical and allied industries.

Note: For reference to the Advertisements see the Alphabetical List of Advertisers on page 62.

Thrust!

TIMKEN-EQUIPPED ALLIS-CHALMERS VERTICAL MOTOR

Thrust capacity is the first requisite of vertical motor bearings. Absolute dependability is the first requisite of deep well pump drive. Qualifications like these regularly lead to the choice of Timken-equipped motors, available today through Allis-Chalmers and other leading manufacturers.

By providing higher capacity for loads from all directions Timken Bearings provide more than the expected anti-friction economies. To all possible savings of lubricant and power Timkens add the value of extreme overload capacity. In any position on any form of drive Timken Bearings resist all forms of wear equally well. Only Timken Taper and Timken *POSITIVE ROLL ALIGNMENT* make it possible.

THE TIMKEN ROLLER BEARING CO., CANTON, OHIO

Technical information regarding bearing sizes and mountings is obtainable from the Timken Roller Bearing Service & Sales Company's Branches located in the following cities: Atlanta, Boston, Buffalo, Chicago, Cincinnati. Cleveland, Dallas, Denver, Detroit, Kansas City, Los Angeles, Memphis, Milwaukee, Minneapolis, Newark, New York, Omaha, Philadelphia, Pittsburgh, Richmond, St. Louis, San Francisco, Seattle, Toronto, Winnipeg

TIMKEN
Tapered
ROLLER BEARINGS

Classified Advertiser's Index for Buyers—*Continued*

INSTRUMENTS ELECTRICAL—*Continued*

Scientific, Laboratory, Testing

General Electric Co., Schenectady
Jewell Elec. Instrument Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Roller-Smith Co., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Weston Elec. Inst. Corp., Newark, N. J.

Telegraph

Western Electric Co., All Principal Cities

INSULATING MATERIALS

Board

West Va. Pulp & Paper Co., New York

Cloth

Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Composition

American Lava Corp., Chattanooga
Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Compounds

Minerallac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Fibre

West Va. Pulp & Paper Co., New York

Lava

American Lava Corp., Chattanooga, Tenn.

Mica

New England Mica Co., Waltham, Mass.

Paper

Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Tullis, Russell & Co., Ltd., London, Eng.

Silk

Acme Wire Co., New Haven, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.

Tape

Belden Mfg. Co., Chicago
Minerallac Electric Co., Chicago
Okonite Co., The, Passaic, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Varnishes

Acme Wire Co., New Haven, Conn.
General Electric Co., Schenectady
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago

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Composition

General Electric Co., Schenectady

Glass

Hemingray Glass Co., Muncie, Ind.

Porcelain

Canadian Porcelain Co., Ltd., Hamilton, Ont.
General Electric Co., Schenectady
Lapp Insulator Co., Inc., ReRoy, N. Y.
Locke Insulator Corp., Baltimore
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Post Type

Delta-Star Electric Co., Chicago

INSULATORS, TELEPHONE & TELEGRAPH

Hemingray Glass Co., Muncie, Ind.
Western Electric Co., All Principal Cities

LAMP GUARDS

Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities

LAVA

American Lava Corp., Chattanooga

LIGHTING FIXTURES

Cory & Son, Inc., Chas., New York

LIGHTNING ARRESTERS

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General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LOCOMOTIVES, ELECTRIC

General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MAGNETIC SEPARATORS

Electric Controller & Mfg. Co., Cleveland

METERS, ELECTRICAL

(SEE INSTRUMENTS, ELECTRICAL)

MICA

New England Mica Co., Waltham, Mass.

MOLDED INSULATION

Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Burke Electric Co., Erie, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MOLYBDENUM

Fansteel Products Co., Inc., North Chicago

MOTORS

(See GENERATORS AND MOTORS)

OHMMETERS

Cory & Son, Inc. Chas., New York
Jewell Elec. Instrument Co. Chicago
Roller-Smith Co., New York
Weston Elec. Instr. Corp., Newark, N. J.

OIL SEPARATORS & PURIFIERS

DeLaval Separator Co., The, New York
Sharples Specialty Co., The, Philadelphia
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

PANEL BOARDS

(See SWITCHBOARDS)

PATENT ATTORNEYS

(See PROFESSIONAL ENGINEERING DIRECTORY)

PLUGS

Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

POLES, STEEL

American Bridge Co., Pittsburgh
Pacific Coast Steel Co., San Francisco
Western Electric Co., All Principal Cities

POLES—TIES, WOOD

Western Electric Co., All Principal Cities

POTHEADS

G & W Electric Specialty Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

PROTECTIVE DEVICES

Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities

PULLERS, SLACK

Matthews Corp., W. N., St. Louis

PUMPS

Allis-Chalmers Mfg. Co., Milwaukee

PUMPS, SPIRAL

Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia

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General Radio Co., Cambridge, Mass.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RAILWAY SUPPLIES, ELECTRIC

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Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities
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REACTORS

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Metropolitan Device Corp., Brooklyn, N. Y.

RECTIFIERS

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General Electric Co., Schenectady
Western Electric Co., All Principal Cities
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Matthews Corp., W. N., St. Louis

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Burke Electric Co., Erie, Pa.
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RELAYS

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General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RESISTOR UNITS

Allen-Bradley Co., Milwaukee
General Electric Co., Schenectady
Ward Leonard Electric Co., Mt. Vernon, N.Y.

RHEOSTATS

Allen-Bradley Co., Milwaukee
General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt. Vernon, N.Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ROPE, WIRE

American Steel & Wire Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.

SEARCHLIGHTS

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Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SHEETS, ELECTRICAL

Trumbull Steel Co., The. Warren, O.

SOCKETS AND RECEPTACLES

General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SOLENOIDS

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Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Ft. Wayne. Ind.
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt.Vernon, N.Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SPRINGS

American Steel & Wire Co., Chicago

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Allen-Bradley Co., Milwaukee
Condit Electrical Mfg. Corp., Boston
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Rowan Controller Co., Baltimore, Md.
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt.Vernon, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

STEEL, SHEET & STRIPS

Trumbull Steel Co., The, Warren, O.

STOKERS, MECHANICAL

Sturtevant Company, B. F., Boston
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SUB-STATIONS

General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHBOARDS

Allis-Chalmers Mfg. Co., Milwaukee
Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHES *Automatic Time*

Ferranti, Ltd., London, Eng.
Ferranti Meter & Transformer Mfg. Co., Ltd., Toronto, Ont.
General Electric Co., Schenectady
Minerallac Electric Co., Chicago
Sundh Electric Co., Newark, N. J.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Disconnecting

Burke Electric Co., Erie, Pa.
Condit Electrical Mfg. Corp., Boston
Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
K-P-F Electric Co., San Francisco
Matthews Corp., W. N., St. Louis
Pacific Elec. Mfg. Co., San Francisco
Thoner & Martens, Boston

Fuse

General Electric Co., Schenectady
Matthews Corp., W. N., St. Louis
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston

Knife

Condit Electrical Mfg. Corp., Boston
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Magnetic

Allen-Bradley Co., Milwaukee
Ward Leonard Electric Co., Mt.Vernon, N.Y.

Oil

Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Pacific Elec. Mfg. Co., San Francisco
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Remote Control

Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Rowan Controller Co., Baltimore
Sundh Electric Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TANTALUM

Fansteel Products Co., Inc., North Chicago

TELEGRAPH APPARATUS

Western Electric Co., All Principal Cities

TELEPHONE EQUIPMENT

Cory & Son, Inc., Chas., New York
Western Electric Co., All Principal Cities

TESTING LABORATORIES

Electrical Testing Labs., New York

TOWERS, TRANSMISSION

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Pacific Coast Steel Co., San Francisco
Western Electric Co., All Principal Cities

TRANSFORMERS

Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., London, Eng.
Ferranti Meter & Transformer Mfg. Co., Ltd., Toronto, Ont.
General Electric Co., Schenectady
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Factory

American Transformer Co., Newark, N. J.
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Western Electric Co., All Principal Cities

Furnace

Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh

Metering

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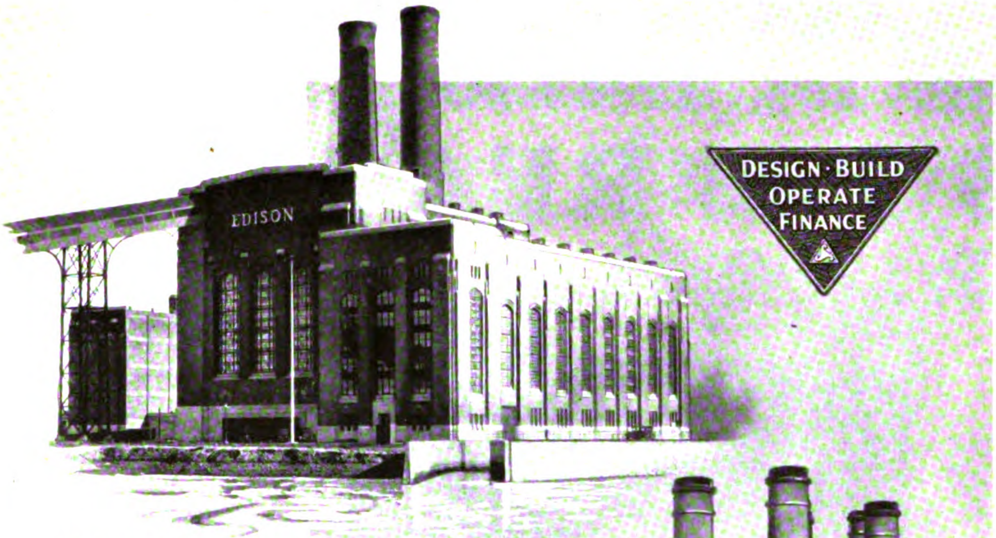

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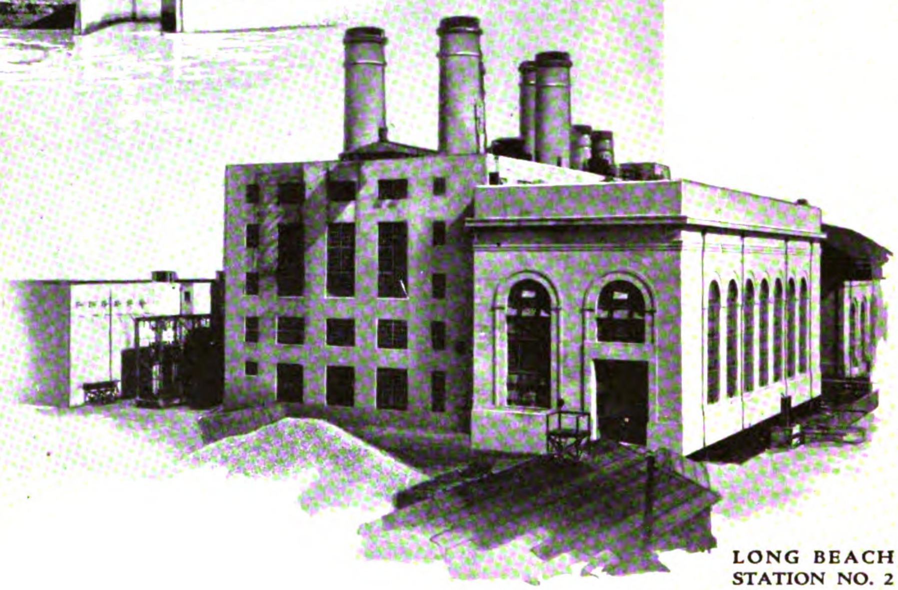

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